California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Feasibility of Sweet Sorghum to Ethanol and Value-added Products

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-09-064, to provide funding opportunities under the Clean Transportation Program for development of new, California-based biofuel production plants and for enhancement the operation of existing ethanol production plants to increase statewide biofuel production and reduce greenhouse gas emissions. In response to PON-09-064, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards August 12, 2010 and the agreement was executed as ARV-10-017 on December 29, 2010.

ABSTRACT

Great Valley Energy, LLC assessed the feasibility of producing advanced biofuels and value-added co-products in California using sweet sorghum as a feedstock. Great Valley Energy took part in three years of field trials using five varieties of commercially-available sweet sorghum. Sweet sorghum agronomics were studied to estimate the delivered price of sweet sorghum billets to a production facility assuming displacement of current crops. An average cost of $46 per ton of sorghum stalks is estimated and 35 tons per acre is achievable.

Great Valley Energy constructed and operated a pilot demonstration plant using fractionation technology from KTC Tilby. The fractionation equipment was used to mechanically separate sweet sorghum stalks into component fractions. These stalk components were sampled and analyzed physically and chemically. Juice was expressed and biomass was dried and pelleted. Several process configurations were engineered to provide mass and energy balances. Equipment was sized, and capital and operating costs were estimated.

Three configurations of biofuel, biofuel intermediates, and value-added co-product manufacturing scenarios were further developed including:

Configuration 1 – Onsite production of denatured fuel ethanol, densified biomass (pellets), and nutraceutical extract powder;

Configuration 2 – Production of 20 percent sugar solution for over-the-fence fuel ethanol production, livestock forage/feed blend stock, and a tolling/offsite arrangement for extraction and upgrading of nutraceutical bioactive dermal layer; and

Configuration 3-Production of 60 percent sugar syrup, construction product (oriented-strand board), and a tolling/offsite arrangement for dermal layer bioactives extraction.

Funding requirements for configurations 1, 2, and 3 (including equipment, installation, site development, infrastructure, reserves and contingency) were estimated at $111 million, $41 million, and $119 million, respectively. These costs are expected to be within 30 percent of fully- engineered costs.

Internal rates of return for configurations 1, 2, and 3 were 19.2 percent, 25.4 percent and -2.7 percent, respectively, with more complex and capital intensive scenarios predicting lower returns.

Keywords: energy, sweet sorghum, purpose-grown feedstock, biomass, ethanol, sugar, cellulosic, drop-in biofuel, fuel pellets, animal bedding, nutraceuticals, bioactive compounds, advanced biofuel

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EXECUTIVE SUMMARY

Great Valley Energy, LLC, a California company headquartered in Bakersfield has evaluated the feasibility of producing ethanol and value-added products from purpose-grown sweet sorghum in the San Joaquin Valley. Beginning in the winter of 2011 and supported in part by funding from the CEC, Great Valley Energy cultivated several varieties of sweet sorghum over three growing seasons; constructed and operated a pilot demonstration plant in Bakersfield; collected crop characteristics and technical data to support engineering design; evaluated and engineered multiple biorefinery configurations; analyzed markets around various configuration products; developed a greenhouse gas profile around the configurations; and determined technical and economic feasibility. This report comprises the results of Great Valley Energy's work, including input from our strategic partners and advisors.

Project Purpose

The purpose for Great Valley Energy's work herein is to identify a clear path to commercialize a low-carbon, advanced biofuel pathway which will be sustainable under the constructs of our environment, our society, and our economy. The underlying premise for the feasibility study is that a biorefinery model involving upfront fractionation of sweet sorghum using a proprietary technology would deliver a suite of products. Such products may be directed to diverse markets depending on market conditions and would result in a more sustainable solution than the traditional "crush and burn" business model of the sugar cane industry. The deliverable from Great Valley Energy's work is a pre-commercial, comprehensive feasibility study assessing the technologies, markets, and economic feasibility of a sweet sorghum to ethanol and co-products facility in the San Joaquin Valley.

Feedstock Cultivation

Great Valley Energy researched the history of sorghum in the United States and globally, focusing specifically on sweet sorghum. Sweet sorghum provides a sugar-based platform instead of a starch-based platform, such as corn ethanol. Thus, Great Valley Energy also evaluated the history and current status of various sugar-based projects producing fuel ethanol domestically and internationally. Based on the research conducted, Great Valley was able to develop an understanding of known strengths and weaknesses of varieties with respect to cultural aspects such as sugar production, disease resistance, drought tolerance, time to maturity, and more.

Over three growing seasons, Great Valley Energy and our strategic partners and participants demonstrated that several varieties of sweet sorghum – publicly-available and proprietary – could be cultivated successfully as a dedicated energy crop in the San Joaquin Valley at a value (quality and cost) correlating well with initial research. Most varieties were modern, improved varieties which had been cross-pollinated to yield desirable cultural characteristics. Great Valley's experience and research resulted in the development of Sustainable Best Management Practices for growing sweet sorghum. Sugar and total biomass yields were determined as dependent on location, variety, water and nutrient input, growing degree units, and other cultural factors. Great Valley Energy developed both a bottom up cost approach for production of sweet sorghum as well as a modeled price analysis for crop switching to determine price points at which San Joaquin Valley farmers may be enticed to grow sweet sorghum for a commercial project.

Great Valley Energy's work resulted in a few key observations and conclusions for pro forma purposes. First, storage of sweet sorghum is limited, as the crop breaks down rather quickly after harvesting. Second, in the San Joaquin Valley, sweet sorghum can be harvested during the months of August through November. This limits biorefinery operation to approximately 122 days. Third, the price of harvested sweet sorghum billets applied heterogeneously over the season is estimated to be $46.61 per ton.

Fractionation

Prior to Great Valley Energy's pilot demonstration plant, the KTC Tilby Fractionation Technology had been demonstrated to operate successfully on sugar cane. Though sweet sorghum was found to have characteristics quite different from sugar cane, the pilot demonstration plant proved that the Tilby technology could be used to successfully fractionate sweet sorghum into the dermal layer, the structural layer, and the sugar-juice bearing inner pith.

Operating the pilot plant resulted in a solid understanding of fraction yields and moisture contents. These variables were determined in detail across a matrix of five varieties, two planting dates, and four harvests for each planting date. Each fraction was further subjected to laboratory characterization of the physical and chemical properties, particularly those variables which impact engineering and operations as well as determine potential product markets.

In addition to laboratory analyses, a market analysis was conducted to determine potential products that might be attractive for a commercial sweet sorghum biorefinery. Great Valley Energy considered the markets for the following products: fuel ethanol, catalytic drop-in fuel, cellulosic ethanol, sugar intermediates, densified biomass, combined heat and power, anaerobic digester gas, livestock forage, engineered wood products, wax, and nutraceuticals.

Fractionation Products Processing

Great Valley Energy evaluated the technologies necessary to produce the suite of products that were evaluated from a market study perspective. The focus of the engineering effort was on a demonstration-scale base sorghum processing facility with a capacity to process 10 tons per hour of sweet sorghum and a similar but larger commercial-scale facility with a capacity to process 50-TPH of sweet sorghum. The core facility based on the Tilby system was engineered to deliver a sugar juice solution, densified biomass, and a nutraceutical extract. In addition to the core facility, the following process options were engineered and evaluated:

- Addition of an ethanol facility onto the base sorghum processing facility for direct production of ethanol from the concentrated sugar solution;
- An ethanol facility that used both the sugar solution and the cellulosic fibrous material to produce ethanol in lieu of pellet production;

- A thermo-catalytic process to convert comfith and comrind[1] to drop-in fuels;
- A base sorghum processing facility that would “bolt on” to an existing ethanol facility;
- Production of engineered wood products; and
- Using comfith and comrind for production of electricity and process heat on site.

Engineering deliverables included process flow diagrams, mass and energy balances, capital cost estimates and operation and maintenance estimates.

Greenhouse Gas Considerations

Based on the inputs needed to grow and deliver a supply of sweet sorghum stalks to a hypothetical processing facility combined with the expected yield of ethanol from those stalks, a feedstock carbon intensity can be derived. The feedstock carbon intensity for sweet sorghum was estimated as 19.1 grams per megajoule which compares favorably with the 21.0 grams per megajoule and 38.2 grams per megajoule ascribed to sugar cane and corn, respectively in other approved well-to-wheels pathways.

This feedstock carbon intensity is then combined with an overall processing carbon intensity for the facility configuration to result in the fuel carbon intensity that would be part of an approved pathway for a configuration. Carbon intensity is projected to be 143.2 gCO2e/MJ, 62.8 gCO2e/MJ and 78.8 gCO2e/MJ for configurations 1, 2 and 3, respectively.

Results indicate that the main variations in greenhouse gas intensity were in the sorghum processing and the saleable by-products from the process. The sorghum processing emissions in Configuration 2 and Configuration 3 are 84 percent and 42 percent less than Configuration 1, respectively. The greenhouse gas intensity of configuration 1 includes the energy required to extract and concentrate the bioactive compounds from the dermal layer. However, as no product currently in the marketplace is displaced, there is not a corresponding product credit. This results in a higher greenhouse gas intensity for the process, without corresponding benefit to the fuel pathway. A reasoned approach would partition these emissions from the rest of the process. However, a mechanism to document that under a new California Air Resources Board Method 2B pathway is future work.

The results from Configuration 2 are similar to those of the California Air Resources Board corn ethanol pathway. Corn ethanol has higher fertilizer and farming emissions while the sorghum pathways require additional energy and emissions for pre-ethanol processing of the sorghum. Based on preliminary modeling, the use of combined heat and power would provide significant reductions for the sorghum processing stage. Reductions in greenhouse gas intensity as high as 70 percent from Configuration 1 results are possible which would result in 55 percent greenhouse gas intensity reductions from the greenhouse gas intensity of California gasoline blend stock.

Optimized Plant Design for Economics

Great Valley Energy evaluated multiple plant configurations, considering possible permutations of various products that could be derived from the fractions of the sweet sorghum plant.

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[1] Tilby Seperation System Sugarcane Terminology (https://www.tilbytechnologies.com/technology)

Initially, three potential plant configurations appeared to have the highest likelihood of economic success. At the core, all three were based on the 50 ton per hour base sorghum processing facility.

Configuration 1 – Onsite production of denatured fuel ethanol, densified biomass (pellets), and nutraceutical extract powder;

Configuration 2 – Production of 20 percent sugar solution for over-the-fence fuel ethanol production, livestock forage/feed blend stock, and a tolling/offsite arrangement for extraction and upgrading of nutraceutical bioactive dermal layer; and

Configuration 3 – Production of 60 percent sugar syrup, construction product (oriented-strand board), and a tolling/offsite arrangement for dermal layer bioactive extraction.

Two of these configurations show promise on a pro forma basis:

- Configuration 1: Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was determined to be 3.99x and the pre-tax internal rate of return on equity was determined to be 19.2 percent.
- Configuration 2: Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was forecast to be 4.12x and the pre-tax internal rate of return to equity was forecast to be 25.4 percent.

From a risk perspective, Configuration 2 might be preferred because the capital outlay is significantly less, and the products are intermediates that expand market choices. However, configuration 2 also relies on downstream processes which may be provided by unrelated business entities, adding commercial risk. Further, there may at times be an economic advantage to producing ethanol, for example, rather than allowing another entity to produce and sell the associated RINs. Finally, there may be other feed stocks available for processing at the facility during times when sweet sorghum is not in season to produce ethanol and nutraceutical extracts. Configuration 1 provides the facilities to take advantage of opportunistic feed stocks that may be available near a sited facility.

Importantly, each of the configurations relies on a high-value specialty bioactive product (or intermediate) to provide additional revenue from each stalk processed. Without this income, none of the configurations studied appears to be economically feasible, with expenses exceeding combined income for the sugar/biofuel and biomass products. Similarly, without the income from sugar/biofuel and biomass products, income from bioactive products is insufficient. As the markets for sugar/biofuel and biomass products are large and relatively mature, it is the marketing of the bioactive fraction that is the critical path for economic feasibility.

Conclusion

Sweet sorghum is a viable crop that grows well in California and provides reduced inputs and substantive sugar yields to have an advantageous carbon intensity compared to other crops for ethanol production. Several processing scenarios designed to add value to the rest of the sorghum stalk are technically feasible. Importantly, economic feasibility of each of the scenarios appears to rely on a high-value bioactive product that can be produced from the dermal layer of the stalk.

CHAPTER 1: Purpose

Great Valley Energy, LLC, has conducted a comprehensive program to identify technologies, construct and operate a pilot scale plant, conduct marketing analyses and perform a detailed feasibility study to construct a commercial scale manufacturing facility that will produce ethanol and other products from sweet sorghum grown in the San Joaquin Valley. The work identified here provides a clear path to commercialize a low-carbon, advanced biofuel pathway which is sustainable under the constructs of our environment, our society and our economy.

Problem Statement

Great Valley Energy has performed preliminary economic analysis of a sweet sorghum to ethanol route using the "crush-and-burn" business model popular in the sugar cane industry. Under this business model, sugar cane is grown, harvested, transported to a central facility and crushed yielding juice that is made into ethanol. The rest of the stalk is burned to provide heat and electricity for the plant and for export to the grid. For sweet sorghum processed in this manner and based on typical yields and agronomic inputs in California, the cost of ethanol produced under this model may provide no compelling economic driver to implement sweet sorghum to ethanol processes.

Problem Solution

Great Valley Energy has licensed a separation technology which when combined with appropriate downstream processing capabilities will produce ethanol with greater economic sustainability than corn or the "crush and burn" business model. This is due to the ability, as facilitated by the separation technology, to add value to at least a portion of the non-ethanol portion of the sweet sorghum stalk in excess of its fuel or feed value, which are likely its lowest values in industrial ecology.

Project Scope and Objectives

The scope provided under this response to solicitation fills a development gap in developing a sweet sorghum to ethanol plant in California. The Department of Energy's Advanced Research Projects Agency-Energy calls this gap the "Valley of Death" in that some transformational technologies cannot bridge between research and demonstration due to perceived implementation, technology and integration risks. The project team completed a scope which leverages past work in sweet sorghum cultivation including California agronomics and technology development to provide enhanced economics which will bridge the gap and bring this value-added business model to wide acceptance.

Feedstock Trials

Sweet sorghum has been grown in the United States since the mid-1800s. Various programs in California were conducted as early as 1990 to characterize inputs and yields of sweet sorghum as an ethanol crop. This work continues today with test crops planted under the direction of University of California at Davis (UC Davis) located at both research facilities and on-farm plots. The results of past tests indicate that sweet sorghum can be grown in the San Joaquin

Valley as a large-scale energy crop at $25-28 per ton. The scope of this proposal leverages the research that is current being completed under a 3-year CEC / California Department of Food and Agriculture grant to develop bioenergy crops and define Sustainability Best Management Practices for production.

Separation Technology Pilot Plant

Great Valley Energy has licensed a proprietary technology which will fractionate sweet sorghum along the stalk radius into chemically distinct portions, which can then be processed into value-added compounds. This technology has been licensed and commercially demonstrated (large scale) for sugar cane processing. The technology was physically demonstrated (limited pilot scale) on California-grown sweet sorghum at Williams, CA in 2009.

The technology was further tested at full pilot scale including full separation processes along with key pilot-scale upgrading technology to determine key variables for designing demonstration and commercial-scale plants. Coinciding with the field trials, sorghum was processed through the separation equipment in order to produce and secure samples for chemical analysis as well as measure yields. This work also produced volumes of material used in downstream processes such as juice extraction, syrup production, and biomass pellet manufacture.

Value Added Products Investigations

Once separated, the sweet sorghum fractions can be processed into products considering the chemical and physical makeup of each fraction. The outer epidermal layer contains various high-value bioactive compounds which are difficult to isolate from a crushed stalk, but which can easily be extracted from a concentrated smaller mass. To quantify the potential nutraceutical applications of a sorghum dermax[1] extract and how bioactive compounds change between the sorghum fractions as well as across sorghum varieties, research was conducted at Colorado State University.

Comrind and comfith can be used to make board products with similar properties to those sourced from timber. Work was completed to manufacture these products and test structural characteristics. Additionally, fuel pellets may be an outlet for comfith and comrind materials. These materials were dried and used as feedstock in lab scale pelletizing equipment to assess physical characteristics. Chemical characteristics were assessed based on analytical results for chemical constituents and heat content. Finally, comfith and comrind may be best suited for use as a feed ration component. Feed analysis was completed on the varietal fraction and evaluated based on a common feed displacement method.

The sugar-laden juice was expressed from the comfith fraction and samples evaluated for sugars, acidity and trace chemical constituents. Further, the juice was concentrated to a syrup of various concentrations from 20 Brix to 70 Brix and evaluated for chemical analytics and storability.

Process Development

In conjunction with the product investigations, processes were designed to make those products using existing equipment types from various manufacturers. For this work, data gained from pilot plant operations as well as product investigations were used to perform mass and energy balances, size equipment, provide utility use estimates, and estimate installed equipment costs through a combination of vendor quotes and standard cost indices. A number of configurations were evaluated and for the purposes of this report, three were identified for further analysis.

The specific processes that may be linked together will depend on various commercial considerations such as whether an existing ethanol production facility is co-located in a "bolt on" arrangement or syrup is shipped. Alternatively, a dedicated ethanol production facility could be built. Further, biomass may be densified through pelleting or perhaps consumed wet as part of a feed ration. The wet feed alternative would require a ready local market within a short distance of the facility, while pellets can be more easily shipped longer distances. Finally, as an alternative to an onsite dermax extraction facility, this material may be shipped offsite for processing under a tolling arrangement.

Greenhouse Gas Emissions Profiles

Key to the goals of this project is the greenhouse gas (GHG) emission profile of the transportation fuels produced on a well to wheels basis. Further, it was the premise of this study that under the crush-and-burn model, ethanol could be produced at a GHG reduction that would qualify it as an advanced biofuel under the Renewable Fuels Standard (which is a volumetric standard) and further provide an advantaged pathway for in-state production of low carbon fuels to help meet the Low Carbon Fuel Standard's (LCFS) "concentration-based" requirements.

To the lifecycle GHG emissions, inputs and yields from the field studies were used to develop a feedstock profile including indirect land use change. This feedstock profile was then applied to the processing inputs for mass and energy determined from the engineering study and applied toward the products of each configuration. Some products such as using comfith and comrind for feed result in offsets to carbon intensity due to their displacement of other products such as corn and soybean meal. Other products such as board products result in credits due to the likelihood of that product amounting to carbon sequestration. Further, the production of sorghum extract may result in a charge toward the biofuel produced due to its process energy use. Finally, the production of syrup or use of raw juice has an energy impact. Each of the three process configurations identified were modeled using the California Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model which is the California Specific version of Argonne National Laboratory's GREET lifecycle analysis of fuels under the LCFS.

Economic Feasibility

Economic models for each of scenarios were built using the feedstock supply study, installed capital cost estimates, energy inputs and product pricing. In addition, expense line items for labor, processing chemicals, water/wastewater, property taxes and others were estimated.

Financing assumptions included percentages allocated to debt, equity and grant funding. The relative proportion of these was kept constant across the three scenarios to dampen effects.

Total capital needs and uses are estimated. We identified three scenarios to characterize a range of possible implementations. These three configurations included the following:

Configuration 1 – Onsite production of denatured fuel ethanol, densified biomass (pellets), and nutraceutical extract powder;

Configuration 2 – Production of 20 percent sugar solution for over-the-fence fuel ethanol production, livestock forage/feed blend stock, and a tolling arrangement for extraction and upgrading of nutraceutical bioactive dermal layer; and

Configuration 3 – Production of 60 percent sugar syrup, construction products oriented-strand board, and a tolling arrangement for dermal layer bioactives extraction.

The financial performance of each of these scenarios is evaluated on Internal Rate of Return on cash available to equity after payments of expenses and debt, but before any tax on those returns.

The effects of changing financial variables on the internal rate of review were calculated. The following sensitivity cases were analyzed by changing the variable indicated and holding all other factors constant in the pro forma.

- Reduced product yield – 5 percent reduction.
- Decreased availability – 90 percent capacity.
- Increased feedstock cost – 10 percent increase.
- Increased non-feedstock operations and maintenance cost – 10 percent increase.
- Reduced ethanol or sugar juice price – 10 percent reduction.
- Reduced biomass product price – 10 percent reduction.
- Reduced extract or dermax price – 10 percent reduction.
- Higher interest on debt – 8 percent interest rate.
- Reduced grant availability – 5 percent of capital.

Further an average change in internal rate of review across all the cases above against the base case was used to evaluate the relative financial stability of each of the business cases.

Goals and Deliverables

This report is a pre-commercial, comprehensive feasibility study assessing the product markets manufacturing processes and economic feasibility of a central processing facility for sweet sorghum grown in the San Joaquin Valley. Using physical and chemical characteristics of the separated materials and using pilot-scale equipment, product pathways were studied to provide the greatest sustainability (e.g., environmental, economic) for the facility. This study incorporates past and present work related to sweet sorghum cultivation, optimizes configuration of a plant for economic and environmental sustainability, and provides conceptual engineering of an optimized plant considering low-energy and low-water use goals. This study serves as a template to develop multiple processing facilities in California and retrofit California's existing ethanol production capacity to produce low carbon fuels from feed stocks produced in the state, which keeps economic benefits in the state.

CHAPTER 2:
About Sweet Sorghum

In recent years, sorghum has risen from relative obscurity and declining acreage to become a leading candidate crop for advanced biofuel. Sorghum is in the top five most important cereal crops in the world and has a significant position in the sugar syrup and forage grass markets.

From an agricultural standpoint, sorghum competes with corn – both are cultivated crops, occupy the same place in the rotation, and are used primarily as feed for livestock. As detailed in Bulletin No. 218 from the Agricultural Experiment Station at Kansas State[2], sorghum's advantages over corn include:

- Adapted to somewhat warmer and drier conditions than corn.
- More resistant to heat and drought.
- More profitable on poor soil than other grain or fiber crops.
- Has about twice as many secondary roots per unit length of primary roots as corn, which increases the ability of the plant to absorb moisture from a dry soil.
- Will remain dormant during periods of drought that kill corn. When rain comes later, the crop will revive and mature.
- At first sorghum grows more slowly than corn and uses the moisture stored in the soil less rapidly, thereby leaving more of it for maturing the grain.
- Uses less water, pound for pound of material produced, than any other grain crop.
- Sorghum grain is gluten free and a good substitute for cereal grains such as wheat, barley, and rye for individuals with celiac disease.

Bulletin No. 218 offers a detailed profile of Kansas sorghum in November 1917, and states: "Since sorghum will grow better than most crops with poor methods, it is often the most neglected crop on the farm. However, good methods usually pay as well as with other crops."

The sorgos, or sweet sorghums, differ from the grain sorghums principally in having sweet, juicy stems, and seeds which when ripe contain considerable quantities of starch. Sweet sorghum is often compared to sugarcane, particularly in discussions around low carbon biofuel production, yet offers multiple advantages over sugarcane as follows:

- Matures in 3 to 4 months, whereas sugarcane requires 12 to 18 months.
- Requires about half the water of sugarcane (based on equivalent quantity of ethanol produced from each crop) and can be a dry land (non-irrigated) crop in most areas of the country.
- Is propagated by seed which can be planted using common farm equipment.

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[2] Smith, W.R., *Growing Sorghum in Kansas*, Kansas State Printing Plant, Topeka, KS. November 1917.

- Grows on marginal land and requires less fertilizer while also adding nitrogen and natural herbicide/pesticide value to the soil.
- Yields both sugar juice and grain starch; sugarcane does not.
- Contains less sulfur than sugarcane.
- Silage from sorghum has a higher feed value than sugarcane.
- Sweet sorghum grown in the U.S. is far superior to Brazilian sugarcane considering environmental aspects of cultivation.

"Considered in an utilitarian point of view, this plant, perhaps, has stronger claims on the American agriculturist than any other product that has been brought into this country since the introduction of cotton or wheat."[3] The remainder of this section of the Report presents an overview of sorghum history, varieties, cultural practices, and current activities in the U.S. related to producing fuel ethanol from sorghum.

History of Sorghum in the United States

The history of sorghum in the U.S. essentially follows four separate and distinct market applications based on the utility of various parts of the plant:

- Brooms and whiskbrooms made from the fibrous seed branches of broomcorn;
- Forage grass using the entire sorghum plant;
- Syrup from the sugar juice of sweet sorghum stalks; and
- Grain from the starch-bearing seeds of grain sorghum.

Broomcorn (Sorghum vulgare). The introduction of broomcorn in the mid-1700s is attributed to Benjamin Franklin, and production eventually spread across the U.S. For the best bristles, the crop was harvested before the seed developed and the remainder of the plant from this variety of sorghum was viewed to have little to no forage value.[4]

Forage Sorghum. In 1840, Colonel William Johnson introduced what is now called Johnsongrass (*sorghum halepense*) to his farmland in Alabama. Originally native to the Mediterranean region, Johnsongrass is now considered to be one of the ten worst weeds in the world. It spreads aggressively, displacing native vegetation and restricting tree seedling establishment. Johnsongrass can produce two or more crops of hay each year, similar to alfalfa in protein content and to timothy in feeding value.[5] Like Johnsongrass, varieties of grain sorghum and sweet sorghum can be used for green chop, hay, silage, and pasture.

Sweet Sorghum. In the 1850s, a U.S. Patent Officer introduced sweet sorghum (*sorghum bicolor*) to America. The U.S. Department of Agriculture conducted experiments on the

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[3] Stansbury, Charles F., *Chinese sugar-cane and sugar making; its history, culture, and adaptation to the climate, soil and economy of the United States*, CM Saxton and Company, New York, 1857.

[4] Editors of the American Agriculturist, *Broom-Corn and Brooms. A Treatise on Raising Broom-Corn and Making Brooms, on a Small or Large Scale*, Orange Judd Company, New York, 1876.

[5] Cardina, John, et. al., *Ohio Perennial & Biennial Weed Guide*, (oardc.ohio-state.edu/weedguide/) accessed May 2013.

extraction of sucrose from sorghum and on crystallization of sorghum syrup, hoping to reduce America's reliance on cane sugar imports and slave-dependent sugar plantations. While it proved too difficult to crystallize dry sugar from sorghum syrup, the local sweetener alternative to cane sugar was welcomed by America's farmers. Production of sorghum syrup reached a peak of 24 million gallons in the 1880s, and then declined over the next century in the face of competing glucose syrup. Resurgence in production has increased sweet sorghum acreage for syrup from 2,400 acres in 1975 to 30,000 acres presently.[6]

Grain Sorghum. In 1875, a grain sorghum (*sorghum bicolor*) variety called kafir arrived in America, and less than a decade later, milo was introduced to America. Other varieties followed over the years, including a variety called feterita which produced grain when other crops failed in the 1913 dry season.[2] In 2012, more than six million acres in the U.S. was planted in sorghum, where it is grown primarily on dry land (non-irrigated) acres. Grain sorghum is exported, used in animal feed domestically, or used in industrial and food uses.[7] Recently, grain sorghum has achieved a favorable rating by the U.S. EPA as an advanced biofuel resource under the renewable fuel standard.

Sweet Sorghum Varieties

Sorghum is an upright, short-day, summer grass that is a member of the Poaceae family. Sorghum's general scientific name is *Sorghum Bicolor (L.) Moench*. Various common names for sorghum used around the world are great millet, kafir corn, kaoliang, durra, Jerusalem corn, sorgo, jowari, and milo maize.

Sorghums exhibit different heights and maturity dates depending on whether they are grain sorghums, forage sorghums, sweet sorghums or otherwise. Cultivars of sorghum are readily available for different geographical regions, climates, soil types, disease resistance, and uses.

Sweet sorghum varieties are available as heirloom, improved, and genetically-modified varieties. Genetic modification of sweet sorghum is a recent phenomenon given the increasing interest in sweet sorghum biofuels product. However, the focus of this report is on the heirloom and improved varieties as described herein. It is recognized that available varieties, perhaps those considered heirloom and those which have been modified, for purposes of this report likely consist of hybridized varieties from natural and anthropogenic cross-pollination.

Heirloom Varieties of Sweet Sorghum

In 1924, a comprehensive effort was undertaken to identify and determine the distribution of sorghum varieties produced in the U.S.[8] Hundreds of varieties were identified, but this report focuses on the top five sorgo varieties in the principal sorghum-producing states which at that

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[6] National Sweet Sorghum Producers and Processors Association (https://nssppa.org/sweet-sorghum-faqs) accessed May 2013.

[7] National Sorghum Producers (sorghumgrowers.com/sorghum-101/) accessed May 2013.

[8] Vinall, H.N. et. al., Identification, *History, and Distribution of Common Sorghum Varieties*, Technical Bulletin No. 506, U.S. Department of Agriculture, Washington, DC, July 1936.

time comprised nearly 80 percent of all sorgos. All varieties can be cultivated in the San Joaquin Valley.

Black Amber shown in Figure 1*.* One of the first varieties brought to the U.S. and a standard for early America, Black Amber sorgo arrived from China through France. This variety may also be known as Early Amber, Minnesota Amber, and Dakota Amber. A grower from the late 1800s said, "This crop ripened much sooner than any other cane known to me, and the sirup [sic] was superior in color and taste to any other produced in the neighborhood." Indeed, Black Amber is a short- season variety and will mature in 80 to 100 days. However, the variety does not yield as well as other varieties where conditions are favorable. Thus, its highest value is where early maturity is of primary importance.

Figure 1: Black Amber Sorghum Nearing Maturity in Timnath, Colorado

Source: Edward Settle, Tapis Energy Group, Inc., September 2013

Sumac. Sumac sorgo is a large, late-maturing variety, requiring from 115 to 125 days to mature. In 1917, Red Top was a commonly used name, and Early Sumac was a selection from Sumac which matured 10 to 15 days earlier.

Orange. This variety of sorgo is considered medium- to late-season, maturing in 100 to 110 days. Synonyms include Early Orange and Kansas Orange sorgo. Orange sorgo is considered suitable for forage, silage, seed and syrup.

Honey. Honey sorgo is a late-season variety requiring 125 days to mature. It is also known as Seeded Ribbon Cane, Honey Drip, and Sugar Drip (Figure 2). The variety is much taller than others at 10 to 12 feet.

Figure 2: Sugar Drip Sorghum in Timnath, Colorado at Nearly 8-feet

Source: Edward Settle, Tapis Energy Group, Inc., September 2013

Red Amber. In 1917, Red Amber sorgo was characterized as a comparatively new variety brought from Australia. Compared to Black Amber, it was found to mature somewhat later and less reliably but was considered to be sweeter and superior where forage and seed was desired.

Modern Improved Varieties of Sweet Sorghum

Sweet sorghum producers have continued to improve sorgos over the years, usually by selecting the seed from the best of a crop or by cross-pollinating varieties which seem to possess desirable characteristics. A 1997 publication of the Kentucky Cooperative Extensive Service[9] advises that the best sweet sorghum varieties should have the following desirable characteristics:

- Produce a high yield of medium to large stalks per acre,
- Have strong, erect growth so it will not readily lodge,
- Contain a high percentage of extractable juice,
- Contain juice with a high total soluble solids (Brix) content, mostly sugars,
- Resist diseases,
- Tolerate drought,
- Tolerate excessive water, and
- Produce high-quality syrup.

Although this advice is offered principally for those engaged in the production of sweet sorghum syrup, the advice applies to growing sweet sorghum for the production of ethanol.

In the last several decades, new and improved varieties of sweet sorghum have been released with most varieties bred at the U.S. Sugar Crops Field Station, Meridian, Mississippi between 1940 and 1980. Three leading hybrids are described below.

Dale. Dale is a mid- to late-season variety bred for its resistance to sweet sorghum diseases such as leaf anthracnose, stalk red rot, and maize dwarf mosaic. Straight, upright stalks and resistance to lodging are hallmarks of this variety. As well, the variety produces a high yield of sugar juice per ton of stalks.

M81E. A late-maturing variety, M81E is similar to Dale in stalk characteristics, resistance to lodging, and resistance to sweet sorghum diseases. From a sorghum syrup production perspective, this variety is considered to produce superior yield and quality as compared to Dale.

Della. Della is a mid-season variety with good disease resistance, a backcross of Dale to an earlier maturing line. Della lacks the lodging resistance of Dale and is more variable in height. The early maturity is beneficial, allowing syrup production operations to begin earlier in the fall.

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[9] Bitzer, Morris J., *Production of Sweet Sorghum for Syrup in Kentucky*, Publication AGR-122, Cooperative Extension Service, University of Kentucky, College of Agriculture, 1997.

Other modern varieties include Theis, Brandes, Williams, Keller, KN Morris, and more. Recent genetic mapping efforts characterize and relate over 100 sweet sorghum varieties at the chromosome level for Brix and height.[10]

Growing Regions for Sugarcane and Sweet Sorghum

Sugarcane is a grass, grown primarily in the tropics and subtropics. More than 75 percent of the world's sugar is derived from the sucrose in sugarcane. Sugarcane is the world's largest crop, and Brazil is the world's leading producer at more than 30 percent of market share. The U.S. is the world's 5th largest producer of sugarcane at 26.7 million tons in 2011.

Given its tropical affinity, sugarcane is generally limited to growth south of the thirty-third parallel. About 90 percent of all U.S. sugarcane is grown in Florida and Louisiana, with Texas and Hawaii producing the balance.[11] On a relatively small scale, sugarcane has been successfully grown in California, Alabama, Georgia and other states. The thirty-third parallel passes through California near the coastal community of Encinitas north of San Diego and near the inland community of Brawley north of El Centro in the Imperial Valley.

A perennial crop, sugarcane is sensitive to climate, soil type, irrigation, fertilizer, pests and diseases, and more. Sugarcane can be harvested 2 to 10 times before replanting, though sugar production wanes with each cutting. Planting is typically accomplished by mechanically planting a sugarcane billet. The harvest in Louisiana, the most northern growing U.S. area, generally runs from late September through late December or early January. The harvest season in other states generally runs from October through March.

Similar to sugarcane, sorghum is a warm-season grass which grows perennially in regions without a winter freeze or annually via seed planting. Production of sorghum requires growing season temperatures above 60^{o} F, and thus, sorghum is usually found in the U.S. south of the forty-fifth parallel. However, sweet sorghum syrup has been produced in every one of the contiguous 48 states.[9] For reference, the forty-fifth parallel passes through the upper portion of the U.S. near, for example, Minneapolis, Minnesota. Sweet sorghum is grown often in one or two acre operations in the southeast U.S. states of Kentucky, North Carolina, Tennessee and several others.

However, sweet sorghum grows where grain sorghum grows. Kansas, Texas and Nebraska are the leading producers of grain sorghum.

Assuming growing conditions of sufficient soil quality and water, lower elevations, and adequate direct sunshine, sorghum can be grown anywhere from the northern to the southern boundary of California.

Traditional Sweet Sorghum Cultivation, Processing and Products

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[10] Murray, Seth C. et. al., *Sweet Sorghum Genetic Diversity and Association Mapping for Brix and Height*, The Plant Genome 2:48-62, Crop Science Society of America, Madison, WI, February 2009.

[11] Crop Production Annual Summary, National Agricultural Statistics Service (NASS), USDA, 2012.

An excellent historical source of information on early sweet sorghum cultivation is found in a book published shortly after introduction of sweet sorghum to the United States: "Chinese Sugar Cane and Sugar Making; Its Culture and Adaptation to the Climate Soil and Economy of the United States" (Charles Stansbury, 1857). The book describes the cultivation of the crop, accounting for various processes for manufacturing sugar from sorgo.

Sorgo proved to be an outstanding crop in the US, growing to a height of 8 to 16 feet, twice the height of the crop in Europe. Traditionally, it was cultivated in hills containing 8 to 10 stalks, one quart of seed per acre, though row crops were also grown, 3 feet apart and "from ten to twelve inches asunder." Hoeing during growth was practiced, and suckers (tillers) were to be removed. Maturity was indicated by the dark purple or black colored seeds at maturity. If lodging occurred before the seed matured, the crop remained on the ground "for weeks without injury."

Traditional manual harvesting of sweet sorghum is similar to sugar cane. In the morning, the cane is snapped or cut about a foot below the panicle to remove the seed head. Using a gloved hand, the leaves are stripped from the stalk and the cane is left standing for a few hours allowing additional conversion of starch to sugar through natural plant enzymes. Later in the day, a machete is used to sheer the stalk off at the base of the plant just above ground level, and the stalks are delivered to the cane processing area.

Another traditional harvesting technique was to cut the entire stalk without removal of seed heads or leaves, using a machete, tractor-mounted sickle bar mower, or corn binder.

Subsequently, the stalks were tied up in bunches of 25 stalks and the bundles were shocked. Shocking is placing about 20 to 25 bundles into a pyramid arrangement which sheds rainfall and allows increased airflow through the bundles as they dry and shrink. Alternatively, bundles were suspended in a secure airy place, sheltered from the rain.

The traditional manner of processing of sweet sorghum for syrup utilized a mill – hand-powered, horse-drawn or tractor-driven depending on mill and operation. Often, one member of the community would own the mill and neighboring farms would bring their sweet sorghum stalks to the mill for processing. Under high pressure, the stalks were squeezed yielding a clear to pea green juice with about 10 to 16 percent sugar by mass (Brix). Through a series of boiling pans, water in the sugar juice would be evaporated off leaving a thick, amber-colored sugar syrup. A third of the sugar was declared "uncrystallizable", though it could be readily fermented. (The decline of sweet sorghum syrup as a household sweetener over the most recent century is attributed to the difficulty in crystallizing sweet sorghum sugars).

The primary product from sweet sorghum was sorghum syrup to be used on the farm for sweetening baked goods and eating on pancakes and biscuits. Its value was also recognized for the production of alcohol (a distilled product described as "less fiery than rum"), beer, and "a product similar to cider" (in France). Co-products included fodder for livestock or mulch from the crushed stalks as well as baking flour or poultry feed from the seeds.

Ethanol Production via Sugar Fermentation

Any source of carbohydrates such as sugar, starch, and cellulose can be used to make ethanol. In the US, nearly all fuel ethanol production is based on corn, that is, the starch in corn is converted to sugars and the sugars are fermented to alcohol. In Brazil, nearly all fuel ethanol production is based on sugarcane and sugarcane molasses, that is, the sugars are fermented directly to alcohol. This section describes the process and economics of producing fuel ethanol from sugar fermentation using various traditional methods and identifies efforts to produce fuel ethanol from sweet sorghum both in the US and around the world.

Overall Production Economics for Traditional Processing

In July 2006, the USDA published a report on "The Economic Feasibility of Ethanol Production from Sugar in the United States." The report investigated the feasibility of producing fuel ethanol from the following feed stocks: (1) sugarcane juice; (2) sugar beet juice, (3) cane or beet molasses; (4) raw sugar; and (5) refined sugar. Comparisons were made with grain feed stocks, specifically corn.

Often, the units describing a particular feedstock and product vary and can be a source of confusion. Thus, for reference, we offer an industry-accepted statistic that a bushel of corn (about 56 pounds) can produce approximately 2.8 gallons of ethanol. That equates to approximately 100 gallons of ethanol per ton of corn. The theoretical yield of ethanol from one ton of sucrose is 163 gallons, though the USDA projected a maximum recovery and yield based on actual plant operations and a refined sugar feedstock would be 141 gallons per ton of sucrose. One ton of raw sugarcane would be expected to yield 19.5 gallons; one ton of sugar beets would be expected to yield 24.8 gallons of ethanol; one ton of molasses (sugarcane or sugar beet) would yield about 69.4 gallons of ethanol; and one ton of raw sugar would yield 135 gallons of ethanol.

Current market pricing for three of these feed stocks is presented in Table 1, along with the calculated feedstock cost per gallon of ethanol.

Table 1: Market Pricing for Ethanol Feed Stocks and Equivalent Feedstock per Gallon Ethanol.

Feedstock	Price per ton ($USD)	Price per gallon ($USD)
Corn	$160	$1.60
Molasses	$165	$2.38
Raw Sugar	$300	$2.22

Source: GVE calculations

The pricing presented in the table would suggest first a significant price advantage to using corn. While there are distinct advantages to corn-based ethanol production, the feedstock price per gallon is an important data point though insufficient for a thorough economic conclusion given the additional processing requirements to produce fuel ethanol from the starch-based feedstock. The pricing presented in the table would also suggest only a slight price difference between raw sugar and molasses. However, current market conditions make it difficult to analyze either of these two feed stocks. Supply and demand are not balanced, the US government is currently underpinning the price of sugar, and molasses is being exported at a relatively low price when compared to recent history.

For raw feed stocks such as corn or sugar beets, feedstock costs are dependent primarily on farm input expenses: seed, fertilizer, water, fuel, labor, land, and other expenses. Fertilizer and fuel costs are directly related to higher prices for natural gas and diesel fuel. Thus, the costs presented in the table above could differ significantly over any given season. Feedstock sourced from sugar juice, molasses, raw or refined sugar is even more dependent on underlying commodity energy prices, reflecting the additional energy-intensive processing applied to a raw feedstock.

Processing costs for each feedstock are different, and for purposes of this discussion, we focus solely on processing corn (dry mill), raw sugar, and molasses (shown in Table 2). Additional data can be found in the USDA study for corn (wet milling), sugarcane, sugar beets, and refined sugar.

Table 2: Processing Costs per Gallon Ethanol

Feedstock	Processing Costs ($USD per gallon)
Corn	$0.52
Molasses	$0.36
Raw Sugar	$0.36

Source: Economic Feasibility of Ethanol Production from Sugar in the United States, USDA, 2006.

As with crop costs, processing costs are highly dependent on input expenses: natural gas, electricity, labor, maintenance, enzymes, yeast, chemicals, and so forth.

The last major component in the cost of ethanol production is capital cost. According to the USDA study, a corn-based ethanol plant was projected to cost $1.50 per gallon of annual capacity assuming a 20 million gallon per year production plant. A comparably-sized plant processing raw sugarcane or sugar beets was estimated to require $2.10 to $2.20 per gallon of annual capacity. A comparably-sized plant processing cane or beet juice or molasses was estimated to have a cost more closely aligned with a corn-based ethanol plant ($1.35 to $1.40 per gallon). Additionally, economies of scale were expected to be comparable for a plant built on any of the studied feed stocks. When annualized (20 years at 7 percent interest), these capital expenses translate into approximately $0.13 to $0.14 per gallon of ethanol.

Existing Sweet Sorghum to Ethanol Projects Outside the United States

Around the world, sweet sorghum is being investigated as a renewable energy feedstock for biofuels and other products. Table 3 presents known sweet sorghum projects located outside the U.S. as maintained on a list courtesy of AgriFuels, Queensland, Australia.

Table 3: Sorghum Projects Outside US

Company	Location	Company	Location	Company	Location
AgriFuels	Australia	Akuo Energy	France	Sweethanol	Europe
Tata Group	India	EUBIA	Ukraine	Petrobras	Brazil
Global Green	Portugal	IPAO-EKITI	Africa	Swaziland Project	Swaziland
Abellon Clean	Ghana	Amyris	Brazil	Tectane	Canada
Cerradinho	Brazil	ZTE Energy	China	Acichan	China

Company	Location	Company	Location	Company	Location
Ceres	Brazil	Eastern Taiwan	Taiwan	Sweet-Fuel	Europe
Anantha Energy	India	Khon Kaen	Thailand	PRAJ	India

Source: Agrifuels, Queensland, AU. 2013

Of the projects listed, PRAJ may have the most international experience with sweet sorghum to ethanol, both at the pilot and plant level (capacity of 1,200 TCD or Tons of Cane per Day), having conducted demonstration trials around the world from 2003 to 2010. PRAJ states that its distillery is designed to operate on sweet sorghum between 6 to 10 months per year given a shorter cultivation season. Such distilleries would require additional feedstock such as syrup/molasses or sugarcane/sugar beet to operate year round or could be constructed as an adjunct operation at a grain ethanol facility. For one cycle of cultivation, PRAJ offers the statistics presented in Table 4 based on the trials.

Table 4: Process Parameters for Large Scale Sorghum Project

Parameter	Quantity
Stalk Production (MT/Hectare)	42 to 55
Fermentable Sugars in Stalk (% w/w)	9.0 to 12.0
Yield of Fermentable Sugar (MT/Hectare)	3.6 to 6.2
Ethanol Yield (L/Hectare)	2,020 to 3,500
Bagasse (MT/Hectare @ 50% moisture)	10 to 14

Source: PRAJ, 2013

Recent United States Sweet Sorghum to Ethanol Trials

Interest in sweet sorghum for ethanol production and other renewable products continues to grow in the US. In addition to the extensive efforts of Great Valley Energy, we identified the following activities to promote sweet sorghum to ethanol in the US.

- The National Corn-to-Ethanol Research Center at Southern Illinois University Edwardsville successfully replaced process water in a corn ethanol plant with sweet sorghum juice to increase production above nameplate capacity. (Farm Industry News, May 2013)
- A commercial sweet sorghum to ethanol plant is being built by Southeast Renewable Fuels LLC in Hendry County, Florida. The plant is designed to produce 20 million
- gallons per year of ethanol, 25 megawatts of electricity from bagasse in a combined heat and power plant, 65,000 tons of carbon dioxide from 18,000 to 25,000 acres of sweet sorghum (two cycles of cultivation). According to the CEO Aaron Pepper, the project is anticipating first equipment arrival in late 2013 and startup in 2015.
- Delta BioRenewables and Commonwealth Agri-Energy produced ethanol from sweet sorghum at the Hopkinsville, Kentucky corn ethanol facility in December 2012. The industrial-scale evaluation used fermentable sugars from Ceres Durasweet sweet sorghum hybrids and was funded in part by the United Sorghum Checkoff Program. Stalks were harvested and crushed, sugary juice was extracted, fermented, and

distilled, and the remaining biomass was used for livestock feed. (Delta BioRenewables, December 2012)

- Solar Fruits Biofuels out of Salisbury, Maryland conducted trials in 2012 on sweet sorghum to ethanol including characteristics of varieties, processing, storage and other variables. (See Sweet Sorghum Ethanol Association, 2013 Conference Proceedings)
- EPEC Biofuels Holdings is a development stage company focused on developing a sweet sorghum to ethanol platform based on farm-integrated, decentralized, modular, distributed production facilities. Based on our research, EPEC has executed supply chain agreements but has not yet piloted its platform[12] (accessed October 2013).
- Highlands EnviroFuels LLC in Riverview, Florida received its major source air permit in 2011 to build a 30 million gallon per year ethanol plant using sugarcane and sweet sorghum. Facility design included a cogeneration plant generating up to 30 MW. Based on our research, we could find no evidence that the Highlands EnviroFuels project has begun construction. (Florida Department of Environmental Protection, website accessed October 2013)
- Louisiana Green Fuels Group in Lacassine, Louisiana owned an idle sugar mill with plans to build an ethanol plant based on sugarcane and sweet sorghum. Based on our research, PRAJ equipment to construct the ethanol plant was sitting unassembled on the site as the company was financially troubled (The Advocate, accessed October 2013). Ultimately, the mill defaulted on property purchase in March 2013 (Jennings Daily News, accessed October 2013)
- In September 2013, California Ethanol and Power received approval to construct a 66 million gallon per year ethanol plant in the Imperial Valley using sweet sorghum and sugarcane for feedstock. The project design includes 49.9 MW of electricity and 940 million cubic feet of biogas production capacity. Uni-systems do Brazil Ltda has preliminarily committed funding for the project, and Shell has executed a five-year offtake agreement for ethanol, power and biogas[13] (accessed October 2013).

In addition to the projects listed above, several universities are conducting various studies on sweet sorghum along the supply chain from seed to fuel and other products. Summarizing the efforts in the US, sweet sorghum appears to show great promise for the production of ethanol though market conditions and other factors contribute to the difficulty of getting projects financed and constructed.

[12] Sorghum Whisky Website (www.epecholdings.com)

[13] California Ethanol and Power Website (www.californiaethanolpower.com)

CHAPTER 3:
Sorghum in the San Joaquin Valley

Sweet sorghum has been evaluated as an energy crop for ethanol production since the 1970s. Various programs in California in recent decades have been conducted to identify inputs and yields of sweet sorghum as an energy crop[14]. This work continues today with test crops currently planted under the direction of UC Davis located at both research facilities and on-farm plots. The results of these tests indicate that sweet sorghum can be grown in the San Joaquin Valley as a dedicated energy crop at a value (quality and cost) which correlates well with Great Valley Energy's analyses. Great Valley Energy has also leveraged current research being completed under a grant from the CEC and California Department of Food and Agriculture to develop bioenergy crops and define Sustainability Best Management Practices for crop production.

This chapter presents a summary of pro forma cultivation aspects and anticipated feedstock pricing for a sweet sorghum project in the San Joaquin Valley. While a crop of sweet sorghum in a given year can be grown and harvested at a calculated cost based on bottom up values, this does not necessarily reflect the price that would be paid for the crop using contract farming as anticipated by Great Valley Energy. Thus, this chapter presents both a bottom up cost approach for information purposes as well as a modeled price for crop switching as conducted by advisors to Great Valley Energy.

Agricultural Best Practices

The global approach to agriculture over the last century has tended toward larger, commercially-owned farms, mechanized production, and highly cost-efficient cultural practices. Some of the benefits of such approach have included year-round availability of crops on a global basis, ever increasing production per acre, moderate pricing of crops, and a reduction in the risks of farming as a business. However, the cost of such approach can be topsoil erosion, groundwater contamination, and other detriments.

Recognizing the impacts of poorly-considered commercial farming practices, the concept of sustainable agriculture has emerged in recent decades and is growing in acceptance in agriculture. Best Management Practices for crop production are being documented and shared among stakeholders, and an online search of the topic returns published manuals from various state agencies and a searchable database of good practices in the Field Office Technical Guide provided by the Natural Resources Conservation Service within the United States Department of Agriculture.[15]

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[14] Hills, F.J., et al, *Sweet Sorghum Cultivars for Alcohol Production*, California Agriculture, University of California-Davis, CA. January-February, 1990.

[15] Settle, D. Edward, *Sustainable Agriculture: Best Management Practices for Growing Sorghum*, Tapis Energy Group, Inc., Timnath, CO. August 2013.

According to UC Davis, sustainable agriculture integrates three main goals – environmental health, economic profitability, and social and economic equity. Sustainability rests on the principle that the needs of the present must be met without compromising the ability of future generations to meet their own needs. Thus, stewardship of both natural and human resources is of prime importance.[16] Black amber sweet sorghum (Figure 3) is an heirloom, short-season variety and was the first sweet sorghum variety brought to the U.S. in the 1850s.

Figure 3: Black Amber Sweet Sorghum Approaching the Final Growth Stage in Timnath, Colorado

Source: Edward Settle, August 2013

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[16] Feenstra, G.; Ingels, C.; Campbell, D. (2013). *What is Sustainable Agriculture?* UC Sustainable Agriculture Research and Education Program, University of California, Davis, CA. Accessed August 22, 2013 (https://asi.ucdavis.edu/programs/ucsarep).

Great Valley Energy, LLC strongly values the principles of stewardship and the broader objectives of sustainable agriculture, particularly as it relates to the protection and maintenance of land and natural resources. Stewardship demands acute awareness of best management practices from site selection and varietal selection through harvest and fallowing. Economic competitiveness is also a crucial component because a stewardship entity that does not remain economically healthy may give way to entities less interested in sustainable practices.

Great Valley Energy's approach to growing sweet sorghum in the San Joaquin Valley, as presented in this chapter of the report, incorporates those elements that we believe are current best management practices for sustainably growing and processing sweet sorghum. However, it is recognized as best practice that any document setting forth best practices should be a living document. As each harvest is cultivated leading to additional knowledge and wisdom, and as improved methods of crop production evolve, the lessons learned should be incorporated.

Cultural Inputs and Costs

Sorghum is a very tolerant and forgiving crop, but optimum growing conditions and proper management inputs are necessary for maximum yields. The following subsections address the key elements of sweet sorghum production and related costs associated with ground preparation, planting, growing, and harvesting sweet sorghum. Double cropping or cultivation of a ratoon crop may be possible, but for pro forma purposes only single cropping is assumed herein.

Crop Planning

Crop planning is a critical farm practice which when done effectively provides a guide for the season's farming activities. Crop planning will document field and crop rotations, varieties, dates for seeding, cover crops, and more. A good plan will also allow for adjustments as needed to accommodate differences between plan and actual conditions, such as weather and temperature changes. A particular driver for sweet sorghum maturity is Growing Degree Units and implementation of an effective crop plan will require close monitoring and adjustment for actual growing degree units in the field. The impact of growing degree units on crop maturity is discussed further below.

While crop planning is important for crops such as field corn and alfalfa, such crops are more forgiving after harvest than crops which are more acutely perishable such as tomatoes and sweet sorghum. Where there is an expensive processing plant standing by to process a crop at a given capacity, planning activities through to harvest a perishable crop around processing capacity is critically important.

A commercial operation based on sweet sorghum will work closely with contract farmers to develop a master crop plan. The master plan will detail the following:

- Field and contractual farming arrangements,
- Seed varieties, source, pricing and ordering requirements,
- Planting dates and days to harvest (early season to late season varieties),
- Row spacing, seeds per unit of row, seeds per acre,

- Seedling emergence and crop progression dates, and
- Nutrient and water input quantity and timing.

Over time, the master plan will result in a growing database of information wealth that will allow for continual improvement in crop production toward best management practices.

Seed Types Evaluated and Costs

The Table 5 presents the seed types evaluated by Great Valley Energy along with the varietal characteristics and costs. Seeds treated with a pre-germination herbicide antidote are available for a nominal 10 percent premium.[17]

Table 5: Seed Prices for Varieties Evaluated

Variety	Cost ($/lb)	Characteristics
Black Amber	$11	Short-season
Sugar Drip	$7	Mid-season
KN Morris	$8	Mid-season
Umbrella	$8	Mid-season
Dale	$7	Mid- to Late-season
Keller	$9	Mid- to Late-season
M81E	$7	Late-season
Proprietary A	NA	NA
Proprietary B	NA	NA
Proprietary C	NA	NA

Source: Townsend Sorghum Mill

Extensive crop planning and experience will result in refinement of varieties added to the mix to extend the harvest period into earlier and later dates. Seed counts per pound of each variety will be determined so that application of seed per acre can be customized. Should proprietary varieties consistently demonstrate a definitive advantage for high biomass and sugar production, additional expense may be necessary for licensing and royalty fees.

Water Management

Sorghum is one of the most drought tolerant crops grown in the U.S. This does not mean it will thrive in dry conditions, but it will typically perform better than corn, cotton or soybeans under stressful conditions. Reasonable yields may be obtained without irrigation in years that have good rainfall patterns and growing conditions. However, when rainfall is not sufficient the yield is reduced. In the San Joaquin Valley, sorghum cannot be farmed with dry land techniques due to insufficient rainfall.

The total amount of water that sorghum needs during the growing season may vary from 1.5 to 3 acre-feet depending on factors such as weather conditions, plant density, fertility, soil type and days to maturity. Irrigation water required will vary depending on the beginning soil moisture and the rainfall received during the growing season. Yields tend to increase with increasing water availability.

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[17] Townsend Sorghum Mill, Seed Procurement, 2011 – 2013.

Sorghum's daily water needs are relatively low in the first 3 to 4 weeks of vegetative growth, and early spring rainfall in the San Joaquin Valley may be sufficient to meet the water demand during this period. Rainfall or irrigation following an extended dry period early in the crop season can result in extensive tillering. Mild irrigation is needed until the plants have about 7 fully developed leaves. At this time, the growth rate increases. Water uptake increases and irrigation is often needed at this time to activate fertilizer and avoid moisture stress.

If nutrient and water needs are met, rapid plant growth continues as it approaches the boot stage. At this time, the crop's water need is increasing to its greatest daily use. Irrigation during the 3 to 4 weeks of boot and bloom period may be critical to meet the crop water needs and achieve a robust harvest.

Testing the grain at soft dough stage and the sugar content of the stalk juice may indicate that the crop is nearing maximum sugar production. For best management practices, irrigation may be stopped as the harvest is approaching, allowing the reduction of moisture and concentration of sugars in the stalk. A reduction in crop moisture coinciding with an increase in sugar concentration is an energy efficiency measure that reduces crop transport and processing energy inputs and related costs. For pro forma purposes, we assume 2.5 acre-ft per crop at a cost of $100 per acre-ft.[18] as water is of premium value in the San Joaquin Valley and its cost variable from year to year, close management will be necessary.

Nutrient Management

In the U.S., sorghum has been traditionally grown in less productive soils and often under dryland conditions, resulting in yields below the potential of the crop. Sorghum develops an aggressive root system that increases the ability of this crop to mine the soil for nutrients and water. Sorghum performs better than most crops under limiting conditions, but considerably higher yields are obtained if grown under optimum water and nutrient conditions.

Nitrogen is probably the most limiting nutrient in sorghum production. Total recommended nitrogen application rates range from 60 pounds per acre for non-irrigated, double-cropped sorghum to 150 pounds per acre or more for irrigated, single-cropped sorghum. The usual recommendation for irrigated sorghum is 120 pounds per acre, compared to 100 pounds for non-irrigated. The sorghum plant does not use much nitrogen during the first 20 days of growth and development, but by the time the plant is 60 days old, it has used nearly 60 percent of the available nitrogen. Consequently, one-third to one-half of the total nitrogen is usually applied before planting, and the remainder is side-dressed by about the sixth- or seventh-leaf stage. For pro forma purposes, we assume 140 pounds per acre of nitrogen.[18]

Pest Management

Pest management includes all cultural decisions appropriate for the control of insects, weeds and diseases. Great Valley Energy has determined that for best management practices, site specific cultural practices should dictate the quantity and type of insecticides used rather than

[18] Kaffka, Stephen, et al., *Evaluation of the Potential Supply of Sweet Sorghum as a Bioenergy and Bioproducts Feedstock in Fresno, Kern, Kings and Tulare Counties*, California Biomass Collaborative, UC Davis Energy Institute, University of California, Davis, CA. June 2013.

application of a broad spectrum insecticide. Therefore, application of insecticide will not be pre-determined. Similarly, best management practices for sorghum diseases must consider the specific circumstances of the site and variety. Strategies to control disease can be employed such as varietal resistance, planting date, crop rotations and seed bed preparation. Based on contemporary work from UC Davis, costs for insecticide and disease are not significant.[18]

Weed control for sweet sorghum may not permit use of a broad spectrum herbicide because sweet sorghum is a grass. Weeds are best managed by use of Concep (Syngenta) ready seeds and a pre-germination herbicide or other safener/herbicide system. Mechanical practices are very effective after seedling emergence, and weeds are typically minimal after the sweet sorghum canopy develops due to sorghum outcompeting weeds.[15] Physically removing weeds proves to be too expensive to be employed at any commercial scale.

Harvest Management

Best management practices suggest that a harvest should occur when the sugar content in the sap is at its highest level, and this is usually when the sweet sorghum is in the soft dough stage. Physically inspecting the seeds for maturity through the soft dough stage is traditional, but better practice would include monitoring the sap sugar content using a hand-held refractometer. Stopping irrigation well before harvest will allow the sweet sorghum moisture to decline resulting in a more concentrated sugar juice without significantly affecting sugar or dry biomass yield. This is good practice as the fermentation sugar juice may require heating for sterilization before storage or marketing and may require evaporation to reduce transportation costs on a dry sugar basis. To best manage costs and energy inputs downstream of the field, sugar content in the field should be in excess of 10 percent, and with reduced irrigation, could climb to well above 15 percent. Juice that is 10 percent sugar contains twice as much water as juice that is 20 percent sugar on a dry sugar basis, so the economic impact of a lower sugar harvest cascades through the rest of the processes.[15]

Studies have demonstrated that removing the panicle (deheading) prior to harvest increases the sugar in the sap.[19] This may be worthy of additional investigation although the equipment required to dehead sweet sorghum on a commercial basis is not known to exist, and such equipment must necessarily have the capability to retain the seed heads to avoid waste. In addition, this would require an additional harvesting operation and incur additional expense.

Perhaps more importantly than the change in sugar concentration, deheading could reduce lodging potential. Lodging occurs when the stalk of the plant is no longer capable of withstanding gravity or wind and leans to an angle greater than 45 degrees. While lodging doesn't necessarily affect the health of the crop and the crop will continue to mature, it represents a considerable harvesting risk. Once the crop has lodged, efficient mechanical harvesting capacity is severely diminished. Maximum harvester speed may be reduced by 75 percent or more when picking up lodged sorghum.

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[19] Bitzer, Morris J., et al., *Processing Sweet Sorghum for Syrup, Cooperative Extension Service*, University of Kentucky, Lexington, KY. May 2000.

Sweet sorghum is typically harvested with a cane harvester, several of which are commercially available. The cane harvester can remove the leaves and discard them in the field to be plowed under, while retaining the remainder of the stalk in billet form (6- to 18-inch lengths). The billet approach represents best practice over a forage harvester because the billet form helps to preserve the sugar juice longer for processing by leaving it protected by the dermal layer of the stalk. A forage harvester exposes the juice containing plant cells to bacteria, natural yeasts, insects and other pests which will rapidly degrade the sugar and biomass in a matter of hours.

Not unlike perishable foods such as tomatoes, timing of the sweet sorghum harvest must be staged to match the needs of the processing plant as there is no reliable and inexpensive method of storing sweet sorghum beyond short time frames. That said, crop readiness and harvest timing is also dependent on the variety of sorghum grown and heat degree days. Therefore, portions of the crop may be required to stay in the field longer than optimum to avoid waste at the processing facility. A detailed crop harvest plan is required for best management practices. The harvesting operation will need to be closely coordinated if not controlled by feedstock inventory management at the processing facility to provide roughly just-in-time delivery of sorghum feedstock and minimize storage of runstock at the processing facility to a day or two.

Research was conducted on various forms of mechanical harvesting and three main options were identified; commercial self-propelled cane harvester, tractor mounted cane harvester, and a self-constructed cane harvester involving modifications to an existing farm implement.[20]

Commercial Self-Propelled Cane Harvester

There are commercial self-propelled harvesters available, and they can be purchased with "toppers" giving them the ability to cut seed heads from the stalk at heights up to 17 feet on some models. Most models will billet the stalk in lengths ranging from 7 to 10 inches.

Although the physical characteristics of sweet sorghum are slightly different from sugar cane, it is assumed that a harvester made for sugar cane would perform satisfactorily in the mechanical harvesting of sweet sorghum.[21] Due to suitable specifications of numerous self-propelled cane harvesters, their commercial availability, and their high probability of producing satisfactory results, they are considered to be a viable option for sweet sorghum harvesting.

Tractor Mounted Cane Harvester

Research revealed that Simon manufactures a very simple cane harvester which is mounted to a tractor and works in much the same manner as a pulled-behind chopper seen in corn and silage chopping applications. Additional research determined that the Simon harvester is too simplistic and would not be suitable for commercial use, and therefore, is not a viable option.

Self-Constructed Harvester

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[20] Hoffmann, George, *Assessment of Mechanical Harvesting for Great Valley Energy*, FB Consulting, Denver, CO. November 2012.

[21] Wager, Curtis, Telephone Conversation, Glad and Grove Supply Company, Belle Glade, FL, November 2012.

The last option considered was the potential to take an existing piece of farm machinery and to complete modifications to the equipment which would make it suitable for the harvesting of sweet sorghum. If this was done there are several major functions which the equipment would need to be capable to performing: cutting of the sorghum, cutting of the seed heads, stripping of the leaves, billeting of the sorghum, placement of the billets into a wagon or truck, and perhaps placement of the seed heads into a separate hauler.

Major implement manufacturers produce sugar cane harvesters which contain the requirements of a desired mechanical sweet sorghum harvester. This equipment is mass manufactured and distributed throughout the world. Slight modification of a cane harvester may be viable.

In considering the viable options for Great Valley Energy, both John Deere and Case IH make sugar cane harvesters which are currently being utilized in the sugar cane industry. John Deere's newest version is the 3520 Sugarcane Harvester. It has a topper capable of cutting the seed head from the sweet sorghum stalk during the harvesting process. The topper is capable of reaching to a height of 17 feet and the harvester is capable of billeting the stalks in lengths ranging from 7 to 10 in.

Case IH's newest versions are the Austoft 4000 and 8000 series harvester. The 8000 series comes with a topper capable of reaching a maximum height of 13 feet and the harvester is capable of billeting the stalks in lengths ranging from 6.7 to 9.5 in. The 4000 series harvester is a smaller version of the 8000 series and was specifically designed to be utilized for the smaller plots of land often found in developing countries. The 4000 series comes with a topper capable of reaching a maximum height of 10 feet while the billet length of the harvester is unknown.

Both John Deere and Case IH harvesters meet the technical specifications are also more than capable of meeting the required production. Both John Deere 3520 and Austoft 8000 have the ability to harvest well over 150-TPH (or 3 to 4 acres per hour), substantially exceeding the requirements of the 10 and 50 ton per hour Great Valley Energy Configurations. Although the exact production of the Austoft 4000 is unknown, it appears to be capable of harvesting over 100 tons in 8-10 hours.[20]

Although the aforementioned harvesters have the desired ability and availability, capital cost is significant on a per ton harvested basis. A basic John Deere 3520 harvester has a list price of over $377,000 (excluding freight and set-up). It is estimated that a negotiated deal might result in a purchase price as low as $310,000 with an additional $5,000 for freight and set-up. In order to purchase, Great Valley Energy would be required to put down at least 30 percent in order to obtain financing from John Deere. Additionally, it is estimated that annual operation and maintenance expense would be $5,000 - $7,000 per year. Although a Case IH dealer was not contacted, it is estimated that the list price for a new Austoft 8000 would be within 10 percent of the list price for a John Deere 3520.[20]

Great Valley Energy's advisors sought information on previously owned harvesters. Used harvesters are very difficult to find as many investors as possible purchase used harvesters for shipment to developing countries. Generally, used cane harvesters sell for around $150,000.

A new harvester can be assumed at a delivered cost of $350,000. Due to the low volume required daily (250 tons), it is estimated that the annual operations and maintenance expense would be $5,000 - $7,000 per year. Additionally, assuming a useful life of 10 years and a scrap value of $20,000, the annual cost of the harvester (depreciation plus operations and maintenance) would be approximately $40,000 per year. Assuming an annual harvest of 800 acres, the resultant harvester cost would be approximately $50 per acre. Such cost would not include labor, fuel and related expenses for the harvest.[20] Based on engine data, fuel use for the harvester is 9 to 12 gallons per hour. Harvest labor would require 2 people and an additional truck or cart to transport billets out of the field. At $50 per hour for fuel and another $50 per hour for labor, assuming 2 acres per hour yields $50 per acre for labor and fuel. This brings the total of equipment, labor and fuel to approximately $100 per acre for harvest.

Demonstrated Yields

Sweet sorghum yields vary considerably depending on location, variety, water and nutrient input, growing degree units, and other cultural factors. In preliminary small plot trials conducted in Davis and Salinas, California, (UC Davis, Hills, et al, 1990), yields ranged from 36 to 59 tons of green biomass per acre and 30-50 tons of green stalks per acre.

In 2011, Great Valley Energy cultivated 5 varieties of sweet sorghum in California in Bakersfield, Five Points, and Lemoore. In 2012, Great Valey Energy contracted with Blackwell Land Company under typical commercial conditions to grow sweet sorghum in Lost Hills. For the 2012 cultivation, 5 varieties were grown – three proprietary and two publicly-available.

Each variety was planted on two different planting dates, and regular harvests occurred on 4 separate occasions from 117 to 160 days after planting. Production of total green biomass ranged from 27 to 76 tons per acre with average production confidently established for pro forma purposes at 45 tons per acre of total green biomass (including seed heads and leaves). Stalks comprise approximately 80 percent of biomass weight, or 36 tons per acre. The rest of the biomass is leaves and seedheads, approximately 17 and 3 percent respectively.

Production Cost Buildup

Great Valley Energy's advisors prepared an estimate of the costs to produce sweet sorghum (Table 6). Underlying costs were extracted from the UC Cooperative Extension's 2012 Corn (Silage) Costs and Returns Study for the southern San Joaquin Valley which includes Kern, Kings, Tulare and Fresno Counties.[18]

Table 6: Estimated Production Costs for Sweet Sorghum

Operation	Total ($/A)
Irrigation	250
Herbicide	57
Seed	16
Fertilizer	90
Custom	36
Labor	34
Fuel	29
Machine	15
Harvest/Haul	342

Operation	Total ($/A)
Overhead	370
Total	**$1,239**

Source: University of California Corn Silage and Returns Study, 2013

At $1,239 per acre, assuming production of 36 tons of sweet sorghum billets per acre, the cost to produce sweet sorghum billets is estimated to be $34 per ton of billets. We note that harvesting of seeds, if found to be feasible, could result in 1 or more tons per acre of high starch/protein seeds, and if sold at a nominal market equivalent of $200 per ton, could significantly offset billet costs.

A 10 ton per hour project, based on billet feed, would require up to 240 tons of billets at the plant gate per day or about 7.5 acres of harvested crop per day. At 122 days per year of operation, the plant will require 29,280 tons of billets or approximately 915 acres. Plant availability may reduce these values by up to 10 percent. These values scale linearly with increasing plant size; a 50 ton per hour project would require 146,400 tons of billets grown on over 4,500 acres.

Agronomic Inputs and Projected Crop Pricing

The California Biomass Collaborative has developed the Bioenergy Crop Adoption Model a multi-region, multi-input and multi-output model to analyze economically-optimal crop rotations on California's diverse farms. Great Valley Energy commissioned a study of agronomic inputs and projected crop pricing for the southern San Joaquin Valley. The objective of this work was to identify those conditions under which a new bioenergy crop, specifically sweet sorghum, might be adopted by farmers in four counties in California: Kern, Kings, Tulare and Fresno. The crops and land area displaced locally by adoption of sweet sorghum were identified.[18]

Bioenergy Crop Adoption Model captures local marginal cost information to calibrate the model to previously observed cropping patterns in the region, based upon farmers' choices and behavior. After model calibration, the specific scenarios for the Great Valley Energy project objectives were evaluated. Specifically, one scenario assumed that the price would be the same for all production cycles, the homogeneous price case, and the second scenario assumed that the price for each production cycle would differ based on underlying yield, the heterogeneous price case.

Data Sources

Crop choice decisions and production areas were defined by two datasets: the mandatory pesticide use reporting data collected by the California Department of Pesticide Regulation and the historical crop land use recorded by the respective County Agricultural Commissioners. Department of Pesticide Regulation data includes land area for each crop within a designated section (one section is delineated as one square mile or 640 acres). Department of Pesticide Regulation data is incomplete, thus, the County Agricultural Commissioner's data for 2004 through 2008 provide foundation datasets at the county level for gap filling and cross-checking purposes.

Crop budgets were based on the UC Davis Cost and Return Studies enterprise crop budgets. These are derived from growers' reports, extension advisors' observations in each county, and various literature sources. The crop budget for sweet sorghum was derived from the budget for silage sorghum for 2008, updated to 2012. Based on professional judgment of experts at Five Points given sweet sorghum field trials during the 2010 through 2012 seasons, the sweet sorghum budget was further adjusted for yield and agronomic requirements.

Average representative weather data from each of the four counties for 2005 to 2013, specifically daily maximum, minimum and average air temperatures from the California Irrigation Management Information System, were used to predict crop performance.

Model Boundaries

It is common in bioenergy supply and demand discussions to focus on changes in biomass yield, output price, and input costs. However, the focus of this analysis was a maximization of profit, a composite function of the three factors. The solution represents a marginal profit level that acts like a long run incentive, similar to a production contract price. The underlying price is then recovered while keeping yield and input costs constant.

Harvest, storage and transportation costs to the processing facility were not integrated into the model. It was assumed that Great Valley Energy would own the harvesting equipment and organize harvest and transport to the proposed facility on an as needed basis. Additionally, cultivation practices assumed existing technology. Any new cropping pattern would only be adopted if it is more profitable than the observed pattern of crops that was identified using farmers' prior crop adoption and production behavior.

Three additional constraints were imposed on the model as required by Great Valley Energy:

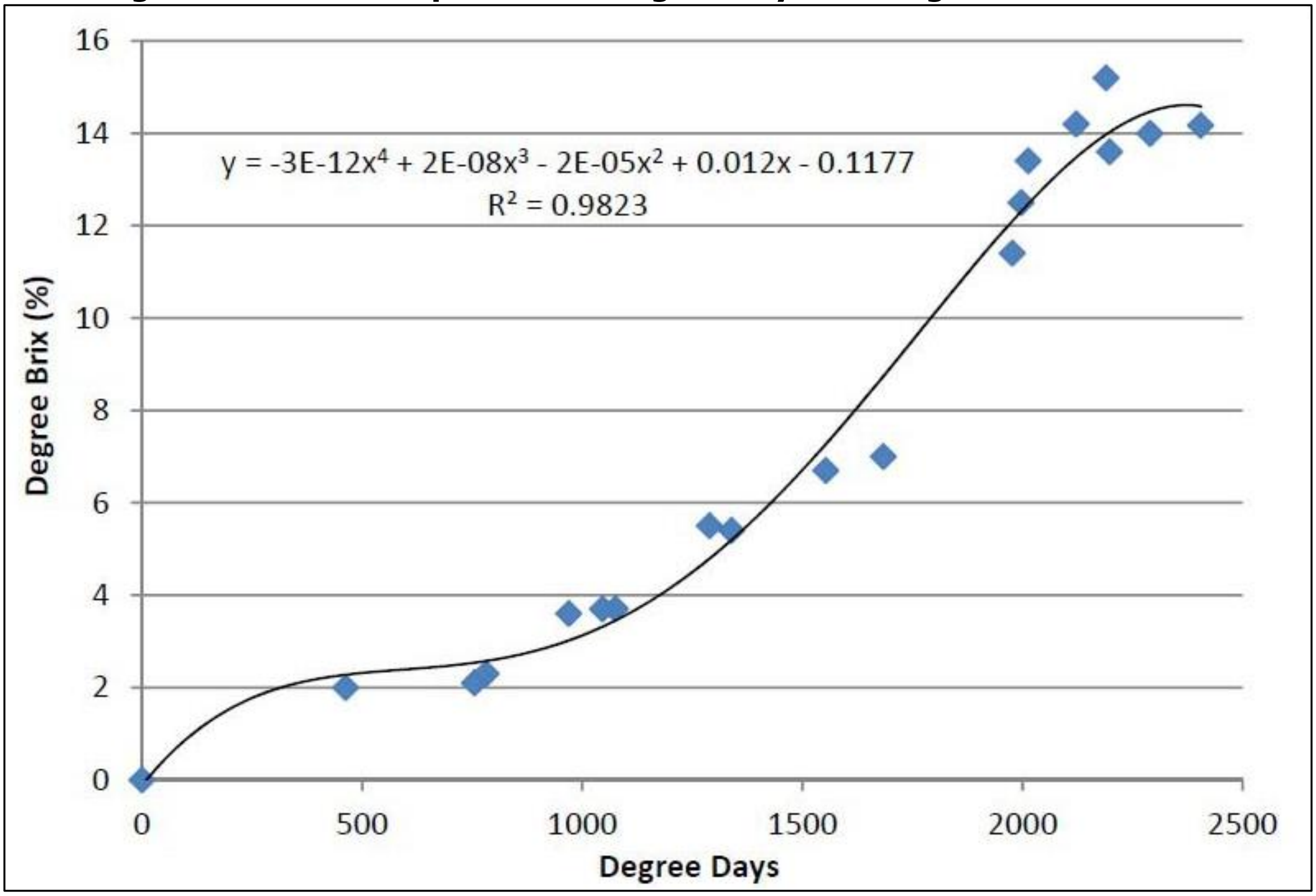
- Minimum quality was assumed to be 10 degrees Brix (hexose sugars),
- Maximum capacity was assumed to be 50,000 tons per month, and
- Product supply was assumed to occur from July to December.

Cropping Schedule Results

A model function was developed to correlate growing degree units, or degree days above 60 F, with degrees Brix of the sweet sorghum assuming a minimum level of Brix at harvest was 10 percent by weight. The function demonstrated a very high correlation coefficient, greater than 98 percent. The degree days were calculated using data from the weather station nearest to the Westside Research and Extension Center, specifically the Five Points weather station in Fresno. The sugar concentrations are data obtained from field trials conducted by Hutmacher, Kaffka and Wright (2013). The correlation (Figure 4) suggests a minimum of 2,100 accumulated degree days from planting was determined necessary to exceed 10 degrees Brix sugar concentration.[18] However, the function predicts that as little as 1,800 degree days may produce a 10 degrees Brix sugar concentration. It should be noted that 10 degrees Brix was assumed to be the minimal economic number of sugars necessary for worthwhile harvest. Processing costs on a per pound sugar basis likely indicate a higher concentration is strongly preferred. The graph below shows that sugars are accumulating rapidly between 1,800 and

2,300 growing degree units. Depending on the time of year, 500 growing degree units may accumulate over the course of several weeks.

Figure 4: Relationship Between Degree Days and Sugar Concentration



Source: Kaffka et al., Sweet Sorghum Agronomic Study, 2013

The results determined that the physiological requirements of sweet sorghum dictated that no harvest would be possible before August 15 each year, and such crop would be planted on May 1. This result was reliant on the agronomic trials conducted at Five Points, CA. Great Valley Energy believes that additional analyses may point to both earlier planting dates and an earlier first harvest date. For example, certain varieties will germinate at lower soil temperatures than others and thus may be planted in early April. Also, certain varieties like Black Amber are short-season varieties that require fewer growing degree days than those varieties included in the field trials at Five Points, CA.

For the final feasibility study, Great Valley Energy assumes a first planting date of April 15 and a first harvest date of August 1 each year. We assume a final planting date of July 1 and a final harvest date of December 1 each year. Field trials also determined that total biomass production would reach a maximum of approximately 40 tons per acre in mid to late September with an approximate normal distribution across the harvest months beginning at 20 tons per year. Great Valley Energy believes that an aggressive cropping program of continually improving variety selection and cultural practices will maintain a crop production at no less than 36 tons of billets per acre averaged over a season.

Homogeneous Crop Price

A single seasonal price will make grower contracting simpler for Great Valley Energy. Thus, the Bioenergy Crop Adoption Model was run assuming one homogeneous price, an upper bound, for all production cycles in each county during the season. The assumed price of sweet sorghum was increased iteratively to simulate the effect of a continuous increase in price. This allowed for a determination of the entry price in each county, the minimum price required to meet potential demand, and which incumbent crops were affected.

The entry price was determined to be around $23 per gross ton or $29 per ton of stalks or billets. At this price, at least 25 percent of the total demand of 50,000 tons per month would be contracted.

However, in order to contract for 100 percent of the total demand at a constant price, Great Valley Energy would be required to pay approximately $39 per gross ton or $49 per net ton of stalks or billets. Again, these prices do not include harvesting, transportation and storage.

The Bioenergy Crop Adoption Model simulations determined that nearly 6,000 acres would be needed to produce 50,000 tons per month of sweet sorghum as demanded for the Great Valley Energy processing facility. The change in land use is predicted to be a displacement of dry beans for 68 percent of the land, followed by corn silage and cotton for displacing more than 90 percent of the land needed. It should be noted that where corn silage is displaced, a portion of sweet sorghum biomass may be substituted for livestock feed.

Finally, Bioenergy Crop Adoption Model was used to determine that the minimum price for an early crop would be approximately $49 per gross ton or $61 per net ton of billets or stalks. In other words, in order for Great Valley Energy to begin operations much earlier than September, a minimum price of $61 per net ton of billets would be required. The high price is primarily due to the low yield expected during the early production cycle at 20 tons per acre.

Heterogeneous Crop Pricing

Because production varies over the season and is dependent on farm-specific crop choices, the Bioenergy Crop Adoption Model model was used to simulate pricing dependent on each production cycle. That is, the model determined the maximum price required for obtaining the output target during any feasible period. When the yield is lowest (20 to 25 tons per acre), the highest price is experienced and ranged from $39 to $49 per gross ton or between $49 and $61 per net ton of billets. When yield is highest (greater than 40 tons per acre), the entry price was lowest at $23 per gross ton or $29 per net ton of billets (Figure 5).

Figure 5: Sorghum Prices per ton for Southern San Joaquin Valley

Planting Date	Harvesting Date	Yield	PRICES 2013			
			Kern	Kings	Tulare	Fresno
1-May	15-Aug	20	[redacted]	[redacted]	[redacted]	$ 49.22
1-May	1-Sep	30	[redacted]	[redacted]	[redacted]	$ 32.81
15-May	15-Sep	40	$ 22.97	$ 23.02	$ 23.03	$ 24.07
15-May	1-Oct	40	$ 23.38	$ 23.56	$ 23.60	$ 24.48
15-Jun	15-Oct	35	$ 26.05	$ 26.08	$ 26.14	$ 27.29
15-Jun	1-Nov	35	$ 26.26	$ 26.54	$ 26.71	$ 27.78
1-Jul	15-Nov	30	$ 30.49	$ 30.66	$ 30.71	$ 32.14
1-Jul	1-Dec	25	$ 36.69	$ 36.80	$ 37.08	$ 38.69

Source: Kaffka et al., Sweet Sorghum Agronomic Study, 2013

Under a heterogeneous pricing system related to each production cycle, Great Valley Energy could contract for crop such that the overall crop costs for the season would be less expensive than the homogeneous pricing system. However, transaction costs and management costs would be increased in order to manage the supply of sweet sorghum to the processing facility under varying production contracts and perhaps a broader audience of farmers. Great Valley Energy will need to analyze the institutional feasibility of such an arrangement to determine whether savings will compensate for the complexity of having different contracts with diverse price and delivery characteristics.

Summary of Pro Forma Inputs for Sweet Sorghum Production

For purposes of the feasibility study, Great Valley Energy has settled on a pro forma approach that is based on the following assumptions:

- Contract farming using a heterogeneous monthly pricing system on a per acre basis,
- Contract harvesting and hauling on a per ton billet basis,
- Set contract price for each month – August, September, October and November, and
- Adjustment at the plant gate based on quality of crop delivered.

Input prices are as set forth in Table 7 for a 10 ton per hour project (7,200 tons per month), leading to a plant gate price for billets of sweet sorghum containing no less than 10 percent sugar. Over the season, the equivalent cost per ton of billet is $46.61.

Table 7: Sorghum Prices per ton Including Harvest and Hauling

Month	Billet Ton/Acre	Grower Contract Price ($/acre)	Harvest/Haul Price ($/ton)	Plant Billet Price ($/ton)
August	20	$984	$9.50	$58.69
September	36	$984	$9.50	$36.83
October	32	$984	$9.50	$40.24
November	24	$984	$9.50	$50.49

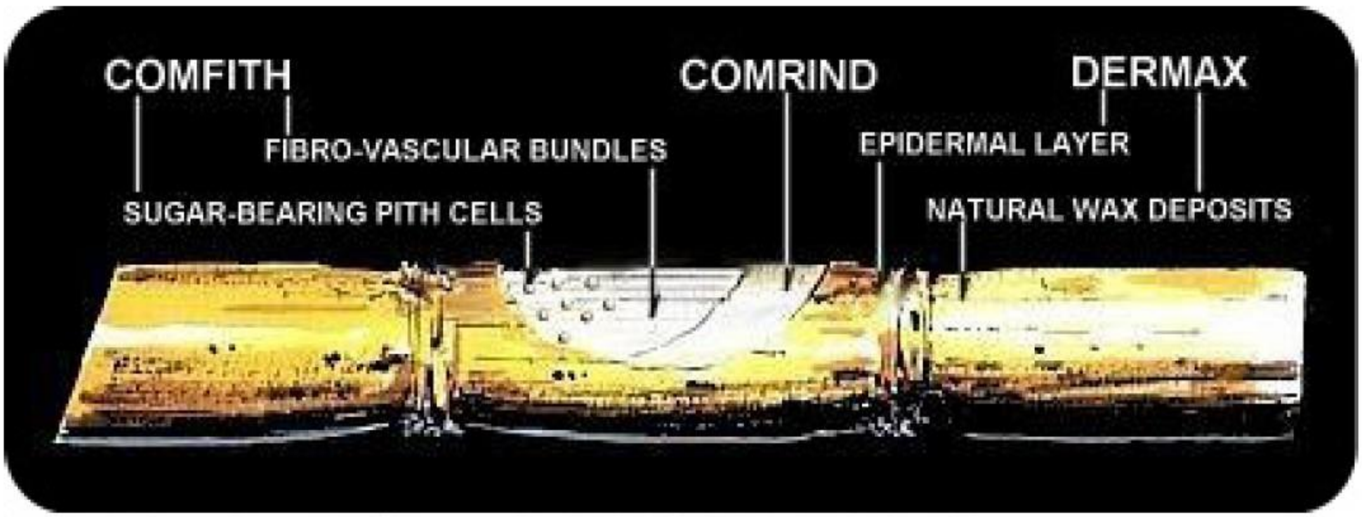
Source: Calculated by Great Valley Energy

CHAPTER 4: Fractionation

Fractionation Described

Figure 6 shows sweet sorghum stalks consisting of three distinct layers from outside in: dermax, comrind, and comfith. The comfith contains juice that is high in sugar, called comflo.

Figure 6: Diagram of Stalk Fractions



Source: KTC Tilby LTD

When entire stalks of sweet sorghum are crushed, as is done in traditional sugar processing, these components lose their physical and chemical identities and, therefore, can only be refined at great expense. Moreover, the structural integrity of comrind is lost when stalks are crushed by conventional milling. The Tilby Separation System fractionates the stalks into its individual components, thereby allowing further processing into value-added products.

For the pilot study, fractionation is achieved by passing the sorghum stalk though a series of machines, each performing an operation on the stalk to provide a singular separation. In commercial practice, these steps would be performed in a rapid sequential manner such that the stalk is continually under process and without changing its orientation.

For the pilot plant, the sequential stations operated were: (1) preprocessing, (2) billeting, (3) splitting, (4) comfith separator, and (5) dermax separator. A commercial plant will receive clean billets for feed into the processing steps of splitting, comfith separation, dermax separation. The comfith is further split into juice and extracted comfith.

Splitting

The splitter is comprised of two flexible feed wheels (one spinning clockwise, the other counter- clockwise) that grab the billet and strike it against a wedge blade edge. The billet is split along its length into two semicircular cross sections seen in Figure 7.

Figure 7: Split Billets from Great Valley Energy's Pilot Facility in Bakersfield, CA

Source: B.Pellens, 2012.

Comfith Separation

The comfith separator is comprised of two equally-sized counter-spinning wheels. One wheel is the cutting wheel, while the other, a holdback wheel, is used to hold the stalk using a metal spike surface. The cutting wheel turns faster than the holdback wheel. As the split stalk moves toward the two rotating wheels it is oriented with the inner pith (flat) part toward the cutting wheel and the outside dermal (curved) part toward the holdback wheel. The split billet is grabbed and moved through the machine by the holdback wheel. While this is occurring, the cutting wheel simultaneously flattens the stalk (against the holdback wheel) and removes the inner pith using a series of scraping blades oriented perpendicular to the stalk flow (Figure 8).

Figure 8: Comfith from Great Valley Energy's Pilot Facility in Bakersfield, CA

Source: B.Pellens, 2012

Once mechanically separated, each side of the stalk is directed for further processing to remove the dermax.

Dermax Separation

The dermax separator uses the same principals of operation as the comfith separator. There are two wheels. One is a holdback; the other is a cutting operation. The rind is oriented such that the outside dermal layer is toward the cutting wheel, while the underside of the rind which was previously contacting the comfith is toward the holdback wheel. The rind is grabbed and moved through the machine by the holdback wheel. While this is occurring, the cutting wheel simultaneously flattens the stalk (against the holdback wheel) and removes the dermal layer using a series of scraping blades oriented perpendicular to the rind flow. Once mechanically separated, each side of the rind is directed for further processing using a deflection plate. Figure 9 shows the separated comrind with dermax.

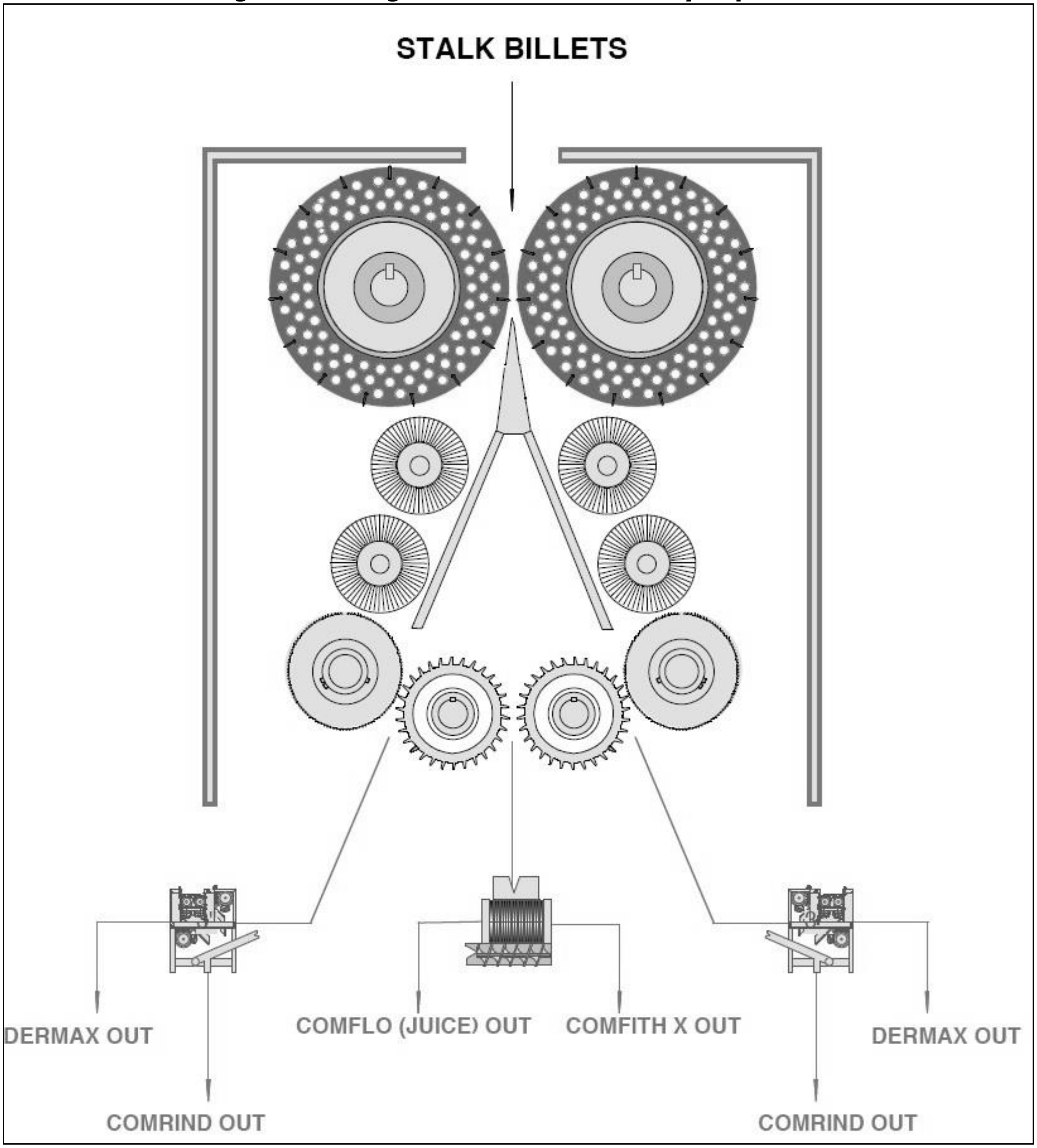
Figure 9: Comrind with Dermax from Great Valley Energy's Pilot Facility in Bakersfield, CA

Source: B.Pellens, 2012.

Comflo Expression

The comfith from the comfith separation (Figure 10) is saturated with sugar juice, which is called Comflo. For the purposes of our pilot trial, separation was accomplished using a bladder press followed by successive washing and pressing to remove sugars from the comfith and quantify both streams. This produced clean streams for both quantification and sampling for determining chemical characteristics, while allowing expediency in the pilot operations. While suitable for pilot operations, a commercial operation would use any number of well characterized pressing operations, such as belt or screw to remove sugar laden moisture from the solid comfith. For process design purposes, various belt and screw configurations were evaluated including physical testing using sweet sorghum comfith.

Figure 10: Diagram of Continuous Tilby Separator



Source: KTC Tilby LTD.

Comfith

After the sugar-laden juice is extracted, fibrous pith remains. This material may be suited for a number of products including cellulosic ethanol feedstock, high fiber flour, dairy feed, cement board, or biomass pellet feed.

Production Amount

As the comfith exits the equipment used to remove the sugar-laden juice, it has a moisture content of around 50 percent. However, on a bone-dry basis and as a percentage of clean stalks fed, the average production ratio is approximately 5.8 to 6.1 bone dry tons per 100 tons of stalks fed, with a range of 4.2 to 7.8 bone dry ton/100 tons of clean stalks.

Physical and Chemical Characteristics

Comfith is a fibrous, off-white material. Fibers are approximately 1/32 inch x 1/4 inch in size. The dry material shows good absorbency characteristics. Comfith produced from each trial run were samples and analyzed for chemical characteristics. Results are summarized in Figure 11 along with the general trend of the chemical characteristic over the growing season.

Figure 11: Chemical Composition of Comfith

			Average Across Varieties			
	Units	Detect Limit	First Planting Average	Time Trend	Second Planting Average	Time Trend
Chloride	mg/kg	1000	2021	↑	1956	↑
Sulfur	mg/kg	500	ND	→	ND	→
Aluminum	mg/kg	5.0	17.8	↘	10.5	↓
Antimony	mg/kg	10	ND	→	ND	→
Arsenic	mg/kg	1.0	ND	→	ND	→
Barium	mg/kg	5.0	7.1	↘	6.4	↓
Beryllium	mg/kg	0.50	ND	→	ND	→
Boron	mg/kg	5.0	3.6	↘	ND	→
Cadmium	mg/kg	0.50	0.8	↑	1.2	↗
Calcium	mg/kg	2.5	684	↗	611	↗
Chromium	mg/kg	2.5	ND	→	ND	→
Cobalt	mg/kg	5.0	ND	→	ND	→
Copper	mg/kg	2.5	3.4	↓	2.5	↑
Iron	mg/kg	5.0	39.0	↘	25.3	↘
Lead	mg/kg	2.5	ND	→	ND	→
Lithium	mg/kg	5.0	ND	→	ND	→
Magnesium	mg/kg	2.5	327	↗	353	↑
Manganese	mg/kg	1.5	5.8	↑	4.1	↗
Molybdenum	mg/kg	5.0	ND	→	ND	→
Nickel	mg/kg	2.5	ND	→	ND	→
Potassium	mg/kg	25	4227	↑	3985	↗
Selenium	mg/kg	2.5	ND	→	3.2	↗
Silica (SiO_2)	mg/kg	200	772	↗	516	→
Silicon	mg/kg	100	362	↗	241	→
Silver	mg/kg	1.0	ND	→	ND	→
Sodium	mg/kg	350	ND	→	ND	→
Strontium	mg/kg	5.0	8.6	→	6.8	↗
Thallium	mg/kg	25	ND	→	ND	→
Tin	mg/kg	5.0	10	↑	10	↓
Titanium	mg/kg	20	ND	→	ND	→
Vanadium	mg/kg	5.0	ND	→	ND	→
Zinc	mg/kg	2.5	9.1	↗	6.7	↑
Gross, BTU/lb	BTU/lb		6901	↗	7442	→
Ash, Wt%	%		2.0%	↗	2.2%	↗
Acid Detergent Fiber	%, Dry		47.8%	↘	46.7%	↘
Acid Detergent Lignin	%, Dry		1.5%	↘	1.4%	↘
Crude Protein (N X 6.25)	%, Dry		2.3%	↓	2.3%	↗
Neutral Detergent Fiber	%, Dry		81.4%	↘	81.4%	↘
Cellulose	%, Dry		46.4%	↘	45.4%	↘
Hemicellulose	%, Dry		33.6%	→	34.6%	→
Total Digestable Nutrients	%, Dry		38.5%	↗	38.5%	↗
Net Energy for Lactation	Mcal/dry lb		0.29	↗	0.29	↗
Relative Feed Value	SU		59.0	↗	60.2	↗
Starch	%, Dry		1.9%	↑	1.8%	↑

Source: Great Valley Energy.

Markets and pricing

Fuel Value Use

The heat content of comfith generally increases throughout the growing season as the crop builds mass with increasing nutrient and water input, photosynthetic activity, and growing degree units. For Great Valley Energy's crops, heat content of comfith ranged from about 6,900 Btu/lb to 7,410 Btu/lb.

The ash content for sweet sorghum comfith is relatively high compared with those of hardwoods. Average values for Great Valley Energy's crop across the varieties and cultivation practices ranged from approximately 2.0 percent to 2.3 percent. For reference, the heat and ash contents of other biomass feed stocks[22] is presented in Table 8. While the heat content of sorghum is at the lower end of the range, its ash content is as well. When compared on a pound ash per million Btu basis with lower numbers being preferred, sorghum comfith ranks as one of the best fuels outperforming all but hardwood sawdust.

Fuel pellets are a subset of a broader market category referred to as densified biomass. The initial scope of work put forth by Great Valley Energy centered on the fuel pellet market.

However, as a result of further market study and consideration of the quality and quantity of potential product from Great Valley Energy's feedstock, the broader market of densified biomass has been explored.

Table 8: Energy Content and Ash for Biomass Fuels

Feedstock	Energy Content (Btu/lb)	Ash %	Pound Ash per mmBtu
Sawdust	8643	0.45	52.1
Bark	8643	3.7	428.1
Logging Leftovers	8944	2.6	290.7
Switchgrass	8256	4.5	545.1
Wheat Straw	6880	6.7	973.8
Barley Straw	7568	4.9	647.5
Corn Stover	7654	3.7	483.4
Sorghum Comfith	**7155**	**2.0**	**279.5**

Source: Penn State College of Agricultural Sciences

Market Analysis

Premium pellets and industrial pellets (Figure 12) serve different markets. Premium pellets are typically used for residential heating purposes in pellet-fired stoves in areas without natural gas service and as a substitute for propane which can be transported and stored onsite. Pricing is typically tied to delivered costs for propane. Due to their small size and simple design, residential pellet stoves do not handle large amounts of ash production well.

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[22] Energy Contents and Ash from *Renewable and Alternative Energy Fact Sheet – Manufacturing Fuel Pellets from Biomass*, Penn State College of Agricultural Sciences, 2009.

Figure 12: Densified Biomass from Sweet Sorghum Stalk Processed at Pilot Plant, Bakersfield, CA

Source: Brian Pellens, October 2012.

Industrial pellets are used in large municipal or industrial combustors and typically replace coal. The larger combustors have ash handling capability and can accommodate higher ash concentrations more easily. Further, industrial pellets are graded mainly on their ash content, but also on several other specifications. Industrial grades used in thresholds for ash shown in Table 9.

Table 9: Ash Content Limits for Industrial Grade Pellets

INDUSTRIAL GRADE	ASH CONTENT, %
1	<1.0
2	<1.5
3	<3.0

Source: Great Valley Energy analytical results, 2013

As such, based on the ash content, pellets made with sorghum comfith would be expected to be marketed as Grade 3 industrial pellets. Pricing for pellets made from comfith material would be expected to follow pricing for coal on an energy basis (approximately $160 per ton).

Another important potential market for densified biomass is the livestock bedding market. In recent years, the recognized value of biomass pellets to those who board livestock, particularly horses, has grown. Advantages over bedding shavings include the smaller area required for fresh pellet storage, reduction in rodent habitat, and the improvement in stall cleaning including reduction by up to 50 percent of wasted bedding in the manure (which improves composted manure performance as well).

Pellets manufactured for either horse bedding or fuel pellets can be used, though generally the fuel pellets contain more dust material. For one horse, four to eight 40-lb bags provide a good initial base for the stall, and a 40-lb bag every two weeks thereafter is usually sufficient.

Pricing for each 40-lb bag of pelletized bedding is $6.99 for basic bedding to more than $10.00 for premium product. In this market, the potential revenue is approximately $350 per ton or higher. A key requirement will be test and verification that the sweet sorghum pellets can provide a comparable to superior performance for bedding over southern yellow pine pellets. In tests, pellets produced from sorghum comfith and comrind absorbed 4.5 times their weight in water, which compares favorably with pellets made from other materials.

Given the primary operation of sugar production, Great Valley Energy's advisors varied potential input pricing to determine the minimum sugar selling prices. For these scenarios, the price of pellets ranged from $80 to $240 per ton. Such prices may be consistent with or even on the higher side for fuel pellet markets given the ash content of the pellets but may be undervalued if a satisfactory livestock bedding product can be delivered to market.

Animal Feed Uses

Based on Great Valley Energy's crops, laboratory analyses determined feed value averages as set forth in Table 10.

Table 10: Average Feed Values for Comfith

VARIABLE	UNITS	VALUE
Acid Detergent Fiber	%, Dry Basis	47.3%
Acid Detergent Lignin	%, Dry Basis	1.5%
Crude Protein	%, Dry Basis	2.3%
Neutral Detergent Fiber	%, Dry Basis	81.4%
Cellulose	%, Dry Basis	45.9%
Hemicellulose	%, Dry Basis	34.1%
total digestible nutrientss	%, Dry Basis	38.5%
Net Energy For Lactation	Mcal/Dry Lb	0.29
Relative Feed Value	SU	59.60
Starch	%, Dry Basis	1.9%

Source: Great Valley Energy analytical results, 2013

The feed value of the comfith can be determined by evaluation of total digestible nutrients and crude protein on a dry matter basis. By expressing these parameter values as a relative percentage of the same parameter value for corn and soybeans, equations can be used to determine market value as an animal feed source. Valuation of comfith for use as an animal feed was estimated using Petersen's Equations.[23] Petersen's equations were developed to provide an evaluation of the value of alternate feeds comparing the relative contents of protein and energy compared to corn and soybean meal.

Petersen's equations are represented below:

- A = [(total digestible nutrients corn x crude protein of test feed) - (crude protein of corn x total digestible nutrients of test feed)] ÷ [(total digestible nutrients corn x crude protein of soybean meal) - (crude protein of corn x total digestible nutrients of soybean meal)]
- B = [(crude protein of test feed) - (crude protein of soybean meal x A)] ÷ crude protein of corn.

Petersen's equations are used to calculate the comparative value of a feed as follows:

- Feed value per dry ton, $ = (A x $ price per Ton soybean meal) + (B x $ price per Ton of corn) For this analysis we used the following values (Table 11) for corn and soybean meal:

Table 11: Corn and Soybean Meal Analysis

VARIABLE	CORN	SOYBEAN MEAL
Total Digestible Nutrients, Percent Dry Basis	89.0%	84.0%
Crude Protein, Percent Dry Basis	9.6%	53.9%
Price, $/Ton Dry Basis	$318	$590

Source: Great Valley Energy

Further, from the feed analysis results presented in Table 12 below:

Table 12: Feed Analysis

VARIABLE	COMFITH	COMRIND
Total Digestible Nutrients, Percent Dry Basis	38.5%	46.8%
Crude Protein, Percent Dry Basis	2.3%	1.8%

Source: Great Valley Energy

Substituting values provides the following feed value results in Table 13:

Table 13: Feed Value Result

FEED MATERIAL	FEED VALUE, $/ bone dry ton
Comfith	$106
Comrind	$122

Source: Great Valley Energy

Cellulosic Fuel Uses

Great Valley Energy and its advisors evaluated the potential to use the cellulosic material from sweet sorghum, the comrind and comfith, to produce cellulosic biofuels. Two specific concepts were chosen for study, the hydro pyrolytic conversion of biomass into a hydrocarbon product

[23] Petersen, J. 1932. A formula for evaluating feeds on the basis of digestible nutrients. J. Dairy Sci. 15:293- 297.

containing gasoline and diesel blend components and the conversion of cellulosic materials using hydrolysis and subsequent fermentation of sugars into fuel ethanol.

The CEC makes data on gasoline pricing breakdown available to the public. Based on 2012 data, costs associated with producing gasoline due only to crude oil and refining result in a gasoline cost ranging from about $2.70 to $3.59 per gallon, with an average of $3.06 per gallon. Using a specific gravity of gasoline of 0.74, gasoline price including only crude and refining costs is $993 per ton. Using a 30 weight (wt) percent comfith to gasoline yield and 2 percent ash content provides a value on a comfith basis of $292 per bone dry ton. With its higher ash content at 3 percent, the value of comrind under this scenario is $288 per bone dry ton.

Highest Value Uses/Markets

In review, there are a number of transformation technologies which can produce salable products from comfith. These technologies range from low tech and minimal capital to high tech and high capital. For summary purposes, the Table 14 is illustrative.

Table 14: Summary of Biomass Market Values

BIOMASS USE	ESTIMATED MARKET VALUE, ($) PER TON OF DRY COMFITH OR COMRIND
Cellulosic Biofuels	$292
Densified Biomass	$160 - $240
Animal Feed	$106
Combined Heat And Power Onsite	$30

Source: Great Valley Energy analytical results, 2013.

Comflo

Production Amount

Comflo comprises between 92 percent and 96 percent of the weight of comfith, the rest being bone dry comfith biomass. On a clean stalk basis, comflo comprises between 62 percent and 67 percent of the weight of clean stalks.

Physical and Chemical Characteristics

As the comflo exits the equipment used to remove the sugar-laden juice from the comfith, it has a sugar content of between 9.7 percent and 10.4 percent (as an average over the growing cycle) for varieties planted in the first planting date and second planting date respectively. The variety-specific averages over the first planting date ranged from 7.5 percent to 11.7 percent and averaged 10.3 percent. The variety specific averages over the second planting date ranged from 8.7 percent to 12.6 percent Brix and averaged 11.0 percent.

Fresh filtered comflo is a clear, yellow to amber colored liquid with a pleasant light odor and taste. Glucose and fructose were found to comprise the majority of the sugars, with sucrose appearing in later harvests and later planting dates. Comflo is a slightly acidic liquid with a pH of around 5.1. Figure 13 below summarizes results from analytical testing conducted along with harvesting and processing variables.

Figure 13: Chemical Characteristics of Comflo

		Average Harvest Data			
	Units	First Planting Average	Time Trend	Second Planting Average	Time Trend
Date Planted	Date	10-May	→	13-Jun	→
Date Harvested	Date	20-Sep	→	7-Nov	→
Sugar Lower Stalk	Brix	9.0	↑	9.9	↗
Sugar Lower Middle Stalk	Brix	10.3	↑	11.0	↗
Sugar Upper Middle Stalk	Brix	11.8	↗	12.9	↗
Sugar Upper Stalk	Brix	12.3	↑	14.8	↗
Juice Brix	%	10.3%	↗	11.0%	↑
pH		5.07	→	5.11	→
Chloride	mg/kg	2662	↗	2745	↗
Phosphorus-Total	mg/kg	45.6	↑	31.9	↑
Fructose, % Total Sugars	%	40.9%	↗	32.1%	↓
Glucose, % Total Sugars	%	50.4%	↗	37.8%	↓
Sucrose, % Total Sugars	%	6.0%	↑	30.1%	↑
Fructose, % Mass	%	3.7%	↗	2.9%	↓
Glucose, % Mass	%	4.5%	↗	3.4%	↓
Sucrose, % Mass	%	0.7%	↑	3.6%	↑
Sugar Yield	Tons/Acre	2.11	↑	3.18	↗
Theoretical Ethanol	gal/acre	297	↑	449	↗

Source: Great Valley Energy.

Possible Markets and Pricing

While there are a wide variety of high value uses for the sugars contained in sweet sorghum in the food, beverage and animal feed markets, the focus of this study is the use of sweet sorghum as a feedstock to produce fuels. Several processing scenarios are discussed below to use sugars to produce ethanol, ethanol being the primary biofuel used in California. These scenarios are as follows: (1) building a dedicated ethanol facility, (2) co-locating sugar production at an existing grain ethanol facility, and (3) processing sorghum offsite and transporting juice or syrup to an existing grain ethanol facility.

Building a Dedicated Ethanol Facility

The sorghum processing capacities evaluated in this report, 10 and 50-TPH of sorghum billets coincide with ethanol production capacities of approximately 1.2 and 6.0 million gallon per stream year. Harris group estimated the capital costs for these dedicated facilities as $9.7 and $23.6 million, respectively. On an annual capacity basis, these capital costs are roughly $8.00 and $3.90 per gallon. A typical benchmark for new installed capital cost in the ethanol industry is in the $2 gallon per stream year range indicating that even the larger facility would be at a 2:1 capital disadvantage to a larger plant on a gallon per stream year basis. Further, barring storage of sugar juice, a dedicated plant would also be hampered by lower utilization due to the availability of fresh sorghum which would be a fraction of the year. Because of these serious disadvantages, a dedicated ethanol production facility is not considered further.

Co-locating at an Existing Grain Ethanol Facility

There are five grain ethanol facilities in California, all located in the San Joaquin Valley, shown in Table 15, to provide a ready distillers grains feed supply to the local livestock market.

Table 15: Existing Grain Ethanol Facilities in California

OWNER	LOCATION	CAPACITY (MMGPY)
Pacific Ethanol	Stockton	60
Pacific Ethanol	Madera	40
Altra Biofuels/Phoenix Bio	Goshen	32
Calgren Renewable Fuels	Pixley	58
Aemetis	Keyes	60

Source: Great Valley Energy.

These facilities generally have capacities that are 5 to 10 times the corresponding sugar production capacity of the largest sorghum processing facility considered in this report. As such, the sorghum sugars used by these facilities would be co-processed with their existing feedstock. Further, the smallest two facilities at Madera and Goshen have experienced extended shutdowns due to market conditions and would represent an additional siting risk.

Harris Group further evaluated a valuation for sorghum sugars based on their replacement of corn in grain-fed ethanol plants. This study included variables related to the price of corn, RIN prices, and natural gas costs and considers processing differences and the lack of a distiller's grain product for sorghum sugars. The relation evaluates to:

$$\textbf{Sugar} = 0.0196\times[\text{Corn} + 0.83] + 0.035\times(\text{D5RIN}-\text{D6RIN}) + 0.00077\times\text{Natural Gas} - 0.0057$$

Where the units are as follows:

- Sugar = $/lb
- Corn = $/bushel
- D5, D6RIN = $/gas
- Natural Gas = $/mmBTU

Unfortunately, very little historical data for D6 and D5 RIN prices exist; however, some publicly available information suggests that 2011 D5 and D6 RIN prices were $0.43-$1.27/gal and $0.00-$0.05/gal, respectively, suggesting a difference range from $0.38-$1.27/gal. Overall, this range would add $0.013/lb to $0.044/lb to the value of the sugar; however, RIN markets are expected to be highly variable and depend on a number of factors including changes in government mandates.

Table 16 is the predicted price of sorghum sugar as a replacement for corn sugars in an ethanol process. As one might discern from the form of the pricing equation the sugar price is most dependent on corn price, followed by the RIN difference. Natural gas price affects sugar price very little in this case.

Table 16: Ranges of Corn-Equivalent Sugar Price

Corn Price, $/bu	RIN Difference, $/gal		Natural Gas Price, $/mmbtu		Sugar Price, $/lb	
	Low	High	Low	High	Low	High
$ 5.00	$ 0.38	$ 1.27	$ 5.00	$ 8.00	$ 0.126	$ 0.159
$ 6.00	$ 0.38	$ 1.27	$ 5.00	$ 8.00	$ 0.145	$ 0.179
$ 7.00	$ 0.38	$ 1.27	$ 5.00	$ 8.00	$ 0.165	$ 0.198
$ 8.00	$ 0.38	$ 1.27	$ 5.00	$ 8.00	$ 0.185	$ 0.218
$ 9.00	$ 0.38	$ 1.27	$ 5.00	$ 8.00	$ 0.204	$ 0.238

Source: Great Valley Energy.

Transporting juice or syrup to an existing grain ethanol facility

Another scenario includes shipping fresh juice or concentrated syrup to an existing grain ethanol facility. The pricing above for the bolt-on configuration represents a delivered price that a biofuels plant may switch to sorghum sugars and reflects the highest net back to the sorghum processing facility. To concentrate the juice requires an input of heat energy to run evaporators to remove water. Further transportation costs can quickly diminish the netback to the sorghum processing facility to zero.

Harris group modeled heat requirements for triple effect evaporation and estimated that a highly efficient configuration could evaporate one pound of water with 364 BTU. The energy required to produce stable 60 percent sugar syrup is highly dependent on the starting sugar concentration. For our purposes a range of starting sugar concentration from 10 to 20 Brix was evaluated. For natural gas costing $5 per mmbtu, the following energy cost per pound of sugar produced can be calculated and are shown in Table 17.

Table 17: Energy Cost to Produce 60 percent Brix Syrup

INITIAL SUGAR CONCENTRATION % BRIX	ENERGY COST $ PER POUND OF SUGAR
10	$ 0.015
15	$ 0.009
20	$ 0.006

Source: Great Valley Energy.

The impact of over the road transportation cost on the net back to the sorghum processing facility is shown in Table 18. The analysis assumes an average carrier cost of $1.71 per mile.[24] The cost of transportation was calculated for both 15 Brix juice and 60 Brix syrup and is presented as a cost per pound of sugar for various one-way transportation distances from 20 to 200 miles for a tanker truck with 5600 gallon capacity. The analysis also assumes that the truck fleet is dedicated, and the return trip is a dead leg. The density of 15 Brix juice and 60

[24] An Analysis of the Operation Costs of Trucking: A 2012 Update, American Transportation Research Institute, September 2012.

Brix syrup are approximately 8.8 and 10.7 pounds per gallon, respectively at room temperature.

Table 18: Trucking Costs (5600 gallon load) for 15 Brix Juice and 60 Brix Syrup

Brix, mass %	15	60
Density, lb/gal	8.84	10.74
Load weight, lb	49,491	60,117
Sugar weight, lb	7,424	36,070
Distance, mi	$/lb sugar	$/lb sugar
20	$ 0.009	$ 0.002
40	$ 0.018	$ 0.004
60	$ 0.028	$ 0.006
80	$ 0.037	$ 0.008
100	$ 0.046	$ 0.009
120	$ 0.055	$ 0.011
160	$ 0.074	$ 0.015
180	$ 0.083	$ 0.017
200	$ 0.092	$ 0.019

Source: Great Valley Energy.

In evaluating the additional energy cost to produce 60 Brix syrup from 15 Brix juice against trucking charges, the breakeven point is approximately 24 miles. Thus, for distances less than 24 miles shipping 15 Brix juice is cheaper than producing and shipping 60 Brix syrup. For distances greater than 24 miles, making and shipping 60 Brix syrup results in a greater net back to the sorghum processing plant.

In summary producing sugar juice or syrup and shipping to an offsite facility will result in a decrease in net revenue of between $ 0.01 and $ 0.03 per pound of sugar for distances between 20 and 200 miles.

Dermax

Dermax contains antioxidant compounds and an amount of wax material. Some plant-based antioxidant materials can be highly valuable in purified form. Dermax is the outer dermal layer of the plant stalk and is removed primarily to aid in processing comrind into board materials.

The dermax and the wax it contains are thought to inhibit binding of the resins to the comrind, decreasing the structural strength of the wood product.

Production Amount

Dermax comprises 5.4 percent stalk weight for the first planting date and 6.3 percent for the second planting date on a wet basis.

Physical and Chemical Characteristics

As described above, dermax may be a useful source of phenolic and antioxidant compounds which would be produced through an extraction process leaving much of the biomass for other purposes. One such purpose for the residue would be as an animal feed, perhaps mixed with other process streams. The average feed value for dermax is shown in Figure 14.

Figure 14: Average Feed Values for Dermax

		Average Dermax Data			
	Units	First Planting Average	Time Trend	Second Planting Average	Time Trend
Date Planted	Date	10-May	→	13-Jun	→
Date Harvested	Date	20-Sep	→	7-Nov	→
Dry Matter	%	29.8%	↗	30.4%	→
Acid Detergent Fiber, Dry	%	34.6%	↘	33.8%	↘
Crude Protein (N X 6.25), Dry	%	2.4%	↓	2.6%	↑
Neutral Detergent Fiber, Dry	%	59.5%	↘	57.3%	↘
Total Digestable Nutrients, Dry	%	50.4%	↗	51.4%	↗
Net Energy for Lactation, Dry	Mcal/lb	0.44	↗	0.45	↗
Relative Feed Value, Dry	SU	99	↗	102	↗

Source: Great Valley Energy.

Further, samples of dermax from each variety and each processing date were analyzed by Colorado State University in a separate and blinded study. The study presented the results of their analysis measured in milligram equivalents for each run for both total phenolic compounds and antioxidant activity. The average results across all varieties tested are summarized in Table 19.

Table 19: Nutraceutical Content of Dermax by Planting Date

INDICATOR	FIRST PLANTING DATE	SECOND PLANTING DATE
Antioxidant Activity (mg/g)	4.8	5.0
Total Phenolic Compounds (mg/g)	1.6	1.7

Source: Great Valley Energy.

An amount of waxy material is visually present on the surface of the stalks and is concentrated into the dermax during processing. One sample of dermax was analyzed for wax via U.S. EPA Method 1664 (for oil and grease) which employs a hexane extraction technique to further separate heavy organics. This analysis was selected as a screening level indicator of the maximum possible concentration of wax range compounds. The results of this test indicated 4,570 mg wax compounds per kg dermax fresh weight. Using and average dermax production rate of 6 percent, the 10 ton per hour configuration would produce 132 pounds per day of wax. The 50 ton per hour configuration would produce 660 pounds per day of wax.

Markets and pricing

Waxes

Most wax is sourced from petroleum and wax prices are heavily influenced by petroleum prices. In 2012, U.S. Bulk Slackwax (a semi-refined wax) prices were about $1,300 per MT.

Naturally occurring waxes are produced by animals (e.g., beeswax, lanolin) and plants e.g., (carnauba, candelilla, rice bran, soy). Owing to their relative difficulty in processing and isolating, natural waxes command a price premium relative to petroleum based waxes. Due to the much smaller markets for these products, pricing information is difficult to assess.

However, pricing listed in online marketplaces such as Alibaba indicate values that are a multiple of their petroleum based counterparts, from $1,600 per ton for soy wax to $5,000 per metric ton for rice bran wax from Asian suppliers, or $0.80 to $2.50 per pound.

Antioxidant compounds

Antioxidants impede oxidation and degradation of organic materials. Antioxidants have a broad array of industrial uses including plastics and rubber, gas and fuel, lubricants, adhesives, cosmetics, and more. The market for antioxidants worldwide exceeded a total volume of 0.88 million tons in 2007, revenue in excess of $3.7 billion, and a market growth rate for antioxidants at 3 percent to 5 percent per year.[25] The overall market statistics imply a value of around $4,200 per ton of industrial use antioxidants.

The food market for antioxidants consists of two primary markets: (1) additives to slow down the oxidative deterioration in fatty food products, and (2) dietary supplements and ingredients intended to slow down the free radical effects on the body. Global growth has been approximately 3 percent per year and the market was valued at $788 million in 2007, although volume data is stated as not generally available due to the differences in quantities used in the manufacture of foods and supplements.[26] Great Valley Energy has chosen to focus on the dietary supplement antioxidant market.

Examples of antioxidants that have been incorporated into food and drink products as a means of providing a health enhancing or functional benefit include:

- Carotenoids (e.g. B-carotene, lutein, lycopene)
- Flavonoids
- Polyphenols

These are often derived from natural foods, for example, lycopene is extracted from tomatoes. Some of these antioxidants are also being integrated with beauty and cosmetic products. The world market for food functional antioxidants was valued at $438 million in 2007, and the US market share is 30 percent.[26]

For bulk pricing information, we evaluated the market price of grape seed extract powder. By conducting an online search, three separate resources identified a price per pound of grape

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[25] Ceresana Research, *Market Study: Antioxidants*, Konstanz, Germany, April 2008.

[26] Leatherhead Food International, *Antioxidants*, Leatherhead, Surrey, United Kingdom, May 2009.

seed extract of $59.90, $64.77, and $67.96 (excluding tax, shipping and handling). We also viewed pricing for acai berry extract powder at a price per pound range of $32.50 to $50.99 (excluding tax, shipping and handling). Although a market for sweet sorghum extract powder would require development from the ground up, health benefits of sweet sorghum extract might eventually result in a bulk pricing in these ranges of $30 per pound or more.

Highest Value Uses and Markets

The processes used to extract antioxidant compounds and waxes both use similar solvents and likely are mutually exclusive such that a process used to extract and isolate waxes will likely extract or destroy antioxidants. Thus, the highest use will be driven by the total value of product derived from each ton of dermax. Table 20 below indicates that sorghum extract powder will result in the highest value for dermax.

Table 20: Comparison of Value of Extract Powder and Wax per ton of Dermax

	Dermax Extract Powder	Dermax Wax
Concentration in Dermax, lb/wet ton	3.20	9.14
Product Value, $/lb	$ 30.00	$ 2.50
Dermax Value, $/wet ton	$ 96.00	$ 22.85

Source: Great Valley Energy.

Comrind

The outer portion of the stalk structure allows the plant to stand upright and protects it from insects and weather. Based on KTC Tilby's previous work in sugar cane, comrind may make an excellent building product substrate, such as oriented strand board. KTC Tilby holds several product and production patents on materials made from sweet sorghum or sugar cane. This material may also be suited for a number of products including cellulosic ethanol feedstock, dairy feed, or biomass pellet feed.

Production Amount

As the comrind exits the separation equipment, it has a moisture content of around 67 percent and comprises between 20.8 to 27.1 percent of the stalk on a wet basis. On a bone-dry basis and as a percentage of clean stalks fed, the average production ratio is approximately 8.5 and 8.0 bone dry tons per 100 tons of stalks fed, for the first and second plant dates, respectively. The overall range of values is between 7.0 and 10.7 bone dry ton/100 tons of clean stalks.

Physical and Chemical Characteristics

Comrind is a woody, off-white material. The material is approximately 1/32 inch x 1/2 inch x 6 inches in size. The length of the comrind is determined by the length of the billet. The width is influenced by the diameter of the stalk. The dry and wet material show reasonable structural integrity and can be broken by hand pressure. Fibers run parallel to plant growth.

Comrind produced from each trial run were sampled and analyzed for chemical characteristics. Results are summarized in Figure 15 along with the general trend of the chemical characteristic over the growing season.

Figure 15: Average Feed Values for Comrind

			Averages Across Varieties			
	Units	Detect Limit	First Planting Average	Time Trend	Second Planting Average	Time Trend
Chloride	mg/kg	1000	7770	↗	6945	↓
Sulfur	mg/kg	500	576	↑	571	↘
Aluminum	mg/kg	5.0	10.6	↓	7.9	↑
Antimony	mg/kg	10	ND	→	ND	→
Arsenic	mg/kg	1.0	ND	→	ND	→
Barium	mg/kg	5.0	9.8	↗	11.8	→
Beryllium	mg/kg	0.50	1.4	↓	3.2	↑
Boron	mg/kg	5.0	17.7	↗	ND	→
Cadmium	mg/kg	0.50	1.4	↑	1.1	↘
Calcium	mg/kg	2.5	703	↗	604	↓
Chromium	mg/kg	2.5	ND	→	ND	→
Cobalt	mg/kg	5.0	ND	→	ND	→
Copper	mg/kg	2.5	3.0	↗	2.2	↘
Iron	mg/kg	5.0	69.2	↑	71.9	↑
Lead	mg/kg	2.5	ND	→	ND	→
Lithium	mg/kg	5.0	ND	→	ND	→
Magnesium	mg/kg	2.5	933	↗	809	↘
Manganese	mg/kg	1.5	22.3	↑	16.2	↘
Molybdenum	mg/kg	5.0	ND	→	ND	→
Nickel	mg/kg	2.5	ND	→	ND	→
Potassium	mg/kg	25	13300	↗	11705	↓
Selenium	mg/kg	2.5	4.6	↘	4.8	↑
Silica (SiO2)	mg/kg	200	606	↗	574	↘
Silicon	mg/kg	100	284	↗	268	↘
Silver	mg/kg	1.0	ND	→	ND	→
Sodium	mg/kg	350	ND	→	ND	→
Strontium	mg/kg	5.0	7.8	↗	5.8	↓
Thallium	mg/kg	25	ND	→	ND	→
Tin	mg/kg	5.0	ND	→	ND	→
Titanium	mg/kg	20	ND	→	ND	→
Vanadium	mg/kg	5.0	ND	→	ND	→
Zinc	mg/kg	2.5	16.2	↘	11.3	↓
Gross, BTU/lb	BTU/lb		7162	→	7322	↗
Ash, Wt%	%		3.8%	↑	3.3%	↓
Dry Matter	%		34%	↗	32%	↘
Acid Detergent Fiber	%, Dry		41%	↘	42%	↘
Acid Detergent Lignin	%, Dry		2%	↗	3%	↘
Crude Protein (N X 6.25)	%, Dry		2%	↓	2%	↑
Neutral Detergent Fiber	%, Dry		66%	↘	65%	↘
Cellulose	%, Dry		39%	↘	39%	↘
Hemicellulose	%, Dry		25%	↘	23%	↘
Total Digestable Nutrients	%, Dry		47%	↗	47%	↗
Net Energy for Lactation	Mcal/dry lb		0.40	↗	0.40	↗
Relative Feed Value	SU		80	↗	81	↗
Starch	%, Dry		8%	↗	6%	↑

Source: Great Valley Energy.

Markets and Pricing

Engineered Wood Products

Engineered Wood or Composite Lumber covers a broad range of wood products that may be produced by preparing and binding the strands, fiber particles, or veneers of wood together with adhesives to form composite materials. These products are engineered to precise design specifications and are tested to meet national or international standards. Engineered wood products are used in a variety of applications from home construction to commercial buildings to industrial products. Uses range from joists, sheathing, subfloors, roofing, beams, studs, insulated wall panels to furniture.

Typically engineered wood products are made from hardwoods and softwoods. Sawmill scraps and other wood waste can be used for engineered wood but require the removal of extraneous matter and classification. Products requiring veneers (plywood) must use whole logs.

Alternatively, it is possible to manufacture comparable, if not superior, engineered cellulosic products from alternative feed stocks such sweet sorghum, hemp, kenaf and sugarcane. For purposes of this market study, the fully integrated oriented strand board facility will utilize the separated comrind fiber from locally sourced sweet sorghum, sugarcane or both and produce wood quality composite boards. The separated comfith fiber from the KTC Tilby System will be utilized for fuel.

Most composite board plants are located in close proximity to forests as shipping feedstock over long distances can be economically prohibitive. California has a unique opportunity to utilize sugarcane and sweet sorghum for the production of composite board products, see Figure 16, such as oriented strand board and limit the need for long transportation distances.

Figure 16: Oriented Strand Board From Comrind (left). Particle Board From Comfith (right). Board Products from Sweet Sorghum Components

Source: TTS Edmonton, 2012.

No modifications are required in order for standard wood-based composite board equipment to receive sweet sorghum fiber from Great Valley Energy. Today, most oriented strand board plants (wood based) are designed to produce at least 200,000 cubic meter of finished board per year, and many are now exceeding 600,000 cubic meter. This minimum size is driven by wood economics and these same limitations do not apply to non-wood fibers. Tilby Separation System can supply high quality fiber to composite board plants in the 100,000 cubic meter range and be competitive.

Product Pricing

Lumber pricing is commonly aggregated into framing lumber and structural panels. The framing lumber composite price is designed as a broad measure of price movement in the lumber market. The framing lumber composite price is a weighted average of 15 key framing lumber prices. The structural panel composite price is a broad measure of the price movement in the structural panel markets. The composite is a measure of 11 key panel items. The composite pricing ranges from approximately $300 to $400 per thousand board feet depending on market conditions. This equates to a price range of $125 to $195 per bone dry ton of comrind.

Pellets

Comrind is a suitable feedstock for pellets. The process and market description above regarding use of comfith for pellets is applicable here. Based on that discussion, the market price for comrind pellets is approximately $160 per ton.

Animal Feed Uses

Based on Great Valley Energy's crops, laboratory analyses determined feed value averages as set forth in Table 21.

Table 21: Average Feed Values for Comrind

VARIABLE	UNITS	VALUE
Acid Detergent Fiber	%, Dry Basis	41.8%
Acid Detergent Lignin	%, Dry Basis	2.6%
Crude Protein	%, Dry Basis	1.8%
Neutral Detergent Fiber	%, Dry Basis	65.8%
Cellulose	%, Dry Basis	39.1%
Hemicellulose	%, Dry Basis	24.1%
total digestible nutrientss	%, Dry Basis	46.8%
Net Energy For Lactation	Mcal/Dry lb	0.40
Relative Feed Value	SU	80.60
Starch	%, Dry Basis	6.7%

Source: Great Valley Energy.

The feed value of the comrind can be determined by evaluation of total digestible nutrients and crude protein on a dry matter basis. By expressing these parameter values as a relative percentage of the same parameter value for corn and soy bean, equations can be used to determine market value as an animal feed source.

Valuation of comfith for use as an animal feed was estimated using Petersen's Equations.[23] Petersen's equations are used to calculate the comparative value of a feed as follows:

- Feed value per dry ton, $ = (A x $ price per Ton soybean meal) + (B x $ price per Ton of corn) For this analysis in Table 22 we used the following values for corn and soybean meal:

Table 22: Corn and Soybean Meal Analysis

VARIABLE	CORN	SOYBEAN MEAL
Total Digestible Nutrients, Percent Dry Basis	89.0%	84.0%
Crude Protein, Percent Dry Basis	9.6%	53.9%
Price, $/Ton Dry Basis	$318	$590

Source: Great Valley Energy

Further, from the feed analysis results presented below in Table 23:

Table 23: Feed Analysis

VARIABLE	COMRIND
Total Digestible Nutrients, Percent Dry Basis	46.8%
Crude Protein, Percent Dry Basis	1.8%

Source: Great Valley Energy

Substituting values provides the following feed value results in Table 24:

Table 24: Feed Value Results

FEED MATERIAL	FEED VALUE, $/ bone dry ton
Comfith	$106
Comrind	$122

Source: Great Valley Energy

Cellulosic Fuel Uses

Great Valley Energy and its advisors evaluated the potential to use the cellulosic material from sweet sorghum, the comrind and comfith, for the production of cellulosic biofuels. Two specific concepts were chosen for study, the hydro pyrolytic conversion of biomass into a hydrocarbon product containing gasoline and diesel blend components and the conversion of cellulosic materials using hydrolysis and subsequent fermentation of sugars into fuel ethanol.

The CEC makes data on gasoline pricing breakdown available to the public.[27] Based on 2012 data, costs associated with producing gasoline due only to crude oil and refining result in a gasoline cost ranging from about $2.70 to $3.59 per gallon, with an average of $3.06 per gallon. Using a specific gravity of gasoline of 0.74, gasoline price including only crude and refining costs is $993 per ton. Using a 30 wt. percent comrind to gasoline yield and 3 percent ash content provides a value on a comfith basis of $288 per bone dry ton.

Highest Value Uses and Markets

In review, there are a number of transformation technologies which can produce salable products from comfith and comrind. These technologies range from low tech and minimal capital to high tech and high capital. For summary purposes, Table 25 is illustrative.

[27] CEC Energy Almanac (https://www.energy.ca.gov/data-reports/energy-almanac)

Table 25: Highest Value Uses for Comrind

BIOMASS USE	ESTIMATED MARKET VALUE, ($) PER TON OF DRY COMFITH OR COMRIND	CAPITAL COST FOR 50-TPH SORGHUM THROUGHPUT, MILLION $	OPERATING COST FOR 50-TPH SORGHUM THROUGHPUT, MILLION $ PER YEAR
Cellulosic Biofuels	$288	$35.2	$3.8
Densified Biomass	$160 - $240	$11.5	$2.1
Animal Feed	$122	Base Case	Base Case
Engineered Wood	$125 - $195	$58.0	$14.3
Combined Heat and Power	$30	$10.0	-$3.8

Source: Great Valley Energy.

While these values may point to certain economic conclusions, a full pro forma treatment including feedstock pricing, financing options and other assumptions is needed to determine whether increased capital investment increases return on investment for the project.

CHAPTER 5: Fractionation Products Processing

GVE contracted with Harris Group to provide engineering support and develop capital cost estimates for a demonstration-scale base sorghum processing facility with a capacity to process 10-TPH of sweet sorghum into a concentrated sugar solution, dermax extract, and biomass pellets. Harris Group also developed capital cost estimates for a base sorghum processing facility processing 50-TPH of sorghum to the same products. In addition to these, GVE evaluated a variety of process options, including:

- Addition of an ethanol facility onto the base sorghum processing facility for direct production of ethanol from the concentrated sugar solution;
- An ethanol facility that used both the sugar solution and the cellulosic fibrous material to produce ethanol in lieu of pellet production;
- A thermocatalytic process to convert comfith and comrind to drop-in fuels;
- A base sorghum processing facility that would "bolt-on" to an existing corn ethanol facility;
- Production of engineered wood products from comrind; and
- Using comfith and comrind for production of electricity and process heat on site.

Additional detail for the base sorghum processing facility and modified facilities are in other reports completed as part of this work including the Comfith and Comrind Marketing Report and the Engineering Report. The balance of this chapter discusses the base sorghum processing facility along with the process options listed above and provides the estimated capital costs for each.

Base Sorghum Processing Facility

The base sorghum processing facility includes the receiving and storage (Area 100), fractionation (Area 200), sugar extraction (Area 300), sugar concentration (Area 400), biomass sizing and drying (Area 500), pellet production (Area 600), dermax extraction (Area 700), and utilities (Area 800) areas. In Area 100, sorghum billets are offloaded to storage and reclaimed for further processing. Billets are then detrashed and fractionated into comrind, comfith and dermax in Area 200. Sugar pressed from the comfith in Area 300 is concentrated to a saleable product via evaporation in Area 400, where it is pumped to an adjacent ethanol facility or to trucks for shipment. The comrind from Area 200 is milled, mixed with comfith residual and dermax residual, and dried in Area 500 in preparation for pelletizing, which takes place in Area 600. In Area 700, valuable extract compounds are extracted from the dermax produced in Area 200. Utilities, including steam, cooling water, compressed air, and chilled water are provided in Area 800. Process detail related to each of these areas is included in Great Valley Energy's engineering report.

Harris Group evaluated four cases for the base sorghum processing facility to produce 20 wt percent and 60 wt percent sugar solutions from 10-TPH and 50-TPH of sorghum feed. The estimated capital costs for the 10-TPH plants producing 20 wt percent and 60 wt percent solutions are $33.8 and $34.3 million, respectively.

Estimated capital costs for the 50-TPH facilities producing 20 wt percent and 60 wt percent sugar solutions are $65.8 and $66.8 million, respectively. Comparing the capital costs of the 10-TPH and 50-TPH facilities both producing 20 wt percent sugar provides a scaling factor of n=0.41, which is reasonable, given the large difference in scale. We have provided details associated with the capital costs for the 50-TPH facilities in Tables 28 and 29 below, and details associated with capital costs for the 10-TPH facilities in Tables 4-4 and 4-5 below. These estimates are conceptual-grade capital cost estimates, or Class 4 per AACE International Recommended Practice No. 18R-97. We expect the accuracy of these estimates to be +30 percent/-30 percent for the included scope and have provided the estimate ranges within Tables 26 through 29 for convenience.

Table 26: Capital Costs for 50-TPH Base Sorghum Processing Facility Producing 20 wt Percent Sugar Solution

Process Area		**Purchased Cost**		**Installed**
Area 100: Receiving and Storage		$1,990,000		$3,380,000
Areas 200 & 300: Sorghum Fractionation/ Sugar Extraction		$7,960,000		$13,560,000
Area 400: Sugar Evaporation		$960,000		$2,110,000
Area 500: Biomass Sizing/Drying		$4,150,000		$7,620,000
Area 600: Pellet Production		$1,670,000		$2,890,000
Area 700: Dermax Extraction		$4,600,000		$11,190,000
Area 800: Utilities		$910,000		$1,690,000
Totals:		$22,240,000		$42,440,000
Direct Costs				
Site Development	7%	of installed cost		$2,970,000
Warehouse				$1,900,000
General Mechanical	5%	of installed cost		$2,120,000
Electrical Infrastructure	7.5	of installed cost		$3,180,000
Total Direct Costs				$52,610,000
Indirect Costs				
Engineering	7%	of total direct		$3,680,000
Construction Management	8%	of total direct		$4,210,000
Contingency	10	of total direct		$5,260,000
Total Indirect Costs				$13,150,000
Total Capital Investment				**$65,800,000**
		Estimate Range		

Process Area	Purchased Cost		Installed
	High Limit (+30%)	Low Limit (-30%)	
	$85,500,000	**$46,100,**	

Source: Harris Group Engineering Study, 2013

Table 27: Capital Costs for 50-TPH Base Sorghum Processing Facility Producing 60 wt Percent Sugar Solution

Process Area	Purchased Cost			Installed
Area 100: Receiving and Storage	$1,990,000			$3,380,000
Areas 200 & 300: Sorghum Fractionation/ Sugar Extraction	$7,960,000			$13,560,000
Area 400: Sugar Evaporation	$1,170,000			$2,610,000
Area 500: Biomass Sizing/Drying	$4,150,000			$7,620,000
Area 600: Pellet Production	$1,670,000			$2,890,000
Area 700: Dermax Extraction	$4,600,000			$11,190,000
Area 800: Utilities	$1,010,000			$1,880,000
Totals:	$22,540,000			$43,130,000
Direct Costs				
Site Development	7	of installed		$3,020,000
Warehouse				$1,900,000
General Mechanical	5	of installed		$2,160,000
Electrical Infrastructure	7.5	of installed		$3,230,000
Total Direct Costs				$53,440,000
Indirect Costs				
Engineering	7	of total direct		$3,740,000
Construction Management	8	of total direct		$4,280,000
Contingency	10	of total direct		$5,340,000
Total Indirect Costs				$13,360,000
Total Capital Investment				**$66,800,000**
	Estimate Range			
	High Limit (+30%)		**Low Limit (-30%)**	
	$86,800,00		**$46,800,00**	

Source: Harris Group Engineering Study, 2013

Table 28: Capital Costs for 10-TPH Base Sorghum Processing Facility Producing 20 wt Percent Sugar Solution

Process Area		Purchased Cost		Installed
Area 100: Receiving and Storage		$1,720,000		$2,930,000
Areas 200 & 300: Sorghum Fractionation/ Sugar Extraction		$3,980,000		$6,810,000
Area 400: Sugar Evaporation		$510,000		$1,090,000
Area 500: Biomass Sizing/Drying		$1,820,000		$3,300,000
Area 600: Pellet Production		$850,000		$1,460,000
Area 700: Dermax Extraction		$2,450,000		$5,840,000
Area 800: Utilities		$430,000		$820,000
Totals:		$11,760,000		$22,250,000
Direct Costs				
Site Development	7%	of installed cost		$1,560,000
Warehouse				$420,000
General Mechanical	5%	of installed cost		$1,110,000
Electrical Infrastructure	7.5	of installed cost		$1,670,000
Total Direct Costs				$27,010,000
Indirect Costs				
Engineering	7%	of total direct		$1,890,000
Construction Management	8%	of total direct		$2,160,000
Contingency	10	of total direct		$2,700,000
Total Indirect Costs				$6,750,000
Total Capital Investment				**$33,800,000**
	Estimate Range			
	High Limit (+30%)		**Low Limit (-30%)**	
	$43,900,00		**$23,700,00**	

Source: Harris Group Engineering Study, 2013

Table 29: Capital Costs for 10-TPH Base Sorghum Processing Facility Producing 60 wt Percent Sugar Solution

Process Area		Purchased Cost		Installed
Area 100: Receiving and Storage		$1,720,000		$2,930,000
Areas 200 & 300: Sorghum Fractionation/ Sugar Extraction		$3,980,000		$6,810,000
Area 400: Sugar Evaporation		$610,000		$1,340,000
Area 500: Biomass Sizing/Drying		$1,820,000		$3,300,000
Area 600: Pellet Production		$850,000		$1,460,000
Area 700: Dermax Extraction		$2,450,000		$5,840,000
Area 800: Utilities		$500,000		$960,000
Totals:		$11,930,000		$22,640,000
Direct Costs				
Site Development	7%	of installed cost		$1,580,000
Warehouse				$420,000
General Mechanical	5%	of installed cost		$1,130,000
Electrical Infrastructure	7.5	of installed cost		$1,700,000
Total Direct Costs				$27,470,000
Indirect Costs				
Engineering	7%	of total direct		$1,920,000
Construction Management	8%	of total direct		$2,200,000
Contingency	10	of total direct		$2,750,000
Total Indirect Costs				$6,870,000
Total Capital Investment				**$34,300,000**
	Estimate Range			
	High Limit (+30%)		**Low Limit (-30%)**	
	$44,600,00		**$24,000,00**	

Source: Harris Group Engineering Study, 2013

Base Sorghum Processing Facility with Elimination of Dermax Processing Onsite

A substantial portion of the capital cost of the base sorghum processing facility is associated with the dermax extraction system in Area 700. Several facilities in the US market the capability to provide this type of extraction service on a tolling arrangement. We therefore decided to evaluate the capital costs, operating costs, and economics associated with both a 50-TPH and a 10-TPH plant (both producing 20 wt percent sugar solutions) that did not include dermax extraction. Following the treatment above, total capital investments are presented in Table 30.

Table 30: Capital Costs for 10 & 50-TPH Base Sorghum Processing Facility Producing 20 wt Percent Sugar Solution without Area 700

Feed Capacity	Total Capital Investment	Total Capital Investment High	Total Capital Investment Low
10-TPH	$24,600,000	$32,000,000	$17,200,000
50-TPH	$47,800,000	$62,100,000	$33,500,000

Source: Harris Group Engineering Study, 2013

Base Sorghum Processing Facility with Elimination of Densified Biomass (Pellets)

In addition to eliminating processing of dermax onsite, Harris Group investigated eliminating processing of the comrind and residual comfith. In this case, after recovery of the sugars, the biomass would be conveyed to a stacker/reclaimer and then trucked away to local farms for as animal feed. Effectively, this results in the elimination of the Areas 500, 600 and 700. However, Area 100 would have to be doubled in size to handle the outgoing biomass. Making these assumptions, we estimated the capital costs for a 50-TPH plant, as provided in Table 5-5. These estimates are equivalent to an AACE Class 5, with a +50 percent/-30 percent range of accuracy. Following the treatment above, total capital investments are presented in Table 31.

Table 31: Capital Costs for 10 & 50-TPH Base Sorghum Processing Facility Producing 20 wt Percent Sugar Solution without Areas 500, 600, and 700

Feed Capacity	Total Capital Investment	Total Capital Investment High	Total Capital Investment Low
10-TPH	$21,300,000	$32,000,000	$14,900,000
50-TPH	$34,800,000	$52,200,000	$24,400,000

Source: Harris Group Engineering Study, 2013

Hydropyrolytic Fuels Production as an Alternative to Pellet Production

Part of Harris Group's ad-hoc engineering and feasibility study for Great Valley Energy was to assess the viability of CRI Catalyst Company's IH^2 process to convert biomass to drop-in fuels. This process is intended to convert biomass to a hydrocarbon product containing fungible gasoline and diesel blend components that can be directly processed within existing refineries or used directly as drop-in fuels.

The IH^2 process is claimed by Gas Technology Institute and CRI Catalyst Company to have the following advantages[28]:

- No external requirement for hydrogen or methane once the process is running, due to the fact that hydrogen is made in-situ.

[28] U.S. Patent Application Publication, No. US2010/0256428 A1. October 7, 2010. Inventors: T.L. Marker, Felix, M.B. Linck

- No external requirement for energy or heat, e.g., natural gas, etc., once the process is running due to the fact that the hydropyrolysis reaction is exothermic.
- No need to "severely dry" the feedstock, but 20 weight percent water is maximum.[29]
- Over 95 percent rejection of oxygen in feedstock as carbon dioxide.
- Production of gasoline and diesel-boiling range product with low oxygen content.
- Product gasoline could potentially be "drop-in" and may require very little processing.[29]

Another advantage from Great Valley Energy's perspective is that testing of bagasse, which should be superficially similar to sorghum has, according to a recent presentation by Gas Technology Institute, been successfully conducted using the IH^2 process.[30] When Harris Group asked Terry Marker, principal investigator for Gas Technology Institute, about using sorghum residual as a feedstock, she indicated that she would expect the performance to be similar to that of bagasse, which has been tested by Gas Technology Institute.[29] The stated liquid hydrocarbon product yield from bagasse was 30wt percent, comparable to lemna (30wt percent) and wood (25-28wt percent), and much higher than corn stover (21wt percent). As such, it is likely that the biomass produced by Great Valley Energy would be technically feasible to use in the IH^2 process.

The National Renewable Energy Lab (NREL) conducted a techno-economic analysis of the IH^2 process in 2011,[31] and estimated a total capital investment of $232.8 MM for a 2,000-dry-metric-tons per day plant with a 96 percent on-stream percentage. NREL also provided estimates for operating costs and determined that a minimum sale price of $1.60 per gallon of hydrocarbon product was required to meet an internal rate of return (IRR, after-tax) of 10 percent. In our conversation with Ms. Marker, she confirmed that the numbers generated by NREL are in line with the economic analyses that have been performed by Gas Technology Institute.

Using the values provided by NREL, rough capital and operating costs were established by Harris Group for the option of taking dried biomass from Great Valley Energy's process and feeding it to an IH^2 process. The estimated costs associated with IH^2 process is shown in Table 32. The overall capacity for such a Great Valley Energy IH^2 unit would be about 95 dry metric tons per day for year-round operation and would produce 2.9MM gallons of liquid product per year. Two cases were developed, one for operating year-round at 95 tons per day, assuming biomass could be stored, and another for operating at 190 tons per day for 180 days per year. The estimated capital costs are provided below in Table 32. The cost estimates are expected to have an accuracy equivalent to that of an AACE International Recommend Practice

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[29] Personal communication with Terry Marker of Gas Technology Institute on February 19, 2013.

[30] Marker, Terry, M. Linck, L. Felix, P. Ortiz-Toral, J. Wangerow, M. Roberts, *IH^2 for the Direct Production of Gasoline and Diesel from Biomass*, Biomass 2012, Washington D.C., 2012.

[31] Tan, Eric. *Techno-economic Analysis of the Integrated Hydropyrolysis and Hydroconversion Process for the Production of Gasoline and Diesel Fuels from Biomass*, NREL, May 23, 2011.

No. 18R-97 Class 5 capital cost estimate with a low range of -20 percent to -50 percent and a high range of +50 percent to +100 percent.

Table 32: Estimated Costs Associated with IH[2] Process

Item	Cost: 95 tons per day	Cost: 190 tons per day (180 days/year)	Cost: 190 tons per day (350 days/ year)
Total Capital Investment (Millions)	35.2	53.5	53.5
Operating Costs (Millions/year)	3.8	4.4	4.9

Source: Harris Group Engineering Study, 2013

Hydrolysis and Fermentation of Comfith and Comrind

Great Valley Energy and its engineering advisor Harris Group further studied enzymatic hydrolysis to convert sorghum fibers to fermentable sugars. In this study, capital and operational costs were estimated using work completed by the National Renewable Energy Laboratory and scaled to match processing throughputs of the Tilby Separation equipment.

Capital cost estimates were developed for plants having a feed rate of 10-TPH of sorghum billets (wet basis) and 50-TPH (operating 180 days per year) by using the previously mentioned NREL report as a basis. Capital costs for each section of the plant, except the base sorghum processing facility, were scaled and escalated to 2013 dollars based on relevant parameters such as feed rates. The base sorghum processing facility was not assessed in this evaluation; rather, only the cellulosic/sugar ethanol facility was studied. The composition of the sorghum fiber was assumed to be the same as that of corn stover in terms of cellulose, lignin, and other components. Further, both cellulosic material and the sugar from the sorghum facility (at a solids concentration of 20 wt percent) were assumed to be routed to the fermenters together.

Total capital cost estimates for the 50-TPH and 10-TPH plants were determined. It is important to note that these plants are sized for the full flow rate but are only assumed to operate 180 days/year. The total capital cost for the 50-TPH plant is $122 MM. Given that the estimated ethanol production operating 180 days per year is 5.9 million gallons per year, the total capital cost per annual gallon is approximately $21 per gallon, which is quite high.

The cost for the 10-TPH plant is considerably lower, at about $46 million total capital cost. However, given that the estimated ethanol made is about 1.2 million gallons per year, the total capital cost per annual gallon is even higher at about $39 per gallon. These costs compare with a value of $7 per gallon obtained by NREL in their report. The differences consist primarily in scale and operating factor. NREL's plant is based on a feed rate of approximately 92-TPH of corn stover on a dry basis, or 115-TPH on a wet basis and an operating period of 8,410 hours per year (96 percent on- stream factor).

Engineered Wood Products

Engineered Wood or Composite Lumber covers a broad range of wood products that may be produced by preparing and binding the strands, fiber particles, or veneers of wood together with adhesives to form composite materials. Typically engineered wood products are made from hardwoods and softwoods. Sawmill scraps and other wood waste can be used for engineered wood but require the removal of extraneous matter and classification. It is possible to manufacture comparable, if not superior, engineered cellulosic products from alternative feed stocks such sweet sorghum, hemp, kenaf and sugarcane. For purposes of this feasibility study, the fully integrated oriented strand board facility will utilize the separated comrind fiber from locally sourced sweet sorghum, sugarcane or both and produce wood quality composite boards. The separated comfith fiber from the KTC Tilby System will be utilized for fuel.

No modifications are required in order for standard wood-based composite board equipment to receive sweet sorghum fiber from Great Valley Energy. Today, most oriented strand board plants (wood based) are designed to produce at least 200,000 cubic meter of finished board per year, and many are now exceeding 600,000 cubic meter. This minimum size is driven by wood economics and these same limitations do not apply to non-wood fibers. Tilby Separation System can supply high quality fiber to composite board plants in the 100,000 cubic meter range and be competitive.

KTC Tilby has designed and installed over 30 board plants around the world. From this design experience capital costs were estimated for a 100,000 cubic meter plant. This plant would take the comrind feed from two separation facilities sized at 50-TPH fresh sorghum input. The installed Capital Cost for 100,000 cubic meter oriented strand board plant is approximately $88 million. For comparison purposes, this capital cost is scaled to a 50 ton per hour capacity as before. This results in a capital cost of $58 million. Operating costs for a 100,000 cubic meter/year facility were also determined and resulted in a total cost of $14.3 million per year excluding fiber costs.

Combined Heat and Power

Great Valley Energy and its advisors developed a capital cost estimate for a base sorghum processing facility that would take residual biomass from the comrind and comfith and use it to provide steam and power to the facility with possible export to the grid. Additional goals were to provide an estimate of expected operational costs and to determine economic feasibility. The brief information provided herein is more fully described in the conceptual engineering reports compiled for the pilot demonstration plant.

To determine viability of a combined heat and power process, rather than producing pellets from the residual biomass, the biomass was designed to be burned for combined heat and power generation. To this end, Area 500 within the plant was renamed "Biomass Energy Recovery," and Section 600, which included the pelletizer and related equipment, was eliminated.

Furthermore, the boiler was removed from Area 800, since the combined heat and power system was included in Area 500. The combined heat and power equipment provides steam required for the base sorghum processing facility and produces sufficient electricity both to operate the base sorghum processing facility and to export electricity to the grid. In fact, it may be beneficial to sell all the produced electricity to the grid and purchase grid electricity for the process, depending on the expected electricity prices for green versus conventional electricity. Auxiliary equipment, e.g., the cooling tower, was also resized as necessary to accommodate increased loads.

Methods
We developed capital cost estimates for plants capable of processing 50-TPH of sorghum billets (wet basis), producing either 20wt percent sugar or 60wt percent sugar using the previously issued report as a basis.[2] Where necessary, we assume capital costs scaled at a 0.6 exponent with capacity, where:

- $Cost2 = (Capacity2 / Capacity1)^{0.6} \times Cost1$

Cost Estimates
A combined heat and power process for Great Valley Energy would cost approximately $10 million (as part of a larger 50-TPH plant producing either 20wt percent sugar or 60wt percent sugar). It is important to note that the plant was sized for the full flow rate but is assumed to operate only 180 days/year.

A 50-TPH plant producing 60wt percent sugar has an operating cost of $10.8 million per year. This compares with $14.6 million annually for the base sorghum processing facility without combined heat and power. A 50-TPH plant producing 20wt percent sugar has an operating cost of $10.6 million, which compares to $14.4 million for the base sorghum processing facility. The byproducts and credits line item includes the income from plant production of electricity. In this case, electricity beyond that needed for the plant operation is produced from burning the residual comrind, comfith fiber, and dermax, and is sold to the grid. More electricity is produced for the 20wt percent case because less energy (less steam) is required for concentrating the sugar, making additional power generation possible.

Electricity Pricing
California has mandated the most ambitious Renewable Portfolio Standard in the U.S., demanding that investor-owned utilities, electric service providers, and community choice aggregators procure at least 20 percent of total energy procurement from eligible renewable energy resources, increasing to 33 percent by 2020. As of 2012, PG&E had achieved procurement of nearly 20 percent renewable resources toward the Renewable Portfolio Standard mandate.

California has set forth a feed-in tariff to procure 250 MW from various bioenergy sources to be placed in service after June 2013. The feasibility study prepared for the California Public Utilities Commission suggested that forest and agricultural residue projects would pay for feedstock at an average cost of $30 per dry ton. Additionally, the report estimated that the levelized cost of electricity for a nominal 3 MW generating facility based on agricultural residues or forest material would range from $134 to $251 per MWh. The initial tariff level was set at $89.23 per MWh, the price adjusts every two months based on capacity, and can rise to a level of $149.23 per MWh if no projects accept the tariff within a year of initial offering.

Integrated Ethanol Production from Sugar Juice

Harris Group developed capital and operating costs associated with the production of ethanol from a base sorghum processing facility processing either 10-TPH sorghum or 50-TPH sorghum. Harris Group performed preliminary process design and preliminary heat and material balances for the proposed ethanol facilities. Based on this work, Harris Group developed an equipment list and used that list to estimate capital costs.

Preliminary operating costs were also estimated based on the heat and material balance. The overall costs associated with both the 10-TPH and 50-TPH cases are provided in Table 5-8 below. As shown in Table 33, the total capital investments were $9.7 million and $23.6 million, for the ethanol facilities processing sugars from the 10-TPH and 50-TPH base sorghum processing facilities, respectively.

Table 33: Estimated Costs Associated with 10-TPH and 50-TPH Base Sorghum Processing Facility Ethanol Production

Base Sorghum Processing Facility Capacity	10-TPH	50-TPH
Purchased Equipment Cost (Millions)	$2.3	$5.7
Total Direct Costs (Millions)	$7.4	$18.2
Total Capital Investment (Millions)	$9.7	$23.6
OPERATING COSTS (Millions/YR)	$2.0	$9.9

Source: Harris Group Engineering Study, 2013

CHAPTER 6: Optimized Plant Design for GHG Reduction

For both the California Low Carbon Fuel Standard (LCFS) and the U.S. EPA Renewable Fuel Standard, Great Valley will need new fuel pathways established for the specific sweet sorghum to ethanol configuration. For both regulations, a full Life Cycle Analysis (LCA) will be necessary to determine the direct energy and emissions of the process. U.S. EPA has already determined a fuel pathway for grain sorghum, and the required 50 percent reduction in greenhouse gas (GHG) emissions to be considered an advanced biofuel can be met if biogas and combined heat and power are used. However, a sweet sorghum pathway has not been determined. The grain sorghum process reviewed by U.S. EPA did not include fractionation and production of other products from the stalk.

Fuels used to comply with LCFS must be assigned a carbon intensity value. If an applicable carbon intensity value is provided in the "Lookup Table", then no analysis is necessary. At this time, the Lookup Table does not have an approved pathway value for sweet sorghum ethanol; therefore, Great Valley must file an application with the CARB to establish a new LCFS pathway (Method 2B). CARB does have a preliminary pathway for grain sorghum where, with 100 percent wet distiller grains, grain sorghum has a carbon intensity of 55.81 gCO_2e/MJ. CARB models the indirect land use change emissions internally with the Global Trade Analysis Project model while U.S. EPA utilizes the FASOM-FAPRI model.

Methodology

ICF International (ICF) performed an LCA for three configurations for the 50-TPH feed input. Results for a 10-TPH input would be similar, but not exact due to differences in process equipment efficiencies and heat losses for the smaller equipment. ICF utilized CA-GREET, developed by CARB, for carbon intensity modeling. ICF produced a technical report detailing the sweet sorghum agricultural data provided by UC Davis, the sorghum to ethanol project, operating data, an indirect land use change comparison, and the resulting carbon intensity.

The information necessary for the report included a detailed process description and process flow diagrams. The following data was necessary to complete the LCA:

- Feedstock input and ethanol output in mass, volume and energy from the ethanol production facility;
- Energy consumption per unit time (e.g. hour, day, year) at the ethanol production facility with a breakdown by type (e.g. electricity, natural gas, diesel, biomass)
- For combustion devices and fuels including natural gas and biomass, how much energy is consumed (MMBtu/hr) and how the energy is consumed (e.g. small boiler, flare
- Quantity and type of co-products and what industries these co-products are used in (e.g. lbs/hr, MMBtu/hr)
- Total transport distance to rack for blending, in miles

ICF performed a comparative analysis of the agricultural inputs for modeling the direct impacts from farming sweet sorghum. ICF compared the data and inputs used by CARB and U.S. EPA to develop their LCA results for grain sorghum with data developed by UC Davis.

ICF then modified the CA-GREET model to account for sweet sorghum farming and the data supplied by Great Valley to generate CA-GREET model inputs. ICF used the energy and emissions allocation methodologies established and used by CARB for co-products. ICF modified the model to account for sorghum farming and modeled each individual step in the process with the correct regional analysis defaults. These defaults include electricity generation mix and natural gas power plant share.

ICF included substitution credits for by-products produced from the sorghum processing and ethanol production facilities. Biomass by-products from the sorghum production process including densified biomass, nutraceutical extract, dermax and forage, receive a GHG credit for substituting corn based feed on a mass basis. In addition, one configuration below produces oriented strand board. GHG credits for substitution of industrial produced oriented strand board are based on an Environmental Product Declaration by the American Wood Council.[32]

Sorghum Feedstock GHG Emissions

The carbon intensity of the feedstock is the same for each of the three configurations evaluated. For the evaluation, ethanol production was set at 14.74 gallons per ton of stalks run. In addition, field production was assumed to be 35 tons of clean stalks per acre. Feedstock was assumed to be sourced within 10 miles of the central facility. It should be noted that these values would represent weighted averages throughout the growing season. Based on the field production studies, the agricultural inputs in Table 34 were assumed. Each has a corresponding carbon intensity which impacts the emissions attributed to feedstock.

Table 34: Feedstock Inputs per Acre for Sweet Sorghum

Material	Use	Amount
Water	Irrigation	30 acre-inches
Yukon	Herbicide	6 ounces
Prowl H2O	Herbicide	3 pints
Nitrogen (80-0-0)	Fertilizer	140 pounds
Lorsban 15G	Insecticide	2 ounces
Lorsban 4E	Insecticide	1 pint
Gasoline	Fuel	0.95 gallons
Diesel	Fuel	7.52 gallons

Source: Great Valley Energy.

These inputs result in the following carbon intensity contribution to each gallon of ethanol that would be produced by a downstream facility from the sorghum sugars (Table 35).

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[32] Environmental Product Declaration by the American Wood Council (http://www.awc.org/pdf/EPDs/OSB_EPD.pdf)

Table 35: Contribution of Feedstock to Ethanol Carbon Intensity

Farming	2.48 g/mJ
Fertilizer	14.04 g/mJ
Herbicide	0.17 g/mJ
Insecticide	0.34 g/mJ
Feedstock Transport	2.03 g/mJ
Total for Feedstock	**19.1 g/mJ**

Source: Great Valley Energy.

As shown in Table 36, feedstock contributes 19.1 gCO2e/mJ to each gallon of ethanol produced. This compares favorably to feedstock values of 38.2 gCO2e/mJ for corn and 21.0 gCO2e/MJ for sugarcane.

Table 36: Contribution of Feedstock to Ethanol Carbon Intensity for Sugar Feedstocks

Feedstock	**Feedstock Contribution to Ethanol Carbon Intensity**
Corn	38.2 g/mJ
Sugarcane	21.0 g/mJ
Sweet Sorghum	19.1 g/mJ

Source: Great Valley Energy.

Process Configurations

For our purposes, to estimate the carbon intensity of the transportation fuel produced requires the contribution of feedstock supply detailed above along with the contribution of processing operations. To determine the contribution of processing, the energy inputs for electricity and natural gas to the process configurations evaluated. In addition, to the extent that other co-products are made, and which displace the carbon intensity associated with other products, a credit is formed and applied against the energy inputs to arrive at a processing carbon intensity number.

Finally, the use of comrind to produce construction materials can be used in a sequestration calculation.

Configuration 1

Plant Configuration 1 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: fuel ethanol (denatured), densified biomass (pellets), and a nutraceutical extract (bioactive dietary supplement) in powder form. Table 37 presents the inputs and products from Configuration 1.

Table 37: Inputs and Products from Configuration 1

Inputs	Annual Amount
Sweet Sorghum	146,400 tons
Denaturant	44,029 gallons
Electricity	7,996 MWh
Natural Gas	279,922 million BTU
Water	11,522,000 gallons
Products	
Fuel Ethanol	2,201,432 gallons
Densified Biomass	25,365 tons
Nutraceutical Extract	1,437,648 pounds

Source: Great Valley Energy.

Configuration 2

Plant Configuration 2 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: dilute sugar juice (20 percent), livestock forage, and raw dermax. Table 38 presents inputs and products from Configuration 2.

Table 38: Inputs and Products from Configuration 2

Inputs	Annual Amount
Sweet Sorghum	146,400 tons
Electricity	3,338 MWh
Natural Gas	40,667 million BTU
Water	5,422,000 gallons
Products	
20 Brix Sugar Juice	15,412 dry tons sugar
Forage (Dry/Wet)	25,365 tons/49,028 tons
Dermax	6,507 tons

Source: Great Valley Energy.

To manufacture ethanol from the sugar juice would require the following inputs, shown in Table 39, at the ethanol production facility.

Table 39: Inputs and Products from Ethanol Production – Configuration 2

Inputs	Annual Amount
20 Brix Sugar Juice	15,412 dry tons sugar
Electricity	1,317 MWh
Natural Gas	50,153 million BTU
Denaturant	44,029 gallons
Products	
Fuel Ethanol	2,201,432 gallons

Source: Great Valley Energy.

Configuration 3

Plant Configuration 3 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: sugar syrup (60 percent Brix), oriented-strand board, and dermax for nutraceutical extract. Table 40 presents inputs and products from Configuration 3.

Table 40: Inputs and Products from Configuration 3

Inputs	**Annual Amount**
Sweet Sorghum	146,400 tons
Electricity	14,538 MWh
Natural Gas	67,778 million BTU
Water	7,267,000 gallons
Products	
60 Brix Sugar Juice	15,412 dry tons sugar
Oriented strand board (3/8" basis)	19,520,000 square feet
Dermax	6,507 tons

Source: Great Valley Energy.

To manufacture ethanol from the sugar juice would require the following inputs at the ethanol production facility. As shown in Table 41, water is needed to dilute the 60 brix juice to the desired sugar concentration in the fermenter.

Table 41: Inputs and Products from Ethanol Production – Configuration 3

Inputs	**Annual Amount**
60 Brix Sugar Juice	15,412 dry tons sugar
Electricity	1,317 MWh
Natural Gas	50,153 million BTU
Denaturant	44,029 gallons
Water	12,312,360 gallons
Products	
Fuel Ethanol	2,201,432 gallons

Source: Great Valley Energy.

GREET Model Results

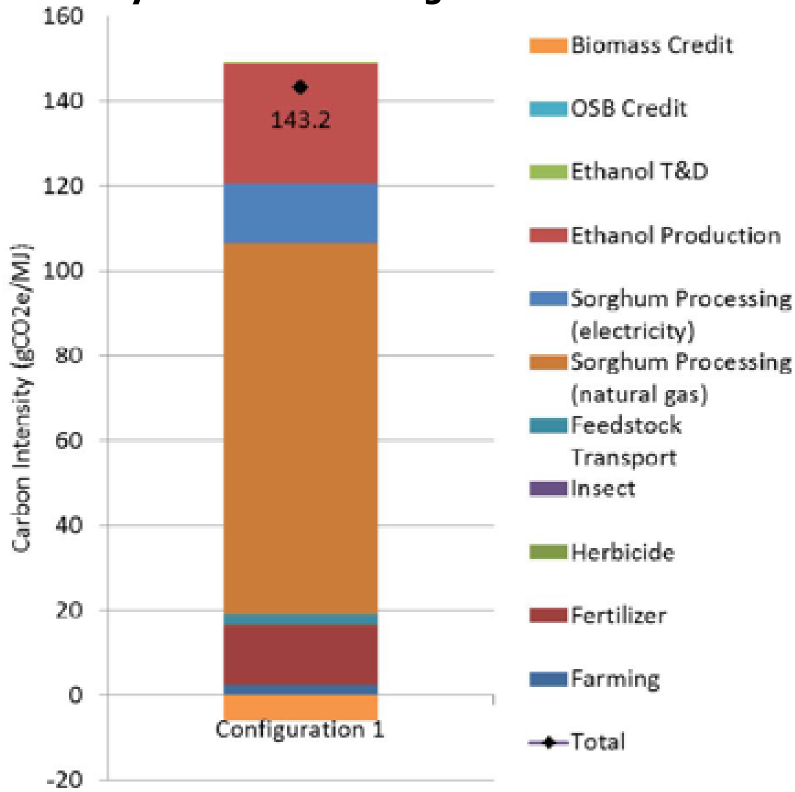
The GREET modeling results are presented in this section individually by configuration. The summary section contains a comparison between the configurations and three (3) California Air Resources Board default pathways for corn, sugarcane, and cellulosic (farmed trees) ethanol that were also produced with CA-GREET.

Configuration 1

Figure 17 below shows the modeling results for Configuration 1. The ethanol production input data from Configurations 2 and 3 were used to estimate the breakdown between electricity and natural gas used for sorghum processing and electricity and natural gas for ethanol production.

Figure 17: Carbon Intensity Results for Configuration 1

	Carbon Intensity (gCO2e/MJ
Farming	2.5
Fertilizer	14.0
Herbicide	0.2
Insect	0.3
Feedstock Transport	2.0
Sorghum Processing (natural gas)	81.5
Sorghum Processing (electricity)	14.0
Ethanol Production	28.3
Ethanol T&D	0.4
Biomass Credit	-6.0
OSB Credit	-
Total	143.2



Source: ICF International, 2013

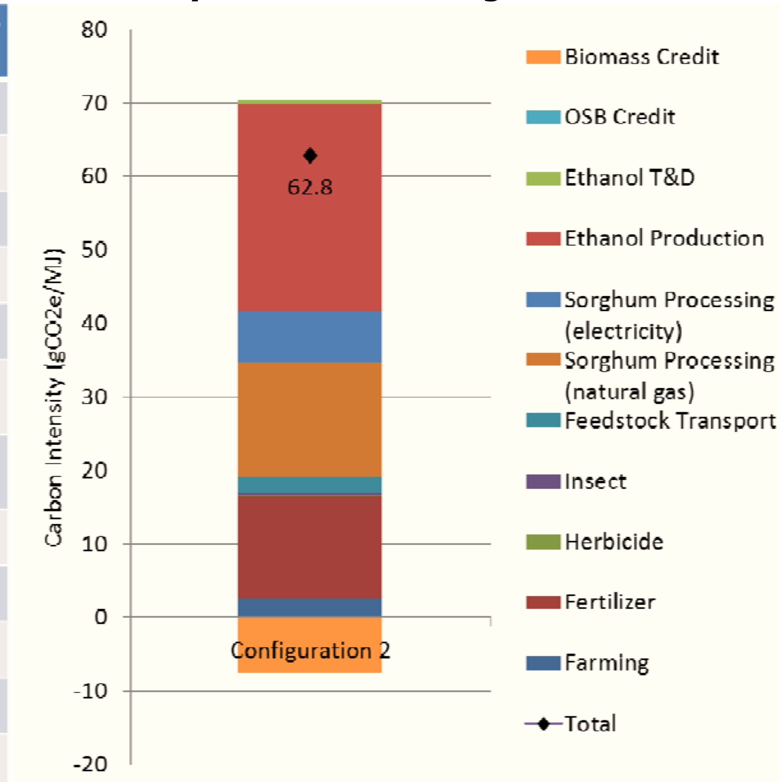
The results show significant GHG emissions associated with the natural gas consumed during the sorghum processing. The GHG substitution credits from the produced densified biomass and nutraceutical extract are included in the sorghum processing emissions. The total lifecycle GHG intensity is 44 percent more than the GHG intensity of California gasoline blendstock (99.2gCO2e/MJ).

Configuration 2

Figure 18 below shows the results from modeling Configuration 2.

Figure 18: Carbon Intensity Results for Configuration 2

	Carbon Intensity (gCO2e/MJ
Farming	2.5
Fertilizer	14.0
Herbicide	0.2
Insect	0.3
Feedstock Transport	2.0
Sorghum Processing (natural gas)	15.6
Sorghum Processing (electricity)	7.0
Ethanol Production	28.3
Ethanol T&D	0.4
Biomass Credit	-7.3
OSB Credit	-
Total	62.8



Source: ICF International, 2013

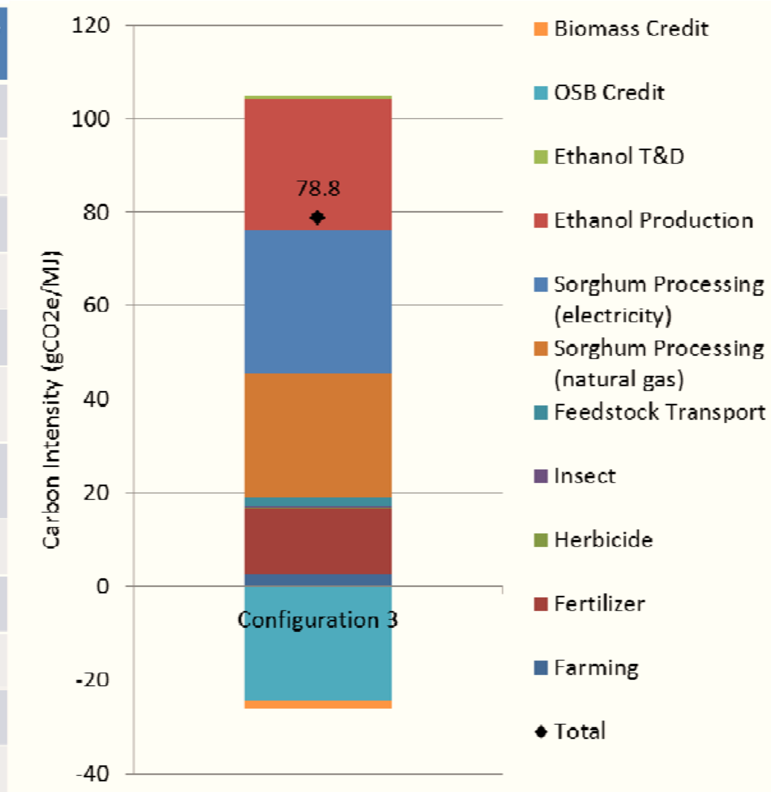
The results show a significant reduction in GHG emissions associated with the natural gas consumed during the sorghum processing. The GHG substitution credits from the produced forage and dermax are included in the sorghum processing emissions. The total lifecycle GHG intensity is 37 percent less than the GHG intensity of California gasoline blendstock (99.2gCO2e/MJ).

Configuration 3

Figure 19 below shows the results from modeling Configuration 3.

Figure 19: Carbon Intensity Results for Configuration 3

	Carbon Intensity (gCO2e/MJ
Farming	2.5
Fertilizer	14.0
Herbicide	0.2
Insect	0.3
Feedstock Transport	2.0
Sorghum Processing (natural gas)	26.5
Sorghum Processing (electricity)	30.5
Ethanol Production	28.3
Ethanol T&D	0.4
Biomass Credit	-1.5
OSB Credit	-24.4
Total	78.8



Source: ICF International, 2013

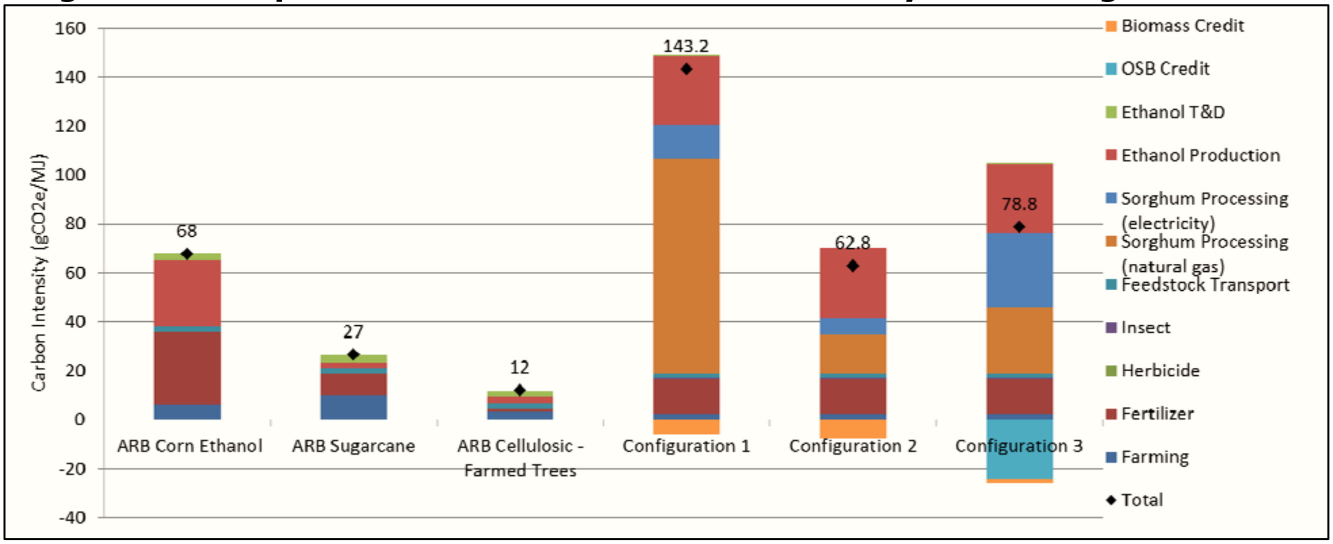
The results show reduced GHG emissions associated with the natural gas consumed during the sorghum processing compared to Configuration 1. The GHG substitution credits from the dermax are included in the sorghum processing emissions. The GHG emission substitution credit for oriented strand board production was calculated separately from the GREET modeling. The credit is based on a factor of 248.3 kgCO2e/cubic meter of oriented strand board.[33] There are 1,130 square feet of 3/8" oriented strand board in one cubic meter which results in a factor of 219.7 gCO2e/sqft. Prior to inclusion of the GHG credit from oriented strand board, the GHG intensity of 103.02 is a 4 percent more than GHG intensity of California gasoline blendstock (99.2gCO2e/MJ). The total lifecycle GHG intensity when taking into account the substitution credit for oriented strand board is 26 percent less than the GHG intensity of California gasoline blendstock.

Summary and Discussion

Figure 20 below shows a comparison between the three configurations and the ARB default values for corn, sugarcane and cellulosic (farmed trees) ethanol.

[33] American Wood Council Environmental Product Declarations (http://www.awc.org/pdf/EPDs/OSB_EPD.pdf)

Figure 20: Comparison of ARB Default Ethanol Pathways and Configurations 1-3



Source: ICF International, 2013

For all three configurations, the sorghum farming and ethanol are the same and the main variations in GHG intensity were in the sorghum processing and the saleable by-products from the process. The sorghum processing emissions in Configuration 2 and Configuration 3 are 84 percent and 42 percent less than Configuration 1, respectively. The GHG intensity of configuration 1 includes the energy required to extract and concentrate the bioactive compounds from the dermal layer. However, as no product currently in the marketplace is displaced, there is not a corresponding product credit. This results in a higher GHG intensity for the process as a whole, without corresponding benefit to the fuel pathway. A reasoned approach would partition these emissions from the rest of the process. However, a mechanism to document that under a new CARB Method 2B pathway is future work.

The results from Configuration 2 are similar to those of the ARB corn ethanol pathway. Corn ethanol has higher fertilizer and farming emissions while the sorghum pathways require additional energy and emissions for pre-ethanol processing of the sorghum. Based on preliminary modeling, the use of combined heat and power would provide significant reductions for the sorghum processing stage. Reductions in GHG intensity as high as 70 percent from Configuration 1 results are possible which would result in 55 percent GHG intensity reductions from the GHG intensity of California gasoline blend stock.

CHAPTER 7: Optimized Plant Design for Economics

Based on the engineering work completed by Harris Group and the marketing studies completed by Great Valley Energy's advisors, multiple plant configurations were evaluated to determine which configurations provide the best economic profile. This work was based on the 50-TPH base sorghum processing facility at the core of each configuration. A commercial demonstration-scale base sorghum processing facility with a capacity to process 10-TPH of sweet sorghum was not likely large enough to stand alone economically.

Following separation, several downstream processing configurations were evaluated for sugars, biomass and bioactive along the following commercial product options:

1) Fuel Ethanol (from sugars)
    a. Producing ethanol onsite from sugar juice
    b. Providing an intermediate sugar solution as syrup or pasteurized juice to an existing fuel ethanol facility
2) Biomass Products (from fibers)
    a. Producing biomass products onsite such as densified biomass or construction products
    b. Providing a livestock feed intermediate for offsite blending
3) Nutraceutical Bioactive Extracts (from dermal layer)
    a. Producing marketable nutraceuticals onsite extraction facility onsite
    b. Providing a raw dermal layer intermediate to a tolling facility offsite

The multitude of configurations from various possible permutations described above combined with project-specific constraints/opportunities will drive the ideal economic scenario. For example, a specific offtake scenario such as a specialty wood products manufacturer may drive a commodity construction products scenario into a higher value market. Further, a food grade sweetener application may drive the sugar processing decision away from fuels or chemicals.

Market uncertainties aside, we identified three scenarios that provide combinations of the alternatives above to characterize a range of possible implementations. These three configurations included the following:

Configuration 1 – Onsite production of denatured fuel ethanol, densified biomass (pellets), and nutraceutical extract powder;

Configuration 2 – Production of 20 percent sugar solution for over-the-fence fuel ethanol production, livestock forage/feed blend stock, and a tolling arrangement for extraction and upgrading of nutraceutical bioactive dermal layer; and

Configuration 3 – Production of 60 percent sugar syrup, construction products (oriented-strand board), and a tolling arrangement for dermal layer bioactives extraction.

Additional detail for the three configurations is provided in each section below including products, price, revenue, expense, and hypothetical financing arrangements. Financial forecasts are inherently unreliable due to project-specific circumstances and events that are different from the assumptions and projections set forth in a base case pro forma. Sensitivities are presented for each configuration to show how certain actual circumstances and unforeseen events (such as an outage that decreases online availability) impact the financial projections.

Plant Configuration 1

Plant Configuration 1 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: fuel ethanol (denatured), densified biomass (pellets), and a nutraceutical extract (bioactive dietary supplement) in powder form. Detailed tables showing inputs and assumptions, forecasted results, and sensitivities are provided at the end of Chapter 7.

Revenues

Ethanol will be produced onsite from sugar juice which is 20 percent sugar by weight that is 10,317 pounds per hour of dry sugar in a mass flow (including water) to fermenters of 51,587 pounds. Anhydrous ethanol will be produced at a nominal rate of 14.74 gallons per wet ton of sweet sorghum billets processed. This production equates to 737 gallons per hour and 421 barrels per stream day. Adding 2 percent denaturant, operation of the plant at nameplate capacity for 122 days per year will result in a volume of denatured ethanol sold of 2.2 million gallons per year. A wholesale price of denatured ethanol of $2.50 per gallon is projected.

Because the ethanol may be advanced biofuel, we estimate a RIN premium of $0.50 per gallon. The ethanol price, but not the RIN premium, is escalated at 2 percent per year. It should be noted that the price of ethanol is highly variable and closely tied to the both the price of oil and price of corn. Further, the price of advance fuel RINs (D5) is highly dependent on volumetric requirements of the Renewable Fuels Standard which are subject to change on an annual basis. D5 RINs have ranged from approximately 20 percent to $120 percent of this value in 2013.

The plant will produce densified biomass (pellets) from comfith and comrind at a rate of 0.173 tons per wet ton of sweet sorghum billets processed. This equates to 8.6-TPH and more than 200 tons per day. Comfith and comrind represent 26 percent and 49 percent, respectively, of the dried biomass fed to the hammer mill and pellet mill. Operating at nameplate capacity, the plant will produce more than 25,000 tons per year. We estimate a wholesale price, free on board (FOB), of $160 per ton, escalating at 2 percent per year.

Nutraceutical extract in powder form will be produced from the dermax at a nominal rate of 9.8 pounds per wet ton of sweet sorghum billets processed. Extractables constitute approximately 11 percent of the dermax fed to the nutraceutical extraction process. This production equates to 490 pounds per hour and nearly 6 tons per day. At nameplate capacity, the plant will produce more than 1.4 million pounds of nutraceutical extract powder per year. The powder is anticipated to be further packaged in smaller amounts and sold into the dietary supplement market. We estimate a market price in year 1 of $10 per pound, escalating at 10 percent per year to approach $25 per pound after 10 years of new market development.

While these extract prices compare favorably with similar nutraceuticals such as grape seed extract on both a mass and activity basis, this market needs to be developed in both volume and pricing. Contrary to sugar or biomass outlets, much more uncertainty remains with respect to volume of this high value market than the price in regard to multi-facility roll out. It should be emphasized that the use of dermax to produce dietary supplements relies on a market that does not yet exist and product pricing for which there is no direct history.

Unrelated to product sales, we have included other revenue which is interest income on reserve funds. We assume that the debt and maintenance portion of the initial reserve account and working capital account (approximately one-third of total funded account) can be invested to generate interest income at approximately half the interest rate assumed for project debt.

Fixed Production Costs

Fixed production costs include direct fixed costs and indirect fixed costs and will generally be incurred regardless of actual feedstock processing rate. Maintenance materials and services cost, the largest fixed production cost, is estimated at 2.5 percent of total direct project cost per year. This allocation is necessary to cover routine annual maintenance costs but excludes maintenance labor. We assume this cost will escalate at approximately 1.5 percent per year.

Labor, at $1.2 million per year is the second largest fixed production cost, escalating at 2 percent each year. This will include approximately 10 full time positions (average income and benefits of $60,000 per year) to include plant manager; plant engineer; maintenance engineer; lab/HSE manager, logistics specialist, support staff, and a mix of production and maintenance personnel. In addition, 40 seasonal labor positions over 18 weeks are included which will be contracted during the 122-day harvesting and production run. These 40 positions will provide approximately 10 people per shift with an average loaded cost of $20 per hour for each position.

Other fixed costs include property tax and insurance, estimated at 1.5 percent of total direct project cost and escalating at 1.5 percent per year. An account has been assumed to cover working capital, debt service reserve, and maintenance reserve. This account is funded from initial financing proceeds. License/royalty payments are required for both the sorghum fraction process and the nutraceutical extract process, indexed at $2 per ton of sweet sorghum billets processed.

Indirect fixed costs include a home office operations and maintenance fee for the holding company that will own the project-level entity. The home office will provide corporate administrative, professional and technical services during the construction phase and on an ongoing basis during commercial operations. The operations and maintenance fee is 4 percent of total project operating expense. A legal/financial services expense has been assumed to cover outside legal counsel and professional accounting and tax services. These costs are estimated to be 1 percent of project operating expenses during the first year of operation, declining to a fixed level of 0.25 percent by year 3.

Variable Production Costs

Variable production costs are generally tied directly to the rate at which the plant is processing billets of sweet sorghum feedstock. The largest variable production cost is the sweet sorghum feedstock. With a plant capacity of 50-TPH over 122 full days of operation, feedstock rate will be over 146,000 tons per year (produced from approximately 5,500 acres of sweet sorghum cultivated). Based on the cost buildup and crop characteristics presented elsewhere in this report, the feedstock price is assumed to be $46.61 per ton in the first year, escalating by 2 percent each year thereafter. Additionally, given the lack of sweet sorghum crop currently cultivated in California, we have incorporated a procurement fee of 10 percent of crop price which will fund crop interest, development, procurement, scheduling, risk management, and contracting activities. Feedstock assumptions are identical for all three configurations.

The second largest variable production cost is for utilities: natural gas and electricity. The fractionation, ethanol production, pelleting, and extraction activities are intense energy consumers requiring nearly 55 kWh of electricity and 1.91 MMBtu of natural gas per ton of sweet sorghum processed. We estimate the price of electricity will be $120 per MWh and the price of natural gas will be $6.00 per MMBtu, each escalating at 2 percent per year. Under this configuration, energy efficiency measures are incorporated, but there is no onsite energy production.

Consumables (yeast, nutrients, water treatment, etc.), denaturant, and water/wastewater make up the remaining variable production costs. Consumables are estimated by Harris Group to be $2.56 per ton of sweet sorghum billets processed. Denaturant, at 2 percent of ethanol sold, is conservatively estimated to cost the same as denatured ethanol at $2.50 per gallon. Water and wastewater across the plant complex is estimated to be 78.7 gallons per ton of sweet sorghum billets processed, at a cost of $4.00 per 1000 gallons, escalating at 2 percent annually.

Sources and Uses of Capital

Funding for the project is assumed to come from three sources: senior debt, equity, and grant. Sources of funds assumptions are identical across all three configurations to normalize the effects of leveraging and non-dilutive capital on equity returns, which is the basis for comparisons between configurations as well as the sensitivity analysis.

Because the project is first-of-a-kind with potentially-high perceived risk and potentially-high perceived value, Great Valley Energy believes that grant funding equivalent to approximately 10 percent of total project cost would be appropriate, sourced from federal, state and/or other interested parties.

Great Valley Energy also believes that the project may be eligible for a loan guarantee or low-interest agency loan (equivalent 5.0 percent interest and 20 year amortization) for 50 percent of the capital stack. Lender fees, brokerage/placement fees, and other miscellaneous fees are estimated to total 6 percent of the loan principal amount. Debt service (principal and interest) would be $4.5 million each year.

The balance of the capital stack (40 percent of total project cost) would be comprised of private equity, placed with the assistance of a broker at a fee rate of 8 percent.

Use of funds is based on Harris Group's engineering and capital cost estimation. Total direct costs, equipment and installation, are estimated at $60.7 million. Development, overhead, and indirect costs are estimated to be $44.3 million, which includes a robust line item for working capital and reserve account funding of $15.2 million (nearly equal to total first year operating expenses). Thus, the total project cost is estimated to be $105 million.

Projected Economics

The end of Chapter 7 shows pro forma assumptions and projected economic results. Because the project entity is likely to be a limited liability company taxed as a partnership, only a pre-tax analysis is provided (through debt service).

Earnings before interest, tax, depreciation and amortization was determined to be $11.3 million in the second year of operation (first full year of operation), or 42 percent of revenue. The earnings averages $17.8 million over the first 10-year period. Simple payback, determined herein as the sum of debt and equity divided by average earnings, is 5.6 years.

Average debt service coverage over the first 10 years is 3.99x, ranging from 1.60 in year 1 to 6.42 in year 10. After principal and interest payments, the cash available for distribution is $6.8 million in the first full year of operation, offering a net operating margin of 25 percent. Average annual cash available for distribution over the initial 10-year period is $13.4 million. The pre- tax project equity internal rate of return is projected to be 19.2 percent over the initial 10- year period of operation.

Sensitivity Analysis

The following sensitivity cases were analyzed by changing the variable indicated and holding all other factors constant in the pro forma.

- Reduced products yield – 5 percent reduction.
- Decreased availability – 90 percent capacity.
- Increased feedstock cost – 10 percent increase.
- Increased non-feedstock operations and maintenance cost – 10 percent increase.
- Reduced ethanol price – 10 percent reduction.
- Reduced densified biomass price – 10 percent reduction.
- Reduced nutraceutical extract price – 10 percent reduction.
- Higher interest on debt – 8 percent interest rate.
- Reduced grant availability – 5 percent of capital.

The impact of these sensitivities on debt service coverage ratio and internal rate of return is summarized at the end of Chapter 7. These sensitivities are further analyzed based on the relative change in project internal rate of review compared to the base case. The largest impacts in order of magnitude are (1) reduced nutraceutical price, (2) decreased online availability, and (3) reduced yield. As a measure of stability, the average reduction over all of the sensitivity cases was a 12.6 percent reduction in internal rate of review from the 19.2 percent base case. It should be noted that each of these cases represent a negative impact on the business case. There is a corresponding positive impact for changes in the factors which move in the opposite direction.

Plant Configuration 2

Plant Configuration 2 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: dilute sugar juice (20 percent), livestock forage, and raw dermax. Detailed tables showing inputs and assumptions, forecasted results, and sensitivities are provided at the end of Chapter 7.

Revenues

For Configuration 2, sugar juice at a 20 percent concentration will be produced from the sweet sorghum billets. The sugar juice is expected to be directed primarily to an existing fuel ethanol producer, but market conditions could result in a flexible redirect to other end products such as juice drink sweetener. The base sorghum processing facility will produce 10,317 pounds equivalent per hour of sugar in a total mass flow (including water) of 51,587 pounds per hour, or approximately 0.11 tons of dry sugar per wet ton of sweet sorghum. At nameplate capacity, the plant is expected to sell 15,412 tons per year of dry sugar equivalent. We estimate a wholesale price of $320 per equivalent dry ton FOB. If this is directed to the advanced biofuel market, a premium may result but has not been included in the assumed market price. The sugar juice price is escalated at 2 percent per year.

The plant will produce livestock forage from comfith and comrind at a rate of 0.335 wet tons per wet ton of sweet sorghum billets processed. This equates to 16.8-TPH and more than 400 wet tons per day. For reference, a typical corn ethanol plant with a 60 million gallon per year annual nameplate capacity might produce 1500 tons per day of wet distillers' grains as a livestock feed. On a dry basis, approximately one-third of the biomass will be comfith and two-thirds will be comrind. Operating at nameplate capacity, the plant will produce nearly 50,000 tons per year. We estimate a wholesale price FOB of $26.80 per wet ton, escalating at 2 percent per year. This price is referenced to the dry feed value determination described elsewhere in this report and adjusted for moisture content.

Raw dermax will be produced at a rate of 0.044 tons per ton of sweet sorghum billets processed. Rather than extracting onsite, the raw dermax will be sold into the market as a feedstock for nutraceutical extraction for dietary supplements. This production of raw dermax equates to approximately 2.2-TPH of raw dermax (65 percent moisture) and more than 50 tons per day. At nameplate capacity, the plant will produce more than 6,500 tons of raw dermax per year. Based on an evaluation of acceptable feedstock pricing to a nutraceutical extraction operation, we estimate a market price in year 1 of $1,600 per ton, escalating at 2 percent per year. As previously stated for Configuration 1, while this price compares favorably with similar nutraceutical products such as grape seed extract on both a mass and activity basis, this market needs to be developed in both volume and pricing. Contrary to sugar or biomass outlets, much more uncertainty remains with respect to volume of this high value market than the price in regard to multi-facility roll out. It should be emphasized that the use of dermax to produce dietary supplements relies on a market that does not yet exist and product pricing for which there is no direct history.

Fixed Production Costs

Fixed production costs include direct fixed costs and indirect fixed costs and will generally be incurred regardless of actual feedstock processing rate. Maintenance materials and services cost is estimated at 2.5 percent of total direct project cost per year. This allocation is necessary to cover routine annual maintenance costs but excludes maintenance labor. We assume this cost will escalate at approximately 1.5 percent per year.

Labor, at nearly $1 million per year is the largest fixed production cost, escalating at 2 percent each year. Configuration 2 will include approximately 10 full time positions (average income and benefits at $60,000 per year) to include plant manager; plant engineer; maintenance engineer; lab/HSE manager, logistics specialist, and support staff. In addition, 25 seasonal labor positions are included over a period of 18 weeks which will be contracted during the 122-day harvesting and production run. These 25 positions will provide approximately 6 production people per shift with an average loaded cost of $20 per hour for each position.

Other fixed costs include property tax and insurance, estimated at 1.5 percent of total direct project cost and escalating at 1.5 percent per year. An account has been assumed to cover working capital, debt service reserve, and maintenance reserve. This account is funded from initial proceeds. License/royalty payments are required for the sorghum fraction process, indexed at $1 per ton of sweet sorghum billets processed.

Indirect fixed costs include a home office operations and maintenance fee for the holding company and a legal/financial services expense as described in Configuration 1.

Variable Production Costs

Variable production costs are generally tied directly to the rate at which the plant is processing billets of sweet sorghum feedstock. The largest variable production cost is the sweet sorghum feedstock as described in "Variable Production Costs."

The second largest variable production cost is for utilities - natural gas and electricity. Configuration 2 is far less energy intensive than other configurations, requiring less than 23 kWh of electricity and less than 0.3 MMBtu of natural gas per ton of sweet sorghum processed. We estimate the price of electricity will be $120 per MWh and the price of natural gas will be $6.00 per MMBtu, each escalating at 2 percent per year. Under Configuration 2, energy efficiency measures are incorporated, but there is no onsite energy production.

Consumables and water/wastewater make up the remaining variable production costs. Consumables are estimated to be $0.05 per ton of sweet sorghum billets processed.

Water/wastewater across the plant complex is estimated to be 37.0 gallons per ton of sweet sorghum billets processed, at a cost of $4.00 per 1000 gallons, escalating at 2 percent annually.

Sources and Uses of Capital

Use of funds is based on Harris Group's engineering and capital cost estimations. Total direct costs, equipment and installation, are estimated at $19.9 million. Development, overhead, and indirect costs are estimated to be $18.5 million, which includes a robust line item for working capital and reserve account funding of $9 million (nearly equal to total first year operating expenses). Thus, the total project cost is estimated to be $40.8 million.

Projected Economics

The end of Chapter 7 shows pro forma assumptions and projected economic results for Configuration 2. Earnings before interest, tax, depreciation and amortization was determined to be $6.3 million in the second year of operation (first full year of operation), or 37 percent of revenue. The earnings averages $6.7 million over the first 10-year period. Simple payback, determined herein as the sum of debt and equity divided by average earnings, is 5.4 years.

Average debt service coverage ratio over the first 10 years is 4.12x, ranging from 2.79 in year 1 to 4.67 in year 10. After principal and interest payments, the cash available for distribution is

$4.7 million in the first full year of operation, offering a net operating margin of 28 percent. Average annual cash available for distribution over the initial 10-year period is $5.1 million. The pre-tax project equity internal rate of return is projected to be 25.4 percent over the initial 10-year period of operation.

Sensitivity Analysis

The following sensitivity cases were analyzed by changing the variable indicated and holding all other factors constant in the pro forma.

- Reduced product yield – 5 percent reduction.
- Decreased availability – 90 percent capacity.
- Increased feedstock cost – 10 percent increase.
- Increased non-feedstock operations and maintenance cost – 10 percent increase.
- Reduced sugar juice price – 10 percent reduction.
- Reduced forage price – 10 percent reduction.
- Reduced raw dermax price – 10 percent reduction.
- Higher interest on debt – 8 percent interest rate.
- Reduced grant availability – 5 percent of capital.

The impact of these sensitivities on debt service coverage ratio and internal rate of return is summarized at the end of Chapter 7. These sensitivities are further analyzed based on the relative change in project internal rate of review compared to the base case. The largest impacts in order of magnitude are (1) reduced product yield, (2) decreased plant online availability, and (3) increased feedstock cost. As a measure of stability, the average reduction over all of the sensitivity cases was a 14.5 percent reduction in internal rate of review from the 25.4 percent base case.

Plant Configuration 3

Plant Configuration 3 consists of those unit operations, integrated into an overall biorefinery, to produce primarily three saleable products: sugar syrup (60 percent Brix), oriented-strand board, and dermax for nutraceutical extract. Detailed tables showing inputs and assumptions, forecasted results, and sensitivities are provided at the end of Chapter 7.

Revenues

Sugar juice will be produced under Configuration 3 and sold to fuel ethanol producers in a highly concentrated syrup form at 60 percent sugar by weight. The syrup is expected to be directed primarily to the fuel ethanol markets, but market conditions may result in a flexible redirect to other end products such as the sweetener market. The base sorghum processing facility will produce 10,527 pounds equivalent per hour of sugar in a total mass flow (including water) of 17,545 pounds per hour, or approximately 0.11 equivalent dry tons of sugar per wet ton of sweet sorghum. We estimate a wholesale price of $320 per equivalent dry ton FOB. If this is directed to the advanced biofuel market, a premium may result but has not been included in the assumed market price. The sugar juice price is escalated at 2 percent per year.

There is an energy cost of about $15 per ton of dry sugar (assuming natural gas priced at $6 per million BTU) associated with concentrating the sugar juice from 20 percent to 60 percent. The higher concentration permits longer shelf life and greater economic shipping distance. However, there is no product price premium assumed for this additional flexibility.

The plant will produce oriented-strand board from comfith and comrind at a rate of 133.33 square feet of oriented strand board panel (in 4 by 8 sheets with an assumed thickness basis of 3/8”) per wet ton of sweet sorghum billets processed. This equates to more than 200 sheets of oriented strand board per hour and 5,000 sheets per day. Operating at nameplate capacity, the plant will produce 19.5 million square feet per year. We estimate a wholesale price FOB of $398 per thousand square feet, escalating at 2 percent per year.

Raw dermax will be produced at a rate of 0.044 tons per ton of sweet sorghum billets processed. Rather than extracting onsite, the raw dermax will be sold into the market as a feedstock for nutraceutical extraction for dietary supplements. This production of raw dermax equates to approximately 2.2-TPH of raw dermax (65 percent moisture) and more than 50 tons per day. At nameplate capacity, the plant will produce more than 6,500 tons of raw dermax per year. Based on an evaluation of acceptable feedstock pricing to a nutraceutical extraction operation, we estimate a market price in year 1 of $1,600 per ton, escalating at 2 percent per year. It should be emphasized that the use of dermax to produce dietary supplements relies on a market that does not yet exist and product pricing for which there is no direct history.

Fixed Production Costs

Fixed production costs include direct fixed costs and indirect fixed costs and will generally be incurred regardless of actual feedstock processing rate. Maintenance materials and services cost, the largest fixed production cost, is estimated at 2.5 percent of total direct project cost per year. This allocation is necessary to cover routine annual maintenance costs but excludes maintenance labor. We assume this cost will escalate at approximately 1.5 percent per year.

Labor, at $1.6 million per year and escalating at 2 percent per year, will include approximately 12 full time positions (average income and benefits package of $60,000 per year) to include plant manager; plant engineer; maintenance engineer; lab/HSE manager, logistics specialist, support staff, and a mix of production and maintenance personnel. In addition, 60 seasonal labor positions are included which will be contracted during the 122-day harvesting and production run. These 60 positions will provide approximately 15 people per shift with an average loaded cost of $20 per hour for each position.

Other fixed costs include property tax and insurance, estimated at 1.5 percent of total direct project cost and escalating at 1.5 percent per year. An account has been assumed to cover working capital, debt service reserve, and maintenance reserve. This account is funded from initial funding proceeds and is sufficient to provide buffer for a season of operating expenses. License/royalty payments are required for the sorghum fraction process indexed at $1 per ton of sweet sorghum billets processed.

Indirect fixed costs are consistent with those in configurations 1 and 2.

Variable Production Costs

After feedstock, the second largest variable production cost is for utilities: natural gas and electricity. The fractionation, syrup, board, and other activities are intense energy consumers requiring nearly 100 kWh of electricity and nearly 0.5 MMBtu of natural gas per ton of sweet sorghum processed. We estimate the price of electricity will be $120 per MWh and the price of natural gas will be $6.00 per MMBtu, each escalating at 2 percent per year. Under this configuration, energy efficiency measures are incorporated, and onsite energy production includes both electricity and heat from surplus comfith.

Consumables (e .g. resin) and water/wastewater make up the remaining variable production costs. Consumables are estimated by Harris Group and KTC Tilby to be $3.58 per wet ton of sweet sorghum billets processed. Water and wastewater across the plant complex is estimated to be nearly 50 gallons per wet ton of sweet sorghum billets processed, at a cost of $4.00 per 1000 gallons, escalating at 2 percent annually.

Sources and Uses of Capital

Funding for the project is assumed to be the same as configurations 1 and 2.

Use of funds is based on Harris Group's engineering and capital cost estimation. Total direct costs, equipment and installation, are estimated at $64 million. Development, overhead, and indirect costs are estimated to be $48 million, which includes a robust line item for working capital and reserve account funding of $17 million (nearly equal to total first year operating expenses). Thus, the total project cost is estimated to be $119 million.

Projected Economics

The end of Chapter 7 shows pro forma assumptions and projected economic results. Because the project entity is likely to be a limited liability company taxed as a partnership, only a pre-tax analysis is provided (through debt service).

Earnings before interest, tax, depreciation and amortization was determined to be $8.1 million in the second year of operation (first full year of operation), or 34 percent of revenue. The earnings averages $8.8 million over the first 10-year period. Simple payback, determined herein as the sum of debt and equity divided by average earnings, is 12.2 years.

Average debt service coverage over the first 10 years is 1.84x, ranging from 1.47 in year 1 to 2.06 in year 10. After principal and interest payments, the cash available for distribution is $3.4 million in the first full year of operation, offering a net operating margin of 14 percent. Average annual cash available for distribution over the initial 10-year period is $4.0 million. The pre-tax project equity internal rate of return is projected to be -2.7 percent over the initial 10-year period of operation.

Sensitivity Analysis

The following sensitivity cases were analyzed by changing the variable indicated and holding all other factors constant in the pro forma.

- Reduced product yield – 5 percent reduction.
- Decreased availability – 90 percent capacity.
- Increased feedstock cost – 10 percent increase.
- Increased non-feedstock operations and maintenance cost – 10 percent increase.
- Reduced syrup price – 10 percent reduction.
- Reduced board price – 10 percent reduction.
- Reduced dermax price – 10 percent reduction.
- Higher interest on debt – 8 percent interest rate.
- Reduced grant availability – 5 percent of capital.

The impact of these sensitivities on debt service coverage ratio and internal rate of return is summarized at the end of Chapter 7. These sensitivities are further analyzed based on the relative change in project internal rate of review compared to the base case. The largest impacts in order of magnitude are (1) increased debt interest rate, (2) reduced raw dermax price, and (3) increased feedstock cost (equivalent change to reduced oriented strand board price). As a measure of stability, the average reduction over the sensitivity cases was a 119.8 percent reduction in internal rate of review from the -2.7 percent base case.

Summary Economics

Great Valley Energy explored multiple biorefinery plant configurations to determine best economic potential for a commercial project. Two configurations designed around a 50 ton per hour base sorghum processing facility show promise on a pro forma basis:

- Configuration 1 with onsite production of denatured fuel ethanol, pelletized densified biomass, and nutraceutical extract. Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was determined to be 3.99x and the pre-tax internal rate of return on equity was determined to be 19.2 percent.
- Configuration 2 with onsite production of dilute sugar juice (20 percent), livestock forage, and separated stalk dermal layer. Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was forecast to be 4.12x and the pre- tax internal rate of return to equity was forecast to be 25.4 percent.

From a risk perspective, Configuration 2 might be preferred because the capital outlay is significantly less, and the products are intermediates that expand market choices. However, configuration 2 also relies on downstream processes which may be provided by unrelated business entities, adding commercial risk. Further, there may at times be an economic advantage to producing ethanol rather than allowing another entity to produce and sell the associated RINs. Finally, there may be other feed stocks available for processing at the facility during times when sweet sorghum is not in season to produce ethanol and nutraceutical extracts. Configuration 1 allows the facilities to take advantage of opportunistic feed stocks that may be available near a sited facility. For all configurations, positive economics rely on using the dermax to produce high value nutritional supplements. The use of dermax to produce dietary supplements relies on a market that does not yet exist and product pricing for which there is no direct history.

CHAPTER 8: Summary

Great Valley Energy has evaluated the feasibility of producing ethanol and value-added products from purpose-grown sweet sorghum in the San Joaquin Valley. Beginning in the winter of 2011 and supported in part by funding from the CEC, Great Valley Energy cultivated several commercially-available varieties of sweet sorghum over three growing seasons; constructed and operated a pilot demonstration plant in Bakersfield; collected crop characteristics and technical data to support engineering design; evaluated and engineered multiple biorefinery configurations; analyzed markets around various configuration products; developed a greenhouse gas profile around the configurations; and determined technical and economic feasibility.

Sweet Sorghum Production in the San Joaquin Valley

In 2011, Great Valley Energy cultivated 5 varieties of sweet sorghum in California in Bakersfield, Five Points, and Lemoore. In 2012, Great Valley Energy contracted with Blackwell Land Company under typical commercial conditions to grow sweet sorghum in Lost Hills. For the 2012 cultivation, 5 varieties were grown – three proprietary and two publicly-available.

Each variety was planted on two different planting dates, and regular harvests occurred on 4 separate occasions from 117 to 160 days after planting.

Production of total green biomass ranged from 27 to 76 tons per acre with average production confidently established for pro forma purposes at 45 tons per acre of total green biomass (including seed heads and leaves). Stalks comprise approximately 80 percent of biomass weight, or 36 tons per acre. The rest of the biomass is leaves and seed heads, approximately 17 and 3 percent respectively. Although sweet sorghum has been shown to be definitively superior to other crops when subjected to drought or nutrient deficiency, a robust crop can be cultivated in the San Joaquin Valley using sustainable best management practices.

For purposes of the feasibility study, Great Valley Energy settled on a pro forma approach based on the following assumptions:

- Contract farming using a heterogeneous monthly pricing system on a per acre basis,
- Contract harvesting and hauling on a per ton billet basis,
- Set contract price for each month – August, September, October and November, and
- Adjustment at the plant gate based on quality of crop delivered.

Based on a 50 ton per hour project (36,500 tons per month) and 10 percent sugar content, a plant gate price for billets of sweet sorghum was modeled at $46.61 per ton.

Process Characteristics of Sorghum Fractions

Prior to Great Valley Energy's pilot demonstration plant, the KTC Tilby System for fractionation of cane had been demonstrated to operate successfully on sugar cane. Though sweet sorghum was found to have characteristics quite different from sugar cane, the pilot demonstration plant proved that the Tilby technology could be used to successfully fractionate sweet sorghum into the dermal layer, the structural layer, and the sugar-juice bearing inner pith. Further processing in the pilot demonstration plant successfully separated wax and bioactive extract from the dermal layer, and separated sugar juice from the pith.

Crop cultivation and pilot plant operation resulted in an unparalleled database of sweet sorghum characteristics along with a solid understanding of fraction yields, moisture contents and chemical constituents. Yield and moisture content were determined in detail across a matrix of five varieties, two planting dates, and four harvests for each planting date. Each fraction was further subjected to laboratory characterization of the physical and chemical properties, particularly those variables which impact engineering and operations as well as determine potential product markets.

More than 95 percent of the sugar juice in sweet sorghum can be separated and fermented to produce fuel ethanol, either directly or as a supplement to a grain ethanol production facility. The sugar juice can also be used as a sweetener in beverages or similar markets. Separation of the sugar juice results in an initial dilution, while the pasteurization and concentration process operation drive off water and increases the sugar content in the juice. Although pasteurization and careful sanitary practices can result in a relatively stable dilute sugar juice, a short shelf life is expected. However, if the sugar juice can be concentrated to at least 60 degrees Brix (60 percent sugar by weight), the resulting syrup is stable with little to no degradation over several years.

Subsequent dilution would permit the syrup to be used at any existing grain ethanol facility.

More than 90 percent of the dermal layer from sweet sorghum can be separated and processed in a sophisticated pharmaceutical-based extraction process operation. The resulting extract has been shown to contain antioxidant and bioactive properties that could be interesting to the dietary supplement market. However, such market does not currently exist and represents a limit to the overall feasibility of a commercial project given pro forma reliance on nutraceutical revenue. Furthermore, the market for such nutraceutical product also represents a constraint on the ability to deploy more than one commercial project which includes the Tilby system. Of note, the nutraceutical extract process renders wax recovery infeasible while the leftover biomass from the process can be combined with other biomass for downstream products.

The balance of biomass – washed comrind, washed and pressed comfith, and processed dermax– can be used in a variety of products. The ash content of the biomass is a potentially limiting factor (price-wise) in the fuel pellet markets. However, the biomass can be successfully formed into stable pellets for use as fuel or for livestock bedding. Biomass moisture content is considerable at 50 to 70 percent, depending on fraction and process, and requires drying before product manufacture.

Value-Added Processing of Sorghum Fractions

GVE contracted with Harris Group to provide engineering support and develop capital cost estimates for a demonstration-scale base sorghum processing facility with a capacity to process 10-TPH of sweet sorghum into a concentrated sugar solution, dermax extract, and biomass pellets. Harris Group also developed capital cost estimates for a base sorghum processing facility processing 50-TPH of sorghum to the same products. In addition to these intermediates and products, GVE evaluated a variety of other value-added process options, including:

- Addition of an ethanol facility onto the base sorghum processing facility for direct production of ethanol from the concentrated sugar solution;
- An ethanol facility that used both the sugar solution and the cellulosic fibrous material to produce ethanol in lieu of pellet production;
- A thermocatalytic process to convert comfith and comrind to drop-in fuels;
- A base sorghum processing facility that would "bolt-on" to an existing grain ethanol facility;
- Production of engineered wood products from biomass; and
- Using comfith and comrind for production of electricity and process heat on site.

Two of these scenarios were deemed to be premature – the production of ethanol from cellulosic fibrous material and the thermocatalytic process to produce drop-in biofuels. The balance of the process options was evaluated and subsequently condensed into three mutually- exclusive configurations for pro forma economic modeling and greenhouse gas considerations.

Optimized Configurations for Economics and Low Carbon Fuels

Great Valley Energy explored multiple biorefinery plant configurations to determine best economic potential for a commercial project. Three configurations designed around a 50 ton per hour base sorghum processing facility were treated to a full pro forma economic analysis and are summarized as follows:

- Configuration 1: onsite production of denatured fuel ethanol, pelletized densified biomass, and nutraceutical extract. Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was determined to be 3.99x and the pre-tax internal rate of return on equity was determined to be 19.2 percent.
- Configuration 2: onsite production of dilute sugar juice (20 percent), livestock forage, and separated stalk dermal layer. Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was forecast to be 4.12x and the pre- tax internal rate of return to equity was forecast to be 25.4 percent.
- Configuration 3: onsite production of concentrated sugar juice (60 percent), construction materials (oriented-strand board), and separated stalk dermal layer for offsite nutraceutical production. An onsite combined heat and power project was included in this configuration. Under assumed conditions and over the first 10 years of operation, the average debt service coverage ratio was forecast to be 1.84x and the pre-tax internal rate of return to equity was forecast to be -2.7 percent.

Configuration 3 was ultimately determined to be infeasible economically. From a risk perspective and with initial observation, Configuration 2 might be preferred because the capital outlay is significantly less, and the products are intermediates that expand market choices. However, Configuration 2 also relies on downstream processes which may be provided by unrelated business entities, adding commercial risk. Further, there may at times be an economic advantage to producing ethanol rather than allowing another entity to produce and sell the associated RINs. Finally, there may be other feed stocks available for processing at the facility during times when sweet sorghum is not in season to produce ethanol and nutraceutical extracts. Configuration 1 provides the facilities to take advantage of opportunistic feed stocks that may be available near a sited facility.

Considering greenhouse gas emissions and life cycle analysis, a key determination made in this feasibility study is that the cultivation of sweet sorghum results in a lower carbon intensity than the cultivation of corn for production of grain ethanol. For all three configurations, the sorghum farming and ethanol are the same and the main variations in GHG intensity were in the sorghum processing and the saleable by-products from the process. The sorghum processing emissions in Configuration 2 and Configuration 3 are 84 percent and 42 percent less than Configuration 1, respectively. However, as noted in Section 6 of this report, results of Configuration 1 GHG intensity are higher than anticipated because the marketplace for the bioactive compound co-product has not been developed and thus, there is not a corresponding product credit for displaced market product.

The results from Configuration 2 are similar to those of the CARB corn ethanol pathway. Corn ethanol has higher fertilizer and farming emissions while the sorghum pathways require additional energy and emissions for pre-ethanol processing of the sorghum. Based on preliminary modeling, the use of combined heat and power would provide significant reductions for the sorghum processing stage. Reductions in GHG intensity as high as 70 percent from Configuration 1 results are possible which would result in 55 percent GHG intensity reductions from the GHG intensity of California gasoline blend stock.

Project Development Steps

Based on the relatively high financial returns, lower greenhouse gas emissions, and commercial stability, configuration 1 is a reasonable scenario to evaluate a project development plan. The plan focuses on the main areas of feedstock supply, site development and engineering, offtake agreements, and financing. Each of these is critical to project success and the first three are often conditions precedent to success in the fourth.

Feedstock Supply

The continual growth and harvest of sorghum over the annual operating period presents scheduling and logistical challenges as over 5000 acres is brought under contract to supply the facility. Harvesting and transport will be tightly controlled during this process such that the facility controls day to day operations. Crop cultivation will need to be completed on a contract basis, with written agreements addressing payment terms, cost allocations, crop risks, and mutual delineation of responsibilities. Planting will continue from spring to early summer, so there is a possibility that land may be unproductive for a number of months awaiting the staged planting.

Offtake Agreements

The facility will produce fuel ethanol, densified biomass, and nutraceutical powder. Agreements for purchase and sale of each of these products will be needed. Counterparties to these agreements will need to be reliable and have credible balance sheets such that payment is assured. Both fuel ethanol and densified biomass may be marketed through brokers, but the fuel ethanol may have enough demand in the marketplace as an advanced biofuel to be marketed directly to fuel blenders.

The nutraceutical powder market will need to be fully established. As this market represents the biggest commercial risk associated with the project due to the project's heavy reliance on income from nutraceuticals, this agreement is the linchpin to the entire plan. As such, executing a marketing plan for nutraceuticals is the first critical gate of the development phase. This step will require a small-scale manufacturing trial in order to produce marketable product for further research and testing.

Site Development and Engineering

Once feedstock supply and product offtake agreements are well underway, a site can be identified. The site will need good access to natural gas and electricity, but more importantly, it needs to be very nearby growers, so transportation costs of the feedstock are minimized. Good road access is also a criterion due to the number of materials moved by truck. Concurrent with this stage, any land use or other potentially long lead permitting items are addressed with various agencies.

With the site identified, detailed engineering can be completed. This would be performed by a design firm that would develop a design package. Typically, a firm separate from the design firm may complete engineering, procurement and construction of the facility. An engineering, procurement and construction contractor may be able to provide performance guarantees for the facility. As a first of its kind, a performance guarantee may not be available.

Project Financing

With these first three steps complete or well underway, it is possible to proceed to project financing. We have identified the routes of debt, equity and grant funding in the pro forma in Chapter 7. Debt financing may be available using a loan guarantee available from several government agencies under for this project. For example, certain aspects of this project may fit under programs offered by the CEC, California Department of Food and Agriculture, US Department of Agriculture or US Department of Energy. These agencies are also sources of grant funding under various programs such as the one that funded this project, Assembly Bill 118. Several of these programs have requirements for match funding which may be met with extra-agency grant funds or with equity. Equity funding, with each of the above project pieces in place will involve matching a potential investor's risk/return profile to the project. Once the risk/return is better understood, after completing feedstock supply, product offtake, site development and with commitments for debt and grant financing, an equity broker or the project developers own contacts may be able to help supply equity. Another source for equity is also companies providing feedstock or product supply.

Recommendations

Based on the feasibility study and the conclusions drawn here, Great Valley Energy has the following recommendations, in order of execution priority, which could lead to the increased production of sweet sorghum, low-carbon fuels in California:

- Initiate market development activities for nutritional supplements made from sorghum dermal layer. These development activities will include producing a significant quantity of dermal layer and subsequent extraction and packaging at suitable facilities. Further a research, testing and marketing plan will need to be developed and executed to facilitate market development.

- Develop one commercial plant (50-TPH) in the San Joaquin Valley based on Configuration 1 (onsite ethanol, pellet, and nutraceutical production).
- Develop one commercial plant (50-TPH) in the San Joaquin Valley, adjacent to an existing grain ethanol plant, based on Configuration 2 but excluding the Tilby fractionation system.
- Conduct advanced studies on sweet sorghum varieties and cultivation practices leading to a variety that has high sugar content; supports an extended growing season; and is more resistant to lodging, drought, disease.
- Develop add-on market opportunities for the commercial plants - from feedstock through intermediates and products - that will extend the operating window of each commercial plant beyond the growing season for sweet sorghum as sole feedstock.

GLOSSARY

BRITISH THERMAL UNIT (Btu) – The standard measure of heat energy. It takes one Btu to raise the temperature of one pound of water by one degree Fahrenheit at sea level. MMBtu stands for one million Btu.

BRIX SCALE—a hydrometer scale for sugar solutions so graduated that its readings at a specified temperature represent percentages by weight of sugar in the solution- also called Brix.[34]

CALIFORNIA AIR RESOURCES BOARD (CARB)—The "clean air agency" in the government of California whose main goals include attaining and maintaining healthy air quality, protecting the public from exposure to toxic air contaminants, and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies

Funding for the Commission's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account and other sources.

CARBON DIOXIDE EQUIVALENT (CO2e)—A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by its global warming potential.

CALIFORNIA GREET (CA-GREET)—The original Argonne model was modified to include California specific values and factors and this model, the CA-GREET model was published on the Low Carbon Fuel Standard February 2009.[35]

CARBON INTENSITY (CI)—The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity

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[34] Merriam-Webster Dictionary (https://www.merriam-webster.com/dictionary/Brix%20scale)

[35] California Air Resources Board California Modified GREET

(https://ww3.arb.ca.gov/fuels/lcfs/072009lcfs_sugarcane_etoh.pdf) and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

COMFITH—Comfith is the soft pithy interior of the stalk that consists of the softer inner core fiber containing all of the high purity sugar bearing juice and virtually all the pith cells are fractured in the separation process.1

COMFLO—Comflo is the sugar extracted from the comfit that conists of all of the high purity juice efficiently extracted from the comfit fiber and none of the impurities associated with crushed cane juice.1

COMRIND—Comrind is the hard, wood like outer section of the stalk that consists of all the structural fiber.1

DERMAX—Dermax is the thing outer epidermal layer of the stalk that consist of all of: the abrasive mill wearing silica; dirt, color, that contriubye to the formation of molasses; all of the natural wax; and all of the valuable bioactive compounds.1

GREENHOUSE GASES (GHG)—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TRANSPORTATION (GREET®)—A full lifecycle model sponsored by the Argonne National Laboratory (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy). GREET® fully evaluates energy and emission impacts of advanced and new transportation fuels, the fuel cycle from well to wheel, and the vehicle cycle through material recovery and vehicle disposal. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

INTERNAL RATE OF RETURN (IRR)—A measurement of an investment's rate of return.[36]

KILOWATT-HOUR (kWh)—The most commonly used unit of measure telling the amount of electricity consumed over time, means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumed 534 kWh in an average month.

LIFECYCLE ANALYSIS (LCA)—A tool that can be used to evaluate the potential environmental impacts of a product, material, process, or activity. An LCA is a comprehensive method for assessing a range of environmental impacts across the full life cycle of a product system, from materials acquisition to manufacturing, use, and final disposition.

LOW CARBON FUEL STANDARD (LCFS)—A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and therefore reduce greenhouse gas emissions. The LCFS standards are expressed in terms of the carbon intensity of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of

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[36] Wikipedia Internal Rate of Return (https://en.wikipedia.org/wiki/Internal_rate_of_return)

a comprehensive set of programs in California that aim cut greenhouse gas emissions and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.

MEGAJOULE (MJ)—A joule is a unit of work or energy equal to the amount of work done when the point of application of force of one newton is displaced one meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about one million joules to make a pot of coffee. A megajoule itself totals one million joules.

MEGAWATT (MW)—A unit of power, equal to one million watts.[37]

MEGAWATT HOUR (MWh)—One-thousand kilowatt-hours, or an amount of electrical energy that would supply 1,370 typical homes in the Western U.S. for one month. (This is a rounding up to 8,760 kWh/year per home based on an average of 8,549 kWh used per household per year.)

METRIC TON—A unit of mass equal to 1,000 kilograms.

NATIONAL RENEWABLE ENERGY LABORATORY (NREL)—The United States' primary laboratory for renewable energy and energy efficiency research and development. NREL is the only Federal laboratory dedicated to the research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. Located in Golden, Colorado.[38]

PACIFIC GAS AND ELECTRIC COMPANY (PG&E)—An electric and natural gas utility serving the central and northern California region.

RENEWABLE IDENTIFICATION NUMBER (RIN)—The U.S. EPA uses Renewable Identification Numbers (RINs) to track renewable transportation fuels. The RIN system allows the U.S. EPA to monitor compliance with the Renewable Fuel Standard, a federal program that requires transportation fuels sold in the United States to contain minimum volumes of renewable fuels.[39]

TONS PER HOUR (TPH)—Abbreviation used to specify the capacity of industrial machinery.[40]

UNITED STATES DEPARTMENT OF ENERGY (U.S. DOE)—The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA)—A federal agency created in 1970 to permit coordinated governmental action for protection of the environment

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[37] Megawatt Definition (https://www.dictionary.com/browse/megawatt)

[38] Encyclopedia Britannica (https://www.britannica.com/technology/cathode)

[39] U.S. DOE Glossary (https://afdc.energy.gov/laws/RIN)

[40] Wikipedia Tons per Hour (https://en.wikipedia.org/wiki/Tph)

by systematic abatement and control of pollution through integration or research, monitoring, standards setting, and enforcement activities.

UNIVERSITY OF CALIFORNIA, DAVIS (UC Davis)—A public research university located in Davis, California. It is one of the 10 campuses in the University of California (UC) system.

WEIGHT (WT)—The amount or quantity of heaviness or mass; amount a thing weighs.[41]

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[41] Weight Definition (https://www.dictionary.com/browse/weight)