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California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

California Low Carbon Ethanol Feedstock Program: Pacific Ethanol

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology 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-13-601to fund advanced biofuel production facilities. In response to PON-13-601, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards on December 16, 2014. The agreement was executed as ARV-14-026 on March 9, 2015 in the amount of $3 million. Pacific Ethanol pledged a $20 million match.

ABSTRACT

Pacific Ethanol implemented the California Low Carbon Ethanol Feedstock Program in collaboration with Aemetis and Calgren, and with implementation support from Chromatin, Inc., Penny Newman, the A.L. Gilbert Company, and JD Heiskell. This program was a transformative feedstock development initiative to assist the state's major ethanol producers in increasing feedstock flexibility to meet both the renewable fuel and greenhouse gas reduction goals stipulated under the federal Renewable Fuel Standard and the state Low Carbon Fuel Standard. The purpose of the project was to initiate sorghum feedstock incentive premiums; carbon intensity reduction for ethanol; the California In-State Sorghum Initiative to bolster sorghum production in California; and California Air Resources Board certification to validate carbon intensity reduction achieved by the project. Pacific Ethanol successfully converted over 56,000 tons of sorghum sourced from the US Midwest into ethanol (at a 30/70 blend of sorghum/corn feedstocks) at their existing ethanol production facility in Stockton, California and produced a total of 5.7 million gallons of sorghum-based ethanol with a carbon intensity value of 76.1 g CO_2e/MJ and reduced CO_2e greenhouse gas emissions by over 9,600 metric tons. Sorghum processing yielded no significant difference in ethanol quality in comparison to corn-based ethanol. The project also successfully completed sorghum grain trials that achieved yields exceeding 6,800 lbs/acre, demonstrated that sorghum can reach reasonable yields even under reduced water application, and brokered the production of sorghum on 1,400 acres in California—the largest in-state annual sorghum production in over 30 years.

Keywords: California Energy Commission, ethanol, sorghum, corn ethanol, sorghum ethanol, carbon intensity, in-state production, feedstock flexibility.

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Introduction

Pacific Ethanol implemented the California Low Carbon Ethanol Feedstock Program with partner ethanol producers Aemetis and Calgren, and in collaboration with Chromatin, Inc., Penny Newman, the A.L. Gilbert Company, and JD Heiskell. This program sought to be a transformative feedstock development initiative to assist the state's major ethanol producers in increasing feedstock flexibility to meet both the renewable fuel and greenhouse gas reduction goals stipulated under the federal Renewable Fuel Standard and the state Low Carbon Fuel Standard. The California Low Carbon Ethanol Feedstock Program was designed and implemented by California's three largest ethanol producers and implemented in collaboration with the CEC and California Air Resources Board.

The California Low Carbon Ethanol Feedstock Program project implemented two key mechanisms to achieve its goal of transformative feedstock development. First, the project sought to provide a partial incentive payment for low-carbon grain sorghum processed by Pacific Ethanol and its California Low Carbon Ethanol Feedstock Program partners. Incentive payments were designed to be used to purchase low-carbon feedstock, install new technologies to support sorghum use, and adopt processes to further reduce carbon intensity value. Second, the project team implemented the California In-State Sorghum Initiative, an innovative partnership that was intended to substantially expand the availability of low-carbon grain sorghum grown in California by investing in a two-year program of outreach, education, and research in California's agricultural and farming communities.

Project Purpose

The purpose of the California Low Carbon Ethanol Feedstock Program was for California ethanol producers to attract grain sorghum to California for ethanol and feed markets, demonstrate sustainable demand for using grain sorghum as a non-corn feedstock for ethanol and feed production, and to encourage local production of grain sorghum for long-term sustainable use for low-carbon ethanol production and feed for local dairies and feedlots.

Project Implementation

Pacific Ethanol sought to implement the California Low Carbon Ethanol Feedstock Program through the following mechanisms:

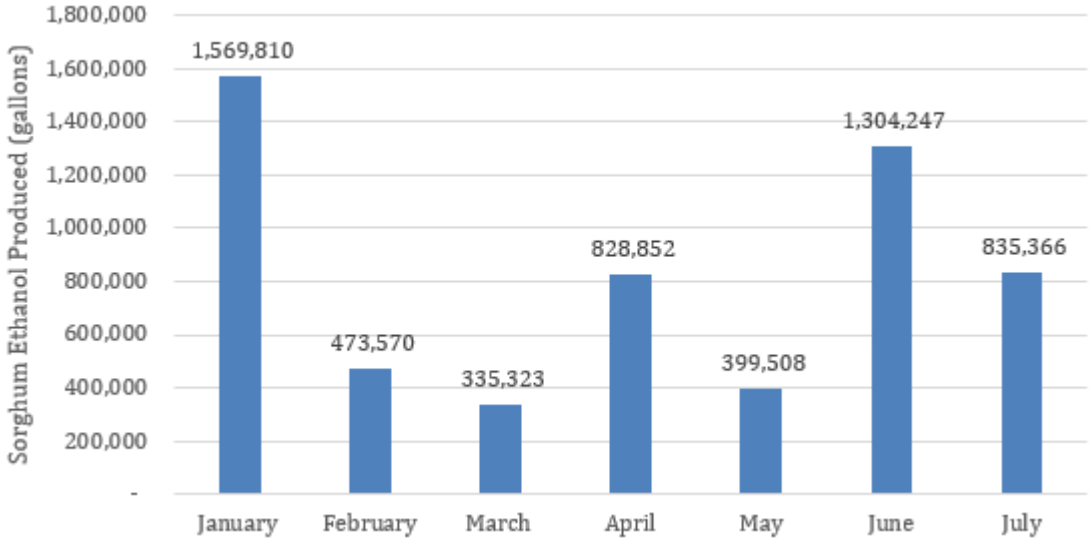
1. **Sorghum Feedstock Incentive Premiums** designed to help offset purchase costs of sorghum feedstock;
2. **Carbon Intensity Reduction Program Implementation** wherein Pacific Ethanol sought to implement systems and processes at its existing ethanol production facility to reduce carbon intensity. These measures included installation of feedstock grinding technology, selective catalytic reduction to eliminate the need for low-NO_x burners, boiler blowdown heat recovery, and cogeneration, as well as capital improvements to receive, store and manage sorghum feedstock, and other capital investments.

3. **The California In-State Sorghum Initiative**, designed to bolster production of sorghum in California.
4. **California Air Resources Board Verification.** Pacific Ethanol proposed to use California Air Resources Board reporting requirements to provide CEC with a regular verification protocol to validate carbon intensity reduction from sorghum feedstock, new technologies and new processes, and benefits of the California In-State Sorghum Initiative.

Project Results

The project successfully demonstrated that production of ethanol from sorghum is technologically feasible under California conditions. Specifically, Pacific Ethanol successfully converted 56.5 tons of sorghum into more than 5.7 million gallons of sorghum-based ethanol over the course of the project (Figure ES-1, Table ES-1). Product fuel carried a carbon intensity value of 76.1 g CO_2e/MJ in comparison to the project's 80.7 g CO_2e/MJ baseline from 2013, equivalent to a 5.7 percent reduction that slightly exceeded the project's targeted reduction of at least 5 percent. Lower than anticipated sorghum processing volumes due to unanticipated economic conditions and unexpected changes in the carbon intensity value of corn resulted in a net greenhouse gas emissions offset of over 9,600 metric tonnes, which was less than expected (Table ES-1). Nonetheless, the product fuel generated from a 30/70 blend of sorghum/corn by Pacific Ethanol was of sufficient quality to meet all specifications, with no noticeable difference in quality as compared to corn-based ethanol. Additionally, facility air emissions did not change during the transition to sorghum-based ethanol. Sorghum processing at Pacific Ethanol's facility did lead to increased wear and tear on the plant, resulting in elevated maintenance costs for select components.

Figure ES-1: Gallons of Sorghum-Based Ethanol Produced by Pacific Ethanol (2016)



Source: Pacific Ethanol

In comparison to corn, which has been highly developed, sorghum as a crop is less consistent in its quality and can have a lower starch content in some cases. The sorghum processed under the project was variable in quality, with some deliveries received that were clearly of lesser quality. Sorghum pricing also led to challenges during project implementation, with high prices impacting the feasibility of sorghum-based ethanol production. Unanticipated changes in carbon intensity handed down by the California Air Resources Board in 2016 dealt a significant blow to the project, resulting in carbon intensity scores that are approximately 7.5 points above that of corn ethanol. This change greatly hampered the team's ability to fully implement the project; instead of having a lower carbon intensity and lower costs than corn, sorghum costs and carbon intensity value changed to be higher than corn.

Table ES-1: Summary of Project Targets

Category	Target Amount	Actual Amount
Sorghum Production Objective	89,082 tons	56,657 tons
Volume of primarily sorghum-based ethanol	8.6 million gallons	5.7 million gallons
CI Reduction	5% or greater (76.6 gCO_2e/MJ or less)	Ethanol from Midwest sorghum pathway: 76.1 g CO_2e/MJ (5.7% reduction)
Greenhouse Gas Emissions Displacement from Sorghum	23,765 MT	9,677 MT (actual)

Source: Pacific Ethanol

Agricultural trials of sorghum were, however, resoundingly successful. Sorghum grain trials achieved yields exceeding 6,800 lbs/acre and demonstrated that sorghum can reach reasonable yields even under reduced water application. The project also successfully completed sorghum related outreach and brokered the production of sorghum on 1,400 acres in California—the largest in-state annual sorghum production in over 30 years.

Benefits to California

The project has made meaningful progress toward supporting the development of sorghum as a crop in California, and has produced useful data that can be used by other ethanol producers considering the use of sorghum as feedstock. With product ethanol being found to carry consistent quality equivalent to that of corn ethanol, the project has also helped to establish sorghum as an alternative feedstock to corn for ethanol production in California, providing in-state ethanol producers with a new alternative to corn should corn feedstock become unfavorable.

Project outreach to help further develop in-state sorghum markets included distribution of marketing materials, outreach phone calls, emails, and direct communications with individuals

and farmers regarding the benefits of planting sorghum. The project team also developed a keystone cost/benefit assessment that compares grain sorghum production to production of corn—a crop with which many farmers are familiar. Grain sorghum estimated to have the potential to generate a net margin of $400.96 per acre, in comparison to $161.84 for conventional corn, demonstrating potential viability of the crop. In spite of these results, many California farmers have multiple other cropping options available to them, many of which are higher value than corn or sorghum production. As a result, farming economics for sorghum remain a meaningful barrier to further development of in-state sorghum markets.

CHAPTER 1: Introduction

Project Overview

Pacific Ethanol implemented the California Low Carbon Ethanol Feedstock Program (CALCEF) in partnership with Aemetis and Calgren, and with implementation support from Chromatin, Inc., Penny Newman, the A.L. Gilbert Company, and JD Heiskell. This program was designed to be a transformative feedstock development initiative to assist the state's major ethanol producers in increasing feedstock flexibility to meet both the renewable fuel and greenhouse gas reduction goals stipulated under the federal Renewable Fuel Standard (RFS) and the state Low Carbon Fuel Standard (LCFS). CALCEF was designed and implemented by California's three largest ethanol producers, and implemented in collaboration with the CEC and the California Air Resources Board (ARB).

The CALCEF project implemented two key mechanisms to achieve its goal of transformative feedstock development. First, the project sought to provide a partial incentive payment for low-carbon grain sorghum processed by Pacific Ethanol and its CALCEF program partners. Incentive payments were designed to be used to purchase low carbon feedstock, install new technologies to support sorghum use, and adopt processes to further reduce carbon intensity (CI) value. Specific actions included:

- Increasing transport and in-state growing capacity of grain sorghum for fuel use;
- Procuring low carbon processing energy such as biogas and renewable electricity to reduce carbon intensity in the near-term;
- Implementing capital improvements to receive, store, and manage grain sorghum feedstock; and
- Installing various capital improvements to provide long-term carbon intensity reduction at facilities.

Second, Pacific Ethanol and its CALCEF partners collectively implemented the California In-State Sorghum Initiative an innovative partnership that was intended to substantially expand the availability of low-carbon grain sorghum grown in California, by investing in a two-year program of outreach, education and research in California's agricultural and farming community.

Project Goals

The project sought to rapidly increase the production of in-state, low carbon ethanol in order to meet the requirements of the RFS and LCFS, while simultaneously establishing a framework for the long-term development of a sorghum market in California. As a result, the project was

designed to benefit farmers, producers, and consumers, while helping to meet statutory requirements related to renewable fuels.

The purpose of the CALCEF Program is for California ethanol producers to attract grain sorghum to California for ethanol and feed markets, demonstrate sustainable demand for using grain sorghum as a non-corn feedstock for ethanol and feed production, and to encourage local production of grain sorghum for long term sustainable use for low carbon ethanol production and feed for local dairies and feedlots. These efforts collectively targeted the central goal of the project, which was to produce ethanol having a significantly lower CI value than that of corn-based ethanol.

Project Objectives

The CEC sought to fund Pacific Ethanol to a maximum amount of $3,088,912 to implement CALCEF, with match funding from Pacific Ethanol of up to $18,919,643. These amounts were estimated to be sufficient to support a production objective of 89,082 tons of sorghum to produce approximately 8.6 million gallons of primarily sorghum-based ethanol. The project was further anticipated to produce sorghum ethanol with at least a 5 percent CI reduction from the baseline of 80.7 gCO_2e/MJ to 76.6 gCO_2e/MJ, while developing an expanded and more vibrant marketplace for in-state sorghum to support future low carbon ethanol production. Finally, based on the anticipated CI reduction and fuels production rate, the project was anticipated to displace at least 23,765 MT of additional greenhouse gas (GHG) emissions from sorghum-based ethanol produced at Pacific Ethanol's Stockton facility during the project (Table 1).

Table 1: Summary of Project Targets

Category	Target Amount
Sorghum Production Objective	89,082 tons
Volume of primarily sorghum-based ethanol	8.6 million gallons
CI Reduction	5% or greater (76.6 gCO_2e/MJ or less)
GHG Emissions Displacement from Sorghum	23,765 MT

Source: Pacific Ethanol

Chapter 2:
The Potential for Sorghum as an Ethanol Feedstock

Recipient Background

Pacific Ethanol, Inc. is the leading producer and marketer of low carbon renewable fuels in the Western United States. The company owns and operates 200 MGY of ethanol production in the Western US and 410 MGY in the Midwest. Its subsidiary, Kinergy Marketing, sells to downstream fuel blending customers, comprised of major oil companies and independent blenders. The company produces and sells low carbon ethanol to gasoline marketers, which include major oil companies and independent producers and marketers of gasoline. Pacific Ethanol Stockton ("PES") is an operating 60 MGY corn ethanol plant located in Stockton, CA.

Pacific Ethanol's differentiated business strategy centers on the local markets for the production of ethanol, feed, and other co-products. Ethanol is sold to blenders of gasoline near the production facilities and the primary feed product, Wet Distillers Grain (WDG), is sold locally to dairies and feedlots. Avoiding an expensive drying process gives PES a lower CI value compared to most all other ethanol production facilities in the United States.

California Renewable Fuels

California's Low Carbon Fuel Standard program is implemented by the California Air Resources Board. The LCFS is designed to encourage the production of cleaner, low-carbon fuels in state, and thereby reduce the CI of California's transportation fuel pool. The LCFS is performance-based and fuel-neutral, allowing market factors to determine many factors regarding clean fuels implementation. The project sought to directly support the LCFS program by producing up to 8.6 million gallons of primarily sorghum-based ethanol with a target CI value of 76.6 gCO_2e/MJ. Simultaneously, the project also helped Pacific Ethanol to operate within the caps for corn-based ethanol production under the national Renewable Fuels Standard (RFS) program, producing ethanol that simultaneously meets both state and federal mandates.

Need for the Project

By implementing the CALCEF program, Pacific Ethanol sought to contribute to California's in-state production of low carbon biofuel, particularly in terms of build-out potential of technology and processes to meet the state's future aggregated demand for ethanol. To meet that demand, and the goals outlined by LCFS as noted above, California must increase production of biofuels, emphasizing those fuels capable of the greatest reduction below the current baseline CI. To date, ethanol constitutes the largest volume—219 MGY—of in-state produced biofuels, mainly from corn. Corn ethanol from dedicated energy crops carries certain limitations with respect to reductions in CI value under current CI accounting structures. By substituting a portion of incoming corn feedstock with an alternative having a lower CI value,

the project carries the potential to reduce net GHG emissions. The project sought to achieve these reductions while facilitating increase in biofuels production overall, while avoiding a regulatory cap on corn-based ethanol production at 15 billion gallons per year under the RFS.

Project Purpose

The purpose of the CALCEF Program was for California ethanol producers to attract grain sorghum to California for ethanol and feed markets, demonstrate sustainable demand for using grain sorghum as a non-corn feedstock for ethanol and feed production, and to encourage local production of grain sorghum for long term sustainable use for low carbon ethanol production and feed for local dairies and feedlots.

Project Benefits

Funding for the CALCEF Program was intended to leverage the procurement of an unprecedented tonnage of lower carbon sorghum feedstock, supporting the development of a domestic sorghum market, and furthering investment in new technologies and processes that would otherwise been unavailable are not cost effective to adopt and implement without benefit of the proposed public-private partnership. The project was designed to achieve the following specific benefits:

- **Carbon Intensity and GHG Emissions Reduction.** Prior to implementation of the project, the Pacific Ethanol Stockton Facility produced 60 MGPY of corn ethanol with a carbon intensity (CI) of 80.7 gCO_2e/MJ.[1] In its proposal for this project, Pacific Ethanol estimated that the completed project would reduce the Pacific Ethanol Facility's CI value to 76.6 gCO_2e/MJ, resulting in a CI reduction of 4.04 gCO_2e/MJ, equivalent to a 5 percent reduction, reducing carbon emissions by 23,765 MT/yr.
- **Sorghum Benefits.** When LCFS was created, it was anticipated that the state's capacity to produce and distribute lower-carbon biofuels would be greater than it currently is. Unfortunately, economic factors (the Great Recession as well as high capital costs) along with technological barriers hampered California's efforts to produce significant volumes of ethanol from advanced feedstock sources. The project envisioned increased sorghum-based ethanol generation as a potentially viable solution to producing lower-carbon, next-generation biofuels.

Immediately prior to the initiation of the project, sorghum was grown in very small quantities in California, even though it had been successfully used inside and outside of California for ethanol production as an alternative to corn feedstocks. In comparison to corn, grain sorghum carries several potential benefits. It requires substantially less water and fertilizer, is more drought tolerant, and grows to maturity in less than four months—permitting multiple crops

1 The Stockton facility's CI was 80.7 g CO_2e/MJ prior to project implementation, before the California ARB updated its pathways in 2016. The Stockton facility currently has an ARB-approved pathway of 70.1 g CO_2e/MJ.

per year in certain climates. Finally, grain sorghum is not a staple within the U.S. food supply, thus, using it for ethanol production would reduce potential to cause any adverse domestic food supply distortions.

- **Feedstock Flexibility.** In comparison to producing ethanol solely from corn, further developing Pacific Ethanol's ability to utilize sorghum for ethanol production has the potential to support increased feedstock flexibility. Commodity prices for corn have historically resulted in wide swings in both baseline cost of ethanol production and the profitability (or even economic viability) of California's ethanol producers. Development of sorghum as an additional feedstock for ethanol production provides California's ethanol producers with increased ability to adapt to changing commodity prices when making feedstock purchases. Feedstock flexibility also has the potential to help increase use of feedstock produced in-state rather than imported, and provides additional flexibility when seeking to reduce CI of produced ethanol.
- **Education and Outreach.** The project sought to initiate development of sorghum as a viable ethanol feedstock alternative to corn in part through sorghum-oriented education and outreach, combined with research and development. Education and outreach related benefits were targeted through a dedicated education and awareness program for sorghum in California. Herein, the project sought to educate farmers on producing and selling sorghum grain for ethanol production, as well as advances in sorghum production and related benefits identified under the project.
- **Sorghum Production in California.** The sorghum market in California has been historically very limited. Development of sorghum as a viable energy crop in-state has the potential to greatly benefit farmers, including during dry years when reduced water supplies are available. Therefore, increased sorghum production in-state carries strong potential to benefit ethanol producers, support state statutory energy goals, and also support continued economic benefit to California's agricultural industry.

CHAPTER 3:
Project Approach

CALCEF Implementation Strategy

Pacific Ethanol implemented the CALCEF program through the following mechanisms:

1. **Sorghum Feedstock Incentive Premiums** designed to help offset purchase costs of sorghum feedstock;
2. **CI Reduction Program Implementation** wherein Aemetis implemented systems and processes at its existing ethanol production facility to reduce CI, including in-state transport and feedstock acquisition, enhanced processing, capital improvements to receive, store and manage sorghum feedstock, and other capital investments.
3. **The California In-State Sorghum (CISS) Initiative**, designed to bolster production of sorghum in California.
4. **California ARB Verification.** Aemetis proposed to use California ARB reporting requirements to provide CEC with a regular verification protocol to validate CI reduction from sorghum feedstock, new technologies and new processes, and benefits of the CISS Program.

The following discussion summarizes provides additional details on each strategy deployed under the project.

Sorghum Feedstock Incentive Premiums

Under the project, the CEC provided a partial incentive payment for each ton of low-carbon grain sorghum purchased by Pacific Ethanol and its CALCEF program partners. The incentive premiums were designed to directly support the transition of in-state ethanol production away from traditional feedstocks grown out-of-state and toward an enhanced feedstock grown here in California, while reducing CI of the resulting ethanol. The $40 per ton reimbursement rate was used to leverage additional capital and operational investments, as well as education, outreach, and research and development by Aemetis. The company invoiced the CEC on a monthly basis for each ton of sorghum purchased.

Corn and sorghum commodity prices dropped unexpectedly after the grant was issued. As a result, the CEC required Aemetis and the other participating ethanol producers to renegotiate the rate at which reimbursements were made under the CISS program. The final renegotiated reimbursement rate agreed upon by the CEC and the three participating ethanol producers was 13.04 percent of the sorghum purchase price. All CISS program reimbursements were made at this rate.

CI Reduction Program Implementation

Pacific Ethanol proposed to leverage the incentive payments from the CEC to leverage additional investment in technologies and processes to further reduce the CI of ethanol produced at its facility. These investments included:

- Increasing transport and in-state growing capacity of grain sorghum for fuel use;
- Enhancing processing energy advancements to reduce carbon in the near-term;
- Implementing capital improvements to receive, store, and manage grain sorghum feedstock; and
- Installing capital improvements to provide long-term CI reduction at facilities.

Under the project, Pacific Ethanol proposed to expand on its previous investment in carbon reduction technologies and pathways, by implementing a package of investments and process updates to improve CI, above and beyond that due to the adoption of sorghum feedstock alone. Pacific Ethanol's proposal committed to selecting individual projects, as needed to reduce CI on site. A non-exclusive list of potential projects was provided in Pacific Ethanol's proposal, which included installation of capital improvements to receive, store, and manage sorghum feedstock, as well as a selective catalytic reduction process for boilers, boiler blowdown heat recovery, and cogeneration.

California In-State Sorghum Initiative

In coordination with its CALCEF program partners, Pacific Ethanol implemented the CISS Initiative, designed to substantially expand the availability of sorghum grown in California. The CISS Initiative included investments in a multi-year outreach, education, and research program in order to help transition sorghum into a viable energy crop in California. The CISS Initiative was initially based on the premise that California ethanol plants would need to provide a reliable demand for sorghum at a price similar to that provided for corn. Therefore, the CISS Initiative sought to implement contracts to purchase all grain sorghum produced under a contracted price that is price-competitive with local corn. Sorghum maintains the added benefits of being used as a common forage crop in the region, with the ability to grow on marginal land and using reduced water volumes than corn. Sorghum is also a reliable double crop behind wheat, which is widely planted in California.

The CISS Initiative relied heavily on Chromatin Inc., a sorghum developer for both traditional agriculture and applications in bio-industrial processes. Chromatin provides high quality sorghum seeds to growers and producers who are attracted to the crop's rapid maturation, tolerance to heat, cold and drought and high yields. CISS also included other leading seed suppliers that are currently working on sorghum breeding programs aimed at improving yields for growers in a variety of climatic, soil, and agronomic systems. Tasks included in the CISS Initiative include:

- **Outreach and Education.** The project sought to drive and develop a new end market for sorghum, where only a few thousand acres of grain sorghum were grown in-state immediately prior to project implementation. The project therefore deployed a dedicated education and awareness program to explain the benefits of sorghum to local growers. Key elements included development of marketing and outreach materials, direct contact with growers, and presentations at growers' meetings throughout California's Central Valley.
- **Incentivizing Sorghum Seed Sales.** The supply chain from farms to Pacific Ethanol's ethanol plant needed to be properly incentivized in order to expand the market. Farmers can benefit from grain sorghum's drought tolerance and reduced input costs, but until recently have not had access to established markets. Additionally, seed dealers had not typically focused on sorghum, but rather on high value crops and/or chemicals. Therefore, Chromatin conducted a dedicated effort to properly educate and align seed dealers to help create a sustainable local supply chain in California. Key elements included development of an incentive plan for seed dealers, and education of seed dealers as to incentives through outreach, presentations and meetings.
- **Sorghum Research.** The project team recognized that sorghum required additional investment in research to realize its full potential as a reliable ethanol feedstock. Therefore, the project team collaborated with leading seed suppliers to further the scientific backing of grain sorghum for feedstock-to-fuel use. Trials initiated under research included creating models to estimate sorghum productivity, water and nitrogen use under different rainfall and management regimes, and productivity under current and future climate change scenarios. These efforts sought to help enable growers' on-farm decision-making and improve the potential for sorghum success in California.
- **Sorghum Development.** In addition to the research program, grain sorghum development programs were initiated in collaboration with leading seed suppliers and the University of California system. These programs sought to improve the farmer's ability to identify the most appropriate grain sorghum hybrids for their local conditions, while developing planned management practices designed to increase the amount of in-state next generation, alternative feedstock production.
- **GHG Modeling.** In December 2012, the U.S. Environmental Protection Agency ruled that under certain production conditions, grain sorghum qualifies as an Advanced Biofuel under the Renewable Fuels Standard. At the time of submission of the original grant proposal for this project, a grain sorghum ethanol pathway did not yet exist for relevant lifecycle modeling tools (i.e., GREET, GHGenius). CISS sought to add GHG benefits to grain sorghum use in ethanol production in order to support GHGenius model work.

California Air Resources Board Certification

Under its initial proposal, Pacific Ethanol and its partners proposed to use existing California ARB reporting requirements to provide the CEC with a regular verification protocol to validate CI reduction from sorghum feedstock. Generally, fuels delivered into the California market must be certified by the ARB for a specific fuel pathway. Prior to project implementation, Pacific Ethanol CI was modeled using the default pathway for corn-based ethanol, produced in CA, using dry mill technology with wet distiller grains. This initial pathway served as the reference pathway for the project. Pacific Ethanol followed the California LCFS Procedures and Guidelines for applying for all new pathways and/or subpathways in using grain sorghum and applicable energy and technology/process improvements that improve CI.

Collaboration with Other In-State Ethanol Producers

The CALCEF Program reflects a visionary collaboration among California's three major ethanol producers, to support California's objective to assure the ability to meet its LCFS goals. Partner ethanol producers include:

- Aemetis (Figure 1) is an advanced renewable fuel and biochemicals company headquartered in Cupertino, California. The company focuses on the production of advanced fuels and chemicals through the acquisition, development and commercialization of innovative technologies to replace traditional petroleum-based products. Aemetis specializes in fuel production as well as conversion of first-generation ethanol and biodiesel plants into advanced Biorefineries. Founded in 2006, Aemetis owns and operates a 60 million gallon per year capacity ethanol and animal feed production facility in Stockton, California (Aemetis Advanced Fuels Stockton). As a byproduct of ethanol production at the Stockton plant, more than 430,000 tons per year of wet distiller's grains (WDG) are produced and shipped throughout California's Central Valley as animal feed for dairies and feedlots.

Figure 1: Aemetis Logo

Source: Aemetis

- **Calgren Renewable Fuels.** Calgren is located in Pixley, California, and is one of California's largest producers of ethanol. The company owns and operates the Pixley Biofuel Facility, a 55 million gallon per year (MGY) facility that has supplied ethanol, distiller's grains, and corn oil to areas in and around Bakersfield and Fresno, California since 2008. The Pixley Biofuel Facility is the longest continuously operating facility in

California, and with its unique energy efficient process—powered by a high-efficiency combined heat and power turbine that supplies plant electrical load and process steam—its fuel ethanol has one of the lowest carbon footprints in the country.

Calgren (Figure 2) is a significant player in the Central Valley community, as it purchases large quantities of corn, distributes fuel, and sells wet distillers grain to dozens of dairies. The Calgren biorefinery is located on a 15-acre parcel on the west side of Highway 99 and the Union Pacific Railroad north of Pixley in Tulare County, the site of the World Agriculture Exposition—the country's largest gathering of farm operators, vendors, and businesses.

Figure 2: Calgren Logo

Source: Calgren

Data Collection and Analysis

During project implementation, Pacific Ethanol and its partners collected data on capital projects and process upgrades completed under the project, plant operations including feedstock consumption, financial parameters, and sorghum-related outcomes under the CISS program. Results from the data collection efforts were aggregated, analyzed, and summarized during the development of this report, and are reviewed in the following chapter.

CHAPTER 4:
Project Outcomes

Sorghum Outreach, Education, and Research and Development

Direct Outreach and Education

The project sought to complete sorghum outreach and education, as well as research and development, to help support development of sorghum production within California. Specifically, the project sought to overcome key obstacles to the development of sorghum production in California.

In recent decades, California growers have not viewed grain sorghum as a viable crop; a change in this paradigm would require a solid market for their sorghum. The project was designed to address this disconnect and to provide a reliable, in-state market for sorghum grain. Other barriers initially targeted by the project included lack of storage for produced sorghum grain and limited transportation and technical infrastructure for sorghum. Under the project, it was anticipated that these issues would become addressable as sorghum production and markets developed in state. Sorghum would also benefit from additional research and development to help develop hybrids that are well suited to production in California's climate and conditions.

Project outreach included receipt and distribution of marketing materials from Chromatin Inc., as well as outreach phone calls, emails, and direct communications with individuals and farmers regarding the benefits of planting sorghum. The project team developed a cost/benefit assessment to compare grain sorghum production to a crop with which many farmers are familiar: corn. Results of this cost/benefit assessment are shown in Table 2. Grain sorghum was found to have the potential to generate a net margin of $400.96 per acre, in comparison to $161.84 for conventional corn. The assessment assumed a slightly higher price for sorghum than for corn, as well as a slightly lower per-acre yield, lower seed costs, slightly reduced fertilizer costs, lower water costs, and slightly higher harvest costs.

Table 2: Project Outreach Materials: Potential Grower Economics for Irrigated Sorghum Production in California

Category	Grain Sorghum	Corn
Revenues		
Yield (bu/acre)	150	155
Price ($/bu)	$6.32	$5.32
Return per Acre	$948	$825
GHG Emissions Displacement	93,882 MT	93,882 MT
Costs		
Seed	$25.20	$93.75
Herbicide	$23.25	$23.25
Fertilizer	$121.40	$125.90
Machinery	$103.57	$103.57
Irrigation labor	$64.00	$64.00
Irrigation water	$127.44	$169.92
Interest on ½ production costs	$8.92	$12.39
Subtotal Input Cost	$473.88	$592.88
Harvest costs	$73.16	$69.88
Total Cost	$547.04	$662.76
Net Margin		
Net margin per acre	**$400.96**	**$161.84**

Source: Pacific Ethanol

In spite of substantial effort, the project team nonetheless found that the vast majority of farmers were reluctant to make a switch to sorghum. Two farmers located in Kern and Tulare counties cited a sorghum price of $500 per ton to consider sorghum over competing alternatives. This high-value ask underscores another key barrier to sorghum development in California: potential revenue generated by high-value competing crops. The project was initiated during a period of intense drought, which severely limited some farmers' ability to explore alternative crops.

After working with farmers for several months to identify a suitable contracting structure to offer a price that is competitive with other land uses, the project team secured sorghum production on 1,400 acres in Kern County. This planting represented the largest sorghum planting in California in at least 30 years and represented a key success for the project team. Additionally, working to streamline supply chains and maximize the revenues going directly to growers could also help to support future agricultural development for sorghum, based on input provided by UC Davis.

The project team completed annual public presentations reviewing field growth (see below) in November 2016 and November 2017. The results were well received and the presentation was attended by approximately 100 people during each event.

Research and Development: Sorghum / Corn Irrigation Trial

The Center for Irrigation Technology (CIT) at Fresno State University completed the sorghum/corn irrigation trial in support of the project. The study evaluated three sorghum hybrids and one corn hybrid, using three irrigation regimes, all of which were replicated four times for a total of 48 plots. In a normal year, the trial area would have had some initial soil moisture at the beginning of the season to buffer any irrigation deficiencies during the growing season. However, with the drought in 2015, the trial was very different: there was no plant available soil moisture at the beginning of the growing season. All seed was germinated with water supplied by the irrigation system. Irrigation water quantities were recorded and irrigations were cut off as the irrigation totals were achieved for the three irrigation treatments. This allowed a true evaluation of production potential of both the sorghum and corn under reduced irrigation water regimes.

Results of the study showed yields for sorghum under crop coefficients (K_c) ranging from 10 to 20 inches of total water application. Yields per plot varied based on hybrid, with the KS310 hybrid strongly outperforming others under K_c values as low as 0.5 (i.e., 10 inches of applied water). Sorghum outperformed corn in terms of yield at K_c values of 0.5 and performed at an almost equivalent rate for K_c values of 1.0 (i.e., 20 inches applied water). Specifically, sorghum hybrid KS310 averaged 3,443.1 lbs/acre, in comparison to corn at 3,462.9 lbs/acre.

Research and Development: Sorghum Grain Hybrid Field Trials

UC Davis completed a series of sorghum grain hybrid field trials in support of the project, to help improve available sorghum hybrids for energy crop development. Five seed companies provided 41 commercial grain sorghum hybrids for the trial. Hybrids were planted in a replicated, randomized block design in four 20-foot rows. Irrigation was applied as furrow irrigation at the Kearney Agricultural Research and Extension center, as overhead sprinklers and flood irrigation at the Desert Research and Extension Center, the Westside Research and Extension Center, and the Russel Ranch Sustainable Agriculture Facility at UC Davis. Water application followed similar recommendations for grain sorghum at each location.

The project team collected data on emergence, vigor, plant height, panicle length, panicle exsertion, yield, seed moisture content at harvest, and 1,000-seed weight. No major pests or

diseases were observed at any of the locations, although plants at two sites were treated for the presence of sugarcane aphids. Flowering dates varied by hybrid, ranging from early flowering at 48.8 days to late flowering at 64.3 days. It had been noted previously that sorghums that flower later in the season tend to have better yield potential, and a similar trend was observed in the data collected in support of the project.

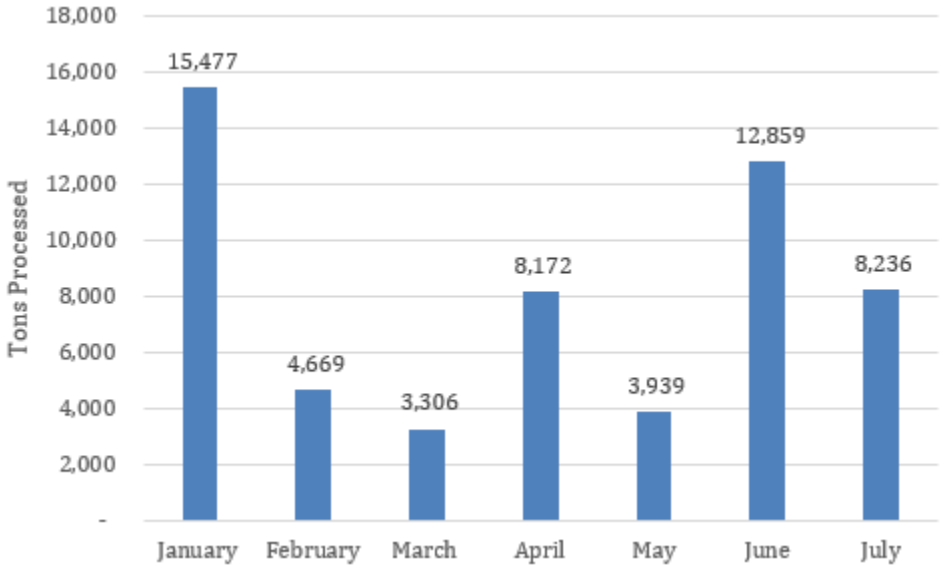
Generally, location had a significant impact on yield data and 1,000-seed weight. Heat stress at the desert site may have contributed to the growth rates observed in the Imperial Valley. Observed yields were the highest using Gayland Ward Seed's GW EXP 9050 hybrid, at 6,861.6 lbs/acre, and lowest using Sorghum Partners' SP 73B12, at 4,251.7 lbs/acre. Generally, the results found that grain sorghum could be an excellent cereal crop applicable in California. Its high yield potential and marketability into various market channels would work well under conservation tillage practices, and as a rotation crop for other annual crops such as cotton, canning tomatoes, or other vegetable crops.

Grain Sorghum Purchase and Processing

Sorghum Purchase from the U.S. Midwest

From the time of project initiation, the team began working, through team member JD Heiskell, to develop supply chain relationships with sorghum producers and suppliers in the U.S. Midwest. At that time, sorghum grain supplied initially from the U.S. Midwest was identified as a temporary preferred source, to give the project's in-state sorghum production initiative time to progress. In early 2016, sorghum prices became within target range for the project, nearing or dropping below $175 per ton. As a result, the team solicited bids for supply of sorghum and placed orders for delivery of sorghum, via train, in Q1 of 2016. All sorghum received was sourced from partners located in either Kansas or Nebraska, with volumes received, as shown in Figure 3. A total of 56,657 tons of sorghum was processed alongside corn in a 30/70 sorghum/corn blend.

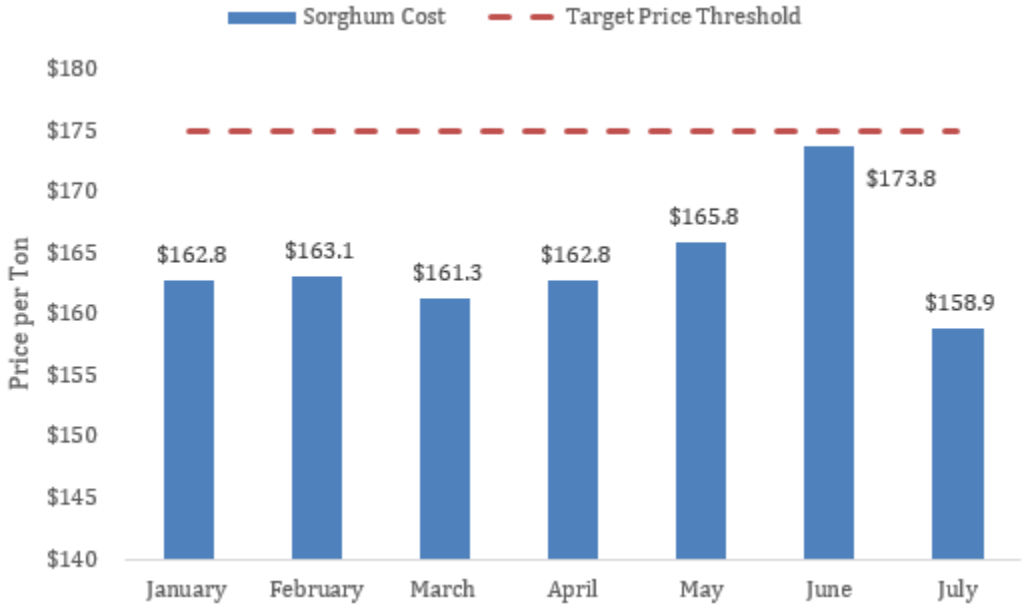
Figure 3: Tons of Sorghum Processed by Pacific Ethanol (2016)



Source: Pacific Ethanol

As shown in Figure 4, sorghum prices during this period for purchase by Pacific Ethanol ranged from $158.9 to $173.8, based on monthly average values. Of this amount, the CEC provided a reimbursement of 13.04% of total purchase price, equivalent to roughly $21 to $22 per ton.

Figure 4: Cost of Sorghum Processed by Pacific Ethanol



Source: Pacific Ethanol

Sorghum Pricing

Sorghum pricing varied substantially during the project. Sorghum is priced as a global commodity, with prices affected by domestic agricultural production and supply rates, as well as export markets. China is a particularly large export market for US-grown sorghum, and exports can vary based on overseas demand, driven by currency values and other macroeconomic trends. In the U.S., sorghum is grown almost exclusively in the Midwest. After fluctuating between $255 and $303 per ton in 2011 through 2013, and settling between $180 and $230 per ton through 2015, sorghum spot prices became very competitive in early 2016. Herein, commodity spot prices dropped, and ranged from $144 to $165 during 2016 (Pacific Ethanol paid slightly higher than spot prices, due in part to long distance rail shipping costs). In early 2016, sorghum prices became very competitive. Strong crop yields resulted in large amounts of sorghum available, and sellers were particularly motivated because the large harvest had resulted in outdoor pile storage. Pacific Ethanol considered purchase of sorghum stored in outdoor piles, but maintained concerns over potentially elevated levels of aflatoxin and mold, and therefore would only agree to purchase at a greater discount. By summer of 2016, however, sorghum prices had increased thanks to an improved export market, as well as sellers holding back to support a price improvement. Sorghum pricing then increased in volatility, consistent with an increase in corn price volatility at the same time. Herein, sorghum pricing generally tracked corn pricing. Sorghum pricing, considered in light of CI values approved by the California ARB (see subsequent discussion), proved unfavorable through the remainder of 2016 and 2017. As a result, Pacific Ethanol did not purchase additional sorghum for processing after July of 2016.

Sorghum Processing Results

Pacific Ethanol was able to successfully process incoming sorghum into ethanol at its existing facility, including prior to making any of the modifications or updates to the plant that were initially proposed. Table 3 summarizes processing results. In total, processing sorghum in lieu of corn ethanol was found to minimally reduce ethanol yield, by less than 0.5 percent. Sorghum did, however, result in much greater reductions in the amount of distiller's oil produced by the facility, by up to approximately 15 percent, based on a 30/70 sorghum/corn input ratio. Reductions in distiller's oil represent a meaningful reduction in a saleable co-product, in comparison to a corn-based process. Routine tests of product fuel indicated no change in fuel quality. Similarly, no change in facility air emissions were observed. Existing equipment was found to be sufficient to process the incoming sorghum feedstock without process interference.

Table 3: Change in Pacific Ethanol Plant Outputs during Sorghum/Corn Co-Processing (30/70 Ration Sorghum/Corn)

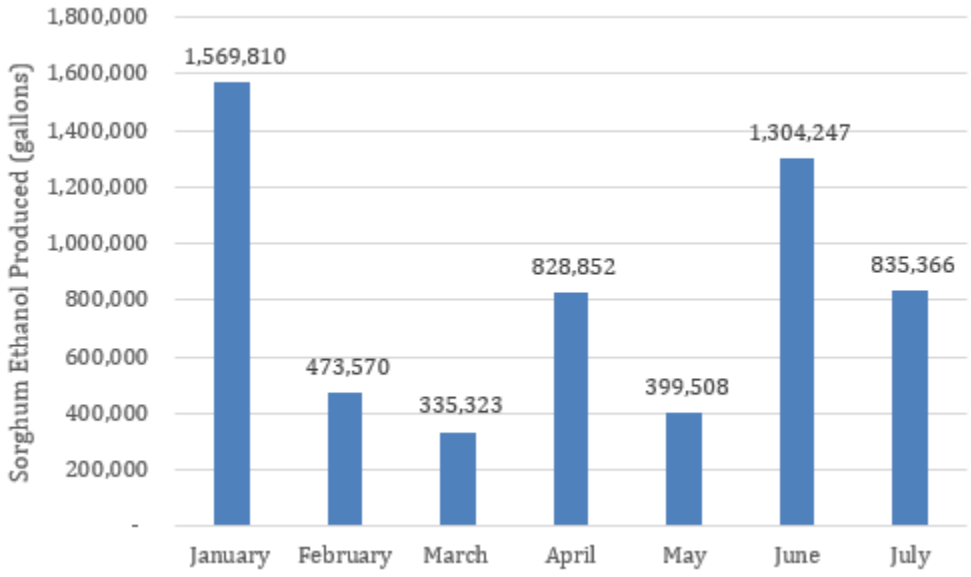
Category	Change Versus Corn Ethanol
Ethanol Yield	Less than 0.5% yield reduction
Distiller's Oil	Up to 15% reduction
Fuel Quality / Composition	No Change
Air Emissions	No Change

Source: Pacific Ethanol

Sorghum Fuel Production

During the project implementation period, Pacific Ethanol successfully produced a total of 5,746,675 gallons of sorghum based ethanol. This volume was produced as a 30/70 blend of sorghum/corn ethanol, for a total sorghum/corn blended fuel volume of approximately 13.5 million gallons. Monthly sorghum ethanol production coincided with purchase periods identified in Figure 5.

Figure 5: Gallons of Sorghum-Based Ethanol Produced by Pacific Ethanol (2016)



Source: Pacific Ethanol

Color of Distiller's Grains

The project team observed a change in the color of distiller's grains produced by the facility, where distiller's grains are sold to the dairy industry for feed, as a coproduct of ethanol production. Conventional corn distiller's grains are light in color. However, if they are improperly handled during processing, corn distiller's grains can take on a darkened, burnt appearance. Sorghum based distiller's grains carry a darker color naturally and appear to be

burnt even when they have been properly produced. Pacific Ethanol actively educated its distiller's grains customers about the change in color (Figure 6). Based on laboratory tests, the distiller's grains were found to have equivalent nutritional composition to corn-based grains, and were adopted by regional the dairy farmers without issue.

Figure 6: Sorghum Distillers Grains (Left) and Corn Distillers Grains (Right)

Source: Aemetis

Increased Maintenance Need

Pacific Ethanol identified accelerated need for maintenance and repair of its facility as a key issue when using sorghum as a feedstock for ethanol production. Specifically, Pacific Ethanol found that grain sorghum poses unique challenges that differ from those associated with corn during processing. First, the grain sorghum kernel is harder, which was found to create increased wear on the hammers that mill the grain, and also caused increased wear on the screens that sift the resulting flour. Grain sorghum was also found to carry higher loads of grit and sand, due to the open nature of the sorghum kernel. This sand was found to work its way through the plant, causing increased wear on a variety of mechanical components. This wear was most evident on the facility's hammer mill, as well as other components coming into direct contact with the sorghum feedstock.

The increased wear from processing sorghum resulted in increased maintenance costs. After processing sorghum for seven months (January through July, 2016), Pacific Ethanol incurred annual maintenance costs that were $510,235 (21 percent) higher than during the previous year. In total, Pacific Ethanol sought additional reimbursements from the CEC to help offset the increased costs of maintenance, incurred as a result of sorghum processing.

Facility and Equipment Updates and Maintenance

While Pacific Ethanol did complete an accelerated maintenance schedule, as discussed previously, facility and equipment upgrades that were initially planned under the project were not deployed. Pacific Ethanol, in coordination with the CEC, concluded that the facility upgrades that were initially proposed would no longer represent the best potential use of

funds under the project. Based on the change in CI value handed down by the California ARB (see next section), anticipated Sorghum pricing, and increased maintenance required for sorghum processing, Pacific Ethanol does not see the need for further investment in sorghum processing equipment in the near term.

While equipment upgrades were not completed, Pacific Ethanol did complete additional maintenance that was not anticipated in the original project proposal. In total, Pacific Ethanol incurred approximately $510,000 in additional sorghum related maintenance costs. The CEC agreed to reimburse Pacific Ethanol for a portion of these costs, consistent with the negotiated reimbursement rate for the purchase of grain sorghum—i.e., at a rate of 13.04 percent. Additional maintenance was required and documented for the following items:

- Grain shoot repair
- Heat exchanger plates
- Centrifuge rebuild
- Bearings for grain system conveyor
- Rotary feeder wheel assembly
- Conveyor
- Knee shoe
- Grain conveyor bottom pans, head, and tail
- Hammers
- Hydroblasting
- Elevator gear box and head sheave repair

All equipment performed as designed once maintenance was complete.

Increased Chemicals Demand

In addition to increased maintenance requirements, Pacific Ethanol found that sorghum required additional chemicals for processing. Increased chemicals demand included marginally higher demand for the enzymes needed to process the sorghum, in comparison to the conventional corn process.

ARB Certification

The project team, along with the National Sorghum Association, worked with the California Air Resources Board to evaluate the merits of sorghum as a low-carbon fuel. Concurrent to this process, the ARB also reviewed CI values for the agricultural production of corn. Results from that analysis led the ARB to identify several changes in GHG emissions associated with corn production, including changes related to the amount of soil additives (such as lime) and their effect on net GHG emissions. As a result, CI values for corn-based ethanol dropped in comparison to CI values for sorghum, causing sorghum-based ethanol pathways to have a CI

value that was **7.5 points higher than the respective corn-based process.**[2] Therefore, the GHG emissions reductions related benefits that the project was expected to provide were effectively negated, due to these higher lifecycle emissions of sorghum-based ethanol.

GHG Emissions Displaced

Pacific Ethanol procured and converted to ethanol 56,657 tons of sorghum during the project, or about 64 percent of the tonnage proposed to the CEC (89,082 tons). Nonetheless, Pacific Ethanol successfully acquired certification from the California ARB for a new sorghum to ethanol production pathway for Midwest-sourced sorghum, having a CI value of 76.14 g CO_2e/MJ (pathway T1R-1198). In comparison to the baseline California ARB CI value at the time of application for this project (80.7 g CO_2e/MJ), this represents a 5.7 percent reduction in carbon intensity for the 5,746,675 gallons of sorghum based ethanol produced under the project.

Total GHG emissions reductions for the project are calculated based on the baseline assumptions documented in Pacific Ethanol's original project application. Briefly, assuming a 2013 LCFS CI standard baseline of 97.05 g CO_2e/MJ, a 2013 average CI for ethanol produced by Pacific Ethanol of 80.7 g CO_2e/MJ, an ethanol energy content of 80.53 MJ/gallon (per ARB guidelines; lower heating value) and a CI value of 76.14 g CO_2e/MJ for sorghum ethanol produced under the project, the project resulted in the following GHG emissions reduction:

Equation 1:

$$5{,}746{,}675\ gallons\ sorghum\ EtOH * 80.53 \frac{MJ\ EtOH}{gallon} * 97.05 \frac{gCO_2e}{MJ}\ baseline * \frac{1\ MT}{1{,}000{,}000\ g}$$
$$= 44{,}913\ MT\ CO_2e\ displaced\ (gross)$$

Equation 2:

$$5{,}746{,}675\ gallons\ sorghum\ EtOH * 80.53 \frac{MJ\ EtOH}{gallon} * 76.14 \frac{gCO_2e}{MJ}\ project * \frac{1\ MT}{1{,}000{,}000\ g}$$
$$= 35{,}236\ MT\ CO_2e\ generated\ from\ project\ fuel\ (gross)$$

Equation 3:

$$44{,}913\ MT\ CO_2e\ displaced\ (gross) - 35{,}236\ MT\ CO_2e\ generated\ from\ project\ fuel\ combustion$$
$$= \mathbf{9{,}676.72\ MT\ CO_2e\ offset\ (net)}$$

2 LCFS Certified carbon pathways (https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm) approved by the California Air Resources Board.

These GHG emissions reductions reflect a lower sorghum-based ethanol production volume, and therefore a lower GHG emissions offset than originally anticipated (23,756 MT CO_2e). Nonetheless, the project generated a slightly greater CI value reduction in comparison to the original proposal (5.7 percent rather than 5.0 percent), highlighting GHG emissions benefits of the project in spite of challenges relating to economics and changes in the CI value of corn based ethanol, as discussed previously.

Sorghum Based Ethanol Production in California: Technological Feasibility, Wear and Tear

The project demonstrated that production of ethanol from sorghum is technologically feasible under California conditions. Specifically, the product fuel generated from sorghum by Pacific Ethanol was of sufficient quality to meet all specifications, with no noticeable difference in quality as compared to corn-based ethanol. Additionally, facility air emissions did not change during transition to sorghum-based ethanol.

Sorghum processing at Pacific Ethanol's facility did lead to increased wear and tear on the plant, resulting in elevated maintenance costs for select components. These additional costs totaled $510,234, of which $66,552 was reimbursed by the CEC. The additional maintenance costs were incurred during seven months of sorghum-based ethanol production, resulting in an estimated annualized additional cost of $874,687. Conversations with equipment vendors revealed that more suitable replacements that are less subject to wear are not available for most of the equipment that had been worn by sorghum use. Other ethanol producers seeking to add sorghum to their feedstock portfolio could do well to work with other existing producers of sorghum-based ethanol (i.e., mostly in the U.S. Midwest) to help identify mitigating strategies for equipment wear.

Distillers Grains

The project team anticipated concerns regarding the color of sorghum-based distiller's grains and completed proactive tests of the coproduct to help assure their customers of quality. Purchasers of distiller's grains were found to be responsive to the project team's education efforts, and continued to purchase and utilize the coproduct throughout the trials.

Sorghum Quality

In comparison to corn, which has been highly developed, sorghum as a crop is less consistent in its quality and can have a lower starch content in some cases. The sorghum processed under the project was variable in quality, with some deliveries received that were clearly of lesser quality. Pacific Ethanol was able to run corn and sorghum together as a blended feedstock, which helped to minimize variable sorghum quality, and to reduce impacts on yield and distiller's grains production. It is not unheard of for suppliers to mark grain of lesser quality for shipment out of state, suggesting that if local agricultural production were to develop, local suppliers might be able to alleviate some of the observed quality issues.

Sorghum Pricing

As discussed previously, several factors influence sorghum price, including production levels in the U.S. (mostly in the U.S. Midwest), as well as export markets. A large domestic crop of sorghum led to reduced prices in early 2016; however, prices rebounded subsequently. Increases in overseas demand, particularly in China, also have the potential to drive up prices. High sorghum prices, along with higher than expected CI values for sorghum-based ethanol, were a major factor constraining the use of sorghum for ethanol during the project.

Greenhouse Gases, Carbon Intensity, and Renewable Fuels Credits

Unanticipated changes handed down by the California ARB in 2016 dealt a significant blow to the project. As noted above, increases in CI value for the project team's sorghum-based ethanol production resulted in CI scores that are now on the order of eight points above that of corn ethanol. Reducing the CI value of the project team's product fuel was a key and critical, driving objective for the project. This change greatly hampered the team's ability to fully implement the project, because sorghum resulted in higher costs along with a higher resulting CI value in comparison to corn ethanol.

The project team has, however, obtained preliminary permission from the U.S. EPA to generate fuels under a category D5 (Advanced Biofuels) Renewable Identification Number (RIN). After a long application process, sorghum would qualify for the RIN under the EPA's QAP program. Thus, as a result of the project, it appears likely that ethanol producers will soon have the potential ability to generated an advanced biofuel RIN by using sorghum as a feedstock. The credits would be applicable nationwide. The project team is currently responding to comments from EPA prior to finalizing this process.

Feedstock Flexibility

Feedstock flexibility is a key consideration for many biofuels producers, especially when feedstock prices become elevated or excessively volatile. The project team tracked sorghum prices closely during the project. During periods of volatility such as mid to late 2016, sorghum prices were found to track corn prices during some periods, and widely vary from corn prices during other periods. When sorghum prices do track corn, the utility of sorghum as an alternate feedstock is limited. In contrast, when sorghum price trends decouple from those of corn, especially during years when export markets combine with reduced or excessive crop yields, ethanol producers may benefit from feedstock flexibility afforded by sorghum. During such periods, the ability to run an alternate feedstock could provide a more meaningful benefit to the industry in general.

Sorghum Drought Tolerance and Hybrid Advancement

Sorghum trials clearly illustrated increased drought resistance for sorghum in comparison to corn, although yields of both sorghum and corn decreased with elevated water stress. Testing revealed good sorghum yields even at 75% of calculated water demand. With respect to hybrid advancement, testing of over 40 individual hybrids completed as a facet of the project has already resulted in large demonstrated benefits to sorghum yield. Specifically, the project

was able to generate sorghum yields exceeding 6,800 lbs/acre in test plots. In spite of its demonstrated benefits and demonstrated yields, even during the historic drought in California that lasted through 2016, most farmers contacted remained reluctant to plant sorghum in large quantities. Their reluctance centered on price-related issues, but crop consistency and hybrid status / advancement were also noted considerations. Key next steps that would help to further support sorghum development could include advances in agricultural chemistry available for the crop (i.e. herbicides and pesticides).

Agricultural Development of Sorghum in California

During the study, the value of alternate crops to sorghum was identified as a critical factor in farmers' decision-making process when considering whether or not to grow sorghum. Growing conditions in California are typically favorable to a wide array of moderate- to high-value crops, many of which could realistically support greater profitability than sorghum cropping in current markets. The project team found this situation to be a substantial barrier to the development of additional sorghum production in California. As a result, many farmers who might choose to produce sorghum typically chose to produce cotton, soybeans, or another crop instead. Nonetheless, the project team was successful in securing 1,400 acres of sorghum production, the largest amount of sorghum planted in state in over 30 years. Key strategies supporting increased sorghum deployment include, to the extent possible, contracting directly with growers to ensure that they receive the highest price for their sorghum as possible, as well as growing sorghum in rotation with tomatoes, cotton, or other rotation crops.

Operational Benefits from Ethanol Production Facility Upgrades

As discussed previously, the facility upgrades initially proposed under the project were not ultimately carried out, due to unfavorable market conditions and CI scores for sorghum-based ethanol.

Conclusions

The project sought to achieve ethanol production with a CI at least 5 percent less than the baseline California ARB pathway for corn ethanol. Unfortunately, increases in CI values for sorghum-based ethanol in comparison to corn ethanol derailed these efforts. Nonetheless, the project successfully tested sorghum as a feedstock for ethanol in California over a five-month period at Pacific Ethanol's facility. Product ethanol was found to carry consistent quality equivalent to that of corn ethanol. Sorghum agricultural testing and trials demonstrated drought resistance of sorghum and helped to identify high-yield hybrids capable of producing over 6,800 lbs/acre in small-scale trials. Further hybrid development and agricultural chemistry development could help support sorghum growers in California. However, at this time, the project team does not anticipate that ethanol production will drive continued development of sorghum in California due to a combination of unfavorable economics and high CI values of the base sorghum crop.

Sorghum as a Potential Alternative Crop for California Farmers

At least on paper, future development of sorghum markets in California could provide options to farmers seeking alternative crops. Outcomes of this project highlight sorghum's viability as a comparatively drought-tolerant crop, rendering it a potential alternative during droughts and in areas with limited water availability in the state. Sorghum also carries potential to be successfully grown on marginal lands. Thus areas such as the drier western flank of the San Joaquin Valley—where farmers are increasing struggling with water availability—may show the greatest potential for sorghum development.

Higher sorghum prices could help to drive future increases in agricultural production in state. However, factors affecting commodity prices and demands for specific crops, such as sorghum, are driven by a wide range of global economic, social, and environmental factors. Commodity price changes occur frequently (Figure 7), are difficult to predict with accuracy over the long term, and are even more difficult to influence. Even if sorghum prices were to rise substantially, it is likely that many higher value crops that can be grown in California's favorable climate could still produce greater returns per acre than sorghum. Perhaps a more viable strategy would be to consider targeted outreach to farmers who currently have drought-fallowed land, otherwise limited water supplies, or marginal lands. Education programs could highlight sorghum's growth potential under these conditions, helping to raise awareness and incrementally develop sorghum production in California.

Figure 7: One Decade of Sorghum Spot Prices Indicating Typical Variability in Sorghum Pricing (2008-2018)

Source: Pacific Ethanol

Regarding in-state demand for sorghum, Pacific Ethanol would consider using sorghum to generate ethanol if conditions were to become favorable. First, a local source of sorghum could reduce quality issues observed. As noted previously, local suppliers may be more concerned with providing quality product to a local repeat purchaser, in comparison to infrequent purchasers located out of state. Second, more favorable CI values could also help drive an increase in sorghum-based ethanol production in state. If, for example, CI values for sorghum production were to decline and become on par with or lower than corn, Pacific Ethanol would be more likely to reconsider sorghum-based ethanol production.

GLOSSARY

CALIFORNIA AIR RESOURCES BOARD (ARB) - 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 IN-STATE SORGHUM INITIATIVE (CISS) – The California ethanol industry's initiative to develop expanded sorghum cultivation in California

CALIFORNIA LOW CARBON ETHANOL FEEDSTOCK PROGRAM (CALCEF) – The combined efforts of California's three largest ethanol producers – Aemetis, Calgren and Pacific Ethanol – to procure and process grain sorghum as a more sustainable non-food feedstock that could supplement or replace corn.

CARBON INTENSITY (CI) - The amount of carbon by weight emitted per unit of energy consumed. The standard measure of carbon intensity in California is the weight of carbon per mega joule of energy. This is expressed as g CO_2e/MJ, or grams of CO2-equivalent per mega joule. When there is only one fossil fuel under consideration, the carbon intensity 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.

GHGenius – A lifecycle analysis model with a primary focus on transportation fuels in Canada. To accomplish this it includes data for activities ranging from crop production, to power generation, to tailpipe emissions in many regions spanning the globe. Development of new feedstocks, fuels, and regions is still ongoing with planned major public releases annually.

GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TRANSPORTATION (GREET®) - A full life-cycle model sponsored by the Argonne National Laboratory (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy). It 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 need to be considered. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

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 (GHG) emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) of gasoline and diesel fuel and their respective substitutes. The LCFS is a key part of a comprehensive set of programs in California to cut greenhouse gas emission 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 1 newton is displaced 1 meter in the direction of the force. It takes 1,055 joules to equal a British thermal unit. It takes about 1 million joules to make a pot of coffee. A megajoule itself totals 1 million Joules.

METRIC TON (MT) - A unit of mass equal to 1,000 kilograms.

RENEWABLE FUEL STANDARD (RFS) - A federal program to increase the volume of renewable fuels used in transportation fuels. Created under the Energy Policy Act of 2005, and revised by the Energy Independence and Security Act of 2007, the RFS program requires increasing annual volumes of renewable fuel, starting from 9 billion gallons in 2008 to 36 billion gallons by 2022. Within those total volumes, the RFS also requires certain volumes of specific fuels, such as cellulosic and advanced biofuels.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) - A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting and enforcement activities.

WET DISTILLERS' GRAINS (WDG) - The wet grain byproduct of the grain fermentation process, which may be used as a high-protein animal feed.