CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Thermophilic Bacterial Pretreatment of Organic Feedstocks

Prepared for: California Energy Commission

Prepared by: California Grinding Inc.

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California Energy Commission

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- Aqua Engineering
- Baker Tilly
- Clements Environmental
- DBG Energy

PREFACE

Assembly Bill (AB) 118 (Nùñez, Chapter 750, Statutes of 2007), created the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). The statute authorizes the California Energy Commission (Energy Commission) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change, clean air, and alternative energy policies. AB 8 (Perea, Chapter 401, Statutes of 2013) re-authorizes the ARFVTP through January 1, 2024. The ARFVTP has an annual budget of approximately $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 non-road 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.

The Energy Commission issued solicitation GFO-18-602 for demonstration-scale advanced biofuels production facilities. To be eligible for funding under GFO-18-602, projects must also be consistent with the Energy Commission's ARFVTP Investment Plan, updated annually. In response to GFO-18-602, California Grinding Inc. (CGI) submitted application 4, which was proposed for funding in the Energy Commission's Notice of Proposed Awards on January 18, 2019, and the agreement was executed as ARV-18-021 on December 19, 2019.

ABSTRACT

The California Energy Commission (CEC) provided financial support to California Grinding Inc (CGI) for the development and demonstration of a new and innovative organic waste pre-digestion technology to be incorporated into conventional anaerobic digestion technology called VERDE. This technology is able to take all organic biomasses, including lignocellulosic biomasses that previously break down poorly if any at all, and turn them into precursors for effective methane formation in the Anaerobic Digestion (AD) process. The breakdown of green waste, food waste, and manure feed stocks could become much more efficient and thorough, allowing for significantly higher production of biogas from these sources. The potential impact of this technology and the use of organic waste for methane production could be a major breakthrough for anaerobic digestion.

This report describes the pilot and pre-commercial demonstration scale testing accomplished in this project. The testing program confirmed that commercial scale utilization of this pre-digestion technology provides a cost-effective solution for organic waste disposal and transportation fuel production. This project demonstrated how the pre-digestion technology can much more effectively convert organic materials, which would otherwise be landfilled, to biomethane (as renewable natural gas (RNG)) for local use to offset fossil fuel consumption in heavy-duty on-road vehicles. This reduces the creation of greenhouse gases through the displacement of fossil fuels and elimination of organic waste in the landfill.

Additionally, the project demonstrated how the pre-digestion technology could reduce local criteria air pollutant generation in this highly polluted air basin by eliminating organic waste disposal to landfill and substituting clean biofuel for fossil-based transportation fuel.

Keywords: (Required for all Commission Reports/Papers) – anaerobic digestion, biogas, *Caldicellulosiruptor bescii (C. bescii),* California Energy Commission, California Grinding Inc, greenhouse gas, organic waste, pre-digestion, renewable natural gas

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
PREFACE ii
ABSTRACT iii
TABLE OF CONTENTS iv
LIST OF FIGURES v
LIST OF TABLES v
EXECUTIVE SUMMARY 1
CHAPTER 1: Project Purpose 4
Facility/Project Site Information 4
Approach 4
Pilot Plant Phase 5
Pilot Plant Renovation 5
Pilot Plant Commissioning and Testing 8
Pilot Plant Operations 9
Pilot Plant Conclusions 11
Demonstration Phase 12
Demonstration System Design, Construction and Commissioning 12
Assembly and Installation of VERDE Pre-digestion Technology Equipment 13
Certification of Completion of Construction and Installation Activities 14
Demonstration Plant Operations 15
Sustainability: From Organic Waste to Biomethane 16
Project Implementation and Responsible Parties 16
Project Team Qualifications 17
Chapter 2: Activity Report 21
Project Schedule 21
Source: California Grinding Inc. 21
Demo Project Budget 21
Business Plan/Total Project Cost 21
Chapter 3: Project Assessment 24

Goals and Results 24
Economics 26
Project Challenges 27
GLOSSARY 28

LIST OF FIGURES

Figure 1: Pilot 1
Figure 2: Demonstration Plant 2
Figure 3: Pilot Plant as Delivered 5
Figure 4: Feed Tanks and Routed PVC pipe to 750-gallon 7
Figure 5: Existing Plywood Lid 8
Figure 6: Upgraded Steel Lid 8
Figure 7: On-site Laboratory 10
Figure 8: Construction Certification of Completion 15

LIST OF TABLES

Table 1: Daily Expected Input Feedstock 13
Table 2: Expected Output Parameters 13
Table 3: Project Schedule 21
Table 4: VERDE Capital Cost Estimate 22
Table 5: VERDE Annual O & M Cost Estimate 22
Table 6: VERDE Simple Payback Analysis 23
Table 7: Increased Methane Production 25
Table 8: TABLE 8 - RCNG Output, CI Score & GHG Reduction 26

EXECUTIVE SUMMARY

Recognizing the contribution of methane emissions from landfilled organic waste California enacted SB 1383, requiring the diversion of organic wastes from landfill disposal. Anaerobic digestion of these wastes to produce biogas is one of the methods encouraged by this legislation.

Unfortunately, the additional cost of AD over landfill is a significant barrier for the communities and private waste management companies required to comply with this new law. Since conversion of organic wastes produces valuable biogas that can be used as vehicle fuel, improvements in the carbon to methane conversion efficiency will significantly relieve the cost to the waste producer of shifting from landfill to biogas production.

This project addresses the barriers and knowledge gaps that hinder the development and widespread use of anaerobic digestion (AD). The project team tested and demonstrated a pre-digestion technology that utilizes C-Bessci thermophilic bacteria that take organic and lignocellulosic biomasses and turn them into precursors for methane formation in the AD process (also called VERDE).

Figure 1: Pilot

Source: Stellar J Corporation

Laboratory and bench scale testing of the VERDE pre-digestion process completed previously showed the potential of this pre-digestion technology to significantly increase the biogas yields from wet organic waste, particularly highly cellulosic materials such as green waste and manure that are subsequently fed into an anaerobic digestion system. The testing completed in this Project at a pilot and pre-commercial demonstration scale confirmed that the breakdown of the green waste and manure through the VERDE process significantly increases production
of methane gas output.

Figure 2: Demonstration Plant

Source: Stellar J Corporation

The overall goal of this project was to demonstrate that the VERDE pre-digestion technology is technically, economically, and environmentally feasible at a commercial scale. The project demonstrated the technical feasibility of processing up to 2 tons per day of feedstock, increasing methane production by up to 55 percent.

The results from this demonstration indicate that the implementation of the VERDE pre-digestion technology at a commercial scale AD system processing 250 tons per

day of organic wastes could produce an additional 220,000 to 270,000 diesel gallon equivalent (DGE) per year of biomethane. This biomethane will meet the rigid pipeline quality specifications required by PG&E as specified in Gas Rule 21 (refer to https://www.pge.com/tariffs/assets/pdf/tariffbook/GAS_RULES_21.pdf) so as to be suitable for injection into the nearby PG&E pipeline to the City of Fresno for use with their existing CNG-bus fleets, with the surplus, if any, going to public or private trucks and bus fleets.

Commercial scale demonstration of this pre-digestion technology provides a cost-effective solution for organic waste disposal and transportation fuel production. This project demonstrated how the pre-digestion technology can much more effectively convert organic waste materials such as food and green wastes and manure, which would otherwise be landfilled, to biomethane (as renewable natural gas (RNG) for local use to offset fossil fuel consumption in heavy-duty on-road vehicles. This reduces the creation of greenhouse gases through the displacement of fossil fuels and elimination of organic waste in the landfill.

Finally, the project demonstrated how the pre-digestion technology could reduce local criteria air pollutant generation in this highly polluted air basin by eliminating organic waste disposal to landfill and substituting clean biofuel for fossil-based transportation fuel.

CHAPTER 1: Project Purpose

Facility/Project Site Information

The Project is located at CGI's existing biomass processing facility – 3077 South Golden State Frontage Road, Fresno, California 93725. This is an ideal location due to land availability, permit status, the plentiful supply of feedstocks, and availability of utilities and labor.

The site is fully permitted to accept and process organic waste materials and is currently processing approximately 350 tons per day. The company is currently developing a commercial scale anaerobic digestion facility at this site where the results of this project's testing will be incorporated.

Approach

The project team tested and demonstrated a pre-digestion technology that utilizes C-Bessci thermophilic bacteria that take organic and lignocellulosic biomasses and turn them into precursors for methane formation in the AD process (also called VERDE).

Laboratory and bench scale testing of the VERDE pre-digestion process completed previously showed the potential of this pre-digestion technology to significantly increase the biogas yields from wet organic waste, particularly highly cellulosic materials such as green waste and manure that are subsequently fed into an anaerobic digestion system.

Production of biogas through anaerobic digestion (AD) offers a proven, readily scalable, and well-understood mechanism for utilizing low-lignin biomass as an energy precursor. The technology has been applied commercially using a variety of low-lignin feedstocks such as organic domestic waste, organic industrial wastes, manure, and municipal biosolids. However, without pretreatment, the current baseline conversion of volatile solids into methane through AD has been poor in most cases. By significantly increasing the fraction of biomass-based carbon converted into biogas, increasing the methane composition of the biogas, and decreasing processing time, lignocellulosic biomass can compete with and surpass the economics of other renewable energy processes.

Biological pretreatment of feedstocks with the thermophilic bacteria *Caldicellulosiruptor bescii (C. bescii)* at 75°C and pH 7-8 for 48 hours facilitates near-complete conversion of cellulose into acetate and lactate, while also solubilizing much of the lignin content within the feedstock. Subsequent AD of these products at either 37°C (mesophilic) or 56°C (thermophilic) promotes conversion of the acetate and lactate into biogas with the potential methane concentration to 70+%. Following minimal scrubbing, the biogas can better be utilized for RNG generation. It can be upgraded more easily to pipeline grade renewable natural gas because of its higher methane content.

The testing completed in this Project at first a pilot scale, and subsequently at a pre-commercial demonstration scale, confirmed that the breakdown of the green waste and

manure through the VERDE process significantly increases production of methane gas output as described below.

Pilot Plant Phase

Prior to commencing the Pilot Plant testing, green waste representative samples of the feedstock to be utilized at the Pilot and Demonstration Plant were prepared by California Grinding Inc (CGI) personnel and shipped to Brigham Young University (BYU) for analyses. Based on these feedstock lab analyses, an existing AD Pilot Plant was procured, renovated and modified to incorporate the Verde Pre-digestion technology. This included adding a pretreatment tank for hyperthermic temperatures for C-Bessci bacteria to grow prior to introduction into the AD system in order to obtain information and data useful to demonstration site installation of the VERDE Pre-digestion technology.

Pilot Plant Renovation

The digester Pilot Plant arrived on site on May 22, 2020. The Pilot had various issues that were addressed to get the plant operational. Repairs were made to the Pilot Plant as needed including the following:

- Installed new pipe insulation
- Removed shaft hosing and repacked shaft gland for receiving tank seal
- Replaced water-tight seals for tanks and pumps
- Reinstalled and repaired hoses and tubes that were damaged in transit
- Replaced digester tank insulation
- Rerouted and repaired electrical wiring
- Reconnected and re-calibrated existing instruments
- Steam-cleaned and removed leftover residue in digester and pre-digestion tanks.

Figure 3: Pilot Plant as Delivered

Source: Stellar J Corporation

Pilot Plant Retrofit

In addition to repairs to the pilot skid described in the preceding section, significant upgrades and modifications to the Pilot Plant were necessary to incorporate the VERDE Pre-Digestion technology. Please see below to see the upgrades that were included.

Flow Meter and SCADA System

Furnishing and installation of a 2" biogas analyzer\flowmeter, including piping, instrumentation, controls, and supervisory control and data acquisition (SCADA) system to measure the gas output from the digester.

Upgraded Site Electrical Service for Pilot

The electrical service needed additional 480 3-phase power to meet the Pilot's load requirements. This was necessary as the existing service at the site was not adequate to power the Pilot with the VERDE Pre-Digestion system including the added pumps and heating requirements.

VERDE Pre-digestion Tank

One of the tanks included in the original Pilot Plant was converted for use as the Verde Pre-digestion tank. It was not insulated, so we added 1" thick tank insulation to enable temperature control and uniformity throughout the Verde pre-digestion tank.

VERDE Pre-digestion Tank Heater

Installed an industrial tankless water heater capable of meeting the required VERDE temperature range. The 750-gallon pre-digestion tank provided the necessary hot water to recirculate in the hot water coils installed in the VERDE tank to keep the VERDE tank fluid in the heat to a range of 158 – 176 degrees Fahrenheit.

Blending Tanks and Pumps

Added two blending and feed tanks, progressive cavity mixing and feed pump, piping insulation, heat trace, wiring and controls. The two feed tanks and piping were connected to a constant feed and mixing pump to ensure the blending of the feed into the VERDE Pre-Digestion tank. The installation of the feed tanks was needed for mixing of feedstock prior to transferring over to the VERDE Pre-Digestion tank.

H and Temperature Probes

Added pH and temperature monitoring devices to the VERDE Pre-Digestion – the temperature probe and a pH indicator for the VERDE Pre-Digestion tank that reads 24/7 and alerts remotely for alarm conditions to ensure optimal operations:

- If temperature drops below 158 degrees Fahrenheit or if temperature goes above 176 degrees Fahrenheit was added to ensure that the VERDE Pre-Digestion tank is at its optimal temperature

- The pH indicator alerts us if the pH drops below 7 (too acidic) or rises above 8 (too much alkalinity). When green waste breaks down, the pH routinely drops during this phase.

Upgrade Verde Tank Lid to Steel

The existing plywood lid was not adequate for the VERDE Pre-Digestion tank, as too much heat would escape the existing plywood lid.

Cooling\Chilling Equipment Upgrades

Cooling\chilling equipment was installed between the Verde Pre-digestion tank and the anaerobic digester to drop the pre-digested feedstock temperature from 170 deg. Fahrenheit to 98 deg. Fahrenheit (digest temperature) prior to introduction into the anaerobic digester.

SCADA and Controls Modifications

The existing controls and control panel\SCADA system for the implementation and recording of VERDE Pre-Digestion test data, were added to gather and record appropriate data and provide alarms during upset conditions for the VERDE system.

Testing Lab

An onsite testing laboratory was added to test samples from the system, including the VERDE Pre-Digestion tank, the AD tank, feed tanks and effluent. The equipment procured included: DR3900 Spectrophotometer, Digital Reactor Block, Drying Oven, Muffle Furnace, centrifuge, feedstock blender and other testing accessories and chemicals.

Figure 4: Feed Tanks and Routed PVC pipe to 750-gallon

Source: Stellar J Corporation

Figure 5: Existing Plywood Lid

Source: Stellar J Corporation

Figure 6: Upgraded Steel Lid

Source: Stellar J Corporation

Pilot Plant Commissioning and Testing

Following completion of the renovation and retrofit activities described above, the Pilot Plant was commissioned, and a testing and data collection program was initiated for the VERDE process. This included completing the following:

- Initial Seeding of the Anaerobic Digester (AD) with 1,200 gallons of seed from a local municipal mesophilic digester.
- Ramp-up of Pilot Anaerobic Digester (AD) with feed from a non-green waste (dry-dog food slurry) to acclimate AD to pilot and build the AD level up to the full tank level of 2,700 gallons
- Operate AD at the designed 20-day AD hydraulic retention time (HRT) and 5-Day Pre-digestion hydraulic retention time (HRT). The time it takes for the anaerobic system to digest the organic waste feedstock (known as "hydraulic residence time" or "HRT") is a very important productivity measurement. It determines the sizing of the AD system. The longer it takes, the larger the system must be sized to hold, increasing both capital and operations/maintenance costs.
- Conversion of the AD feed from non-green waste to green waste feed at between 5-8% total solids.
- Running the AD system with green-waste feed at the prescribed retention times and accumulate baseline test data.
- Seeding with Caldicellulosiruptor bescii (C. bescii) inoculant in Pre-Digestion tank and feeding with green waste.

Pilot Plant Operations

Test parameters were established by the VERDE for the pilot anaerobic digester (PAD), VERDE pre-digestion tank, and the feed mixing tanks. Testing protocols, frequency and methods were established, utilized, and refined during the Pilot testing and will be utilized on the Demonstration Plant as well. Initially, the Pilot testing was based on the utilization of green waste feedstock without the VERDE Pre-Digestion system. This data was used to establish the baseline performance of the anaerobic digestion system operating in conventional mode.

The 2,700-gallon pilot anaerobic digester (PAD) was initially seeded with approximately 1,200 gallons of mesophilic digestate pulled from a nearby wastewater treatment plant on July 24, 2020. The mesophilic bacteria were chosen as the starting testing media as this is their normal status at the anaerobic digester facility. Bacteria each have their own optimum environmental surroundings and temperatures in which they thrive at their fullest potential. The PAD was equipped with a temperature probe and a pH indicator that provides an alert if any pH drops below 7 or goes beyond 8, or if the temperature drops below 98 degrees Fahrenheit or gets above 102 degrees Fahrenheit.

From July 24, 2020, to September 25, 2020, the system was fed with 30 gallons per day of a dry dog food and water mixture on a 24-hour continuous feeding schedule while the biomass/bacteria mass in the PAD became acclimated to its new environment and began to build up the digester's volume from 1,200 gallons to the full hydraulic retention time volume of 2,700 gallons. Various tests were conducted using our on-site lab. Tests included total solids, volatile solids, alkalinity, ORP/Redox, chemical oxygen

demand, methane, hydrogen sulfate, ammonia, phosphate, and carbon monoxide. Split samples were taken and sent to an independent laboratory for verification and confirmation of our in-house laboratory analyses results. The independent results confirmed that our lab work was accurate.

Operations began with a 30-gallon mixture of dog food and water and increased the feedstock rate by 10% every week until September 25, 2020. On September 25, 2020, we were at a design feedstock rate of 144-gallons per day and then began to introduce green waste starting at a 90% dog food\10% green waste feedstock ratio. We also started adding 10% thickened waste activated sludge (TWAS) from a nearby sewage treatment facility for the necessary micronutrients required for the green waste digestion optimization.

The 20-day AD hydraulic retention time and a 5-day VERDE pre-digestion tank equates to a feedstock rate of 144 gallons in a 24-hour span or 6-gallons every hour. We fed the VERDE tank and digester every hour as a best operational practice for the VERDE and AD processes.

On October 2, 2020, the VERDE Pre-Digestion tank pH level dropped to 6.4 ph. This was concerning as the pH level should be between 7 and 8. To raise the pH level, the lab technician added another bicarbonate and mixed it until the pH returned to its desired level. Total bicarbonate added to VERDE Pre-Digestion tank was 20.41 grams. VERDE Pre-Digestion tank pH levels remained between 6.88 - 7.03 ph.

By October 22, 2020, the feedstock was 100% green waste at a feed rate of 6 gallons an hour. Methane content of the biogas produced was at a constant 58%-62% range while feeding the digester only green waste and without the VERDE process in operation.

Figure 7: On-site Laboratory

Source: Stellar J Corporation

During this Pilot Plant operations period, we learned many valuable operational and process lessons and results that were included in the design and operation of the Demonstration Plant.

Some of the Operational lessons learned included:

- The C-Bessii bacteria was much more resilient in the actual field application than was first thought. When we initially had Pre-Digestion mixing mechanical difficulties in the ASB\Verde Tank, we were able to transfer, store at ambient temperature, and then subsequently reinstall the full contents of the Verde Tank and resume operations after the mixers were repaired.
- The nature of the green waste feedstock required near constant mixing of the feed tank to prevent plugging. With this knowledge, we were able to install necessary equipment and process in the Demonstration plant with better mixing capability.
- Preferable feedstock material types, sizing and configuration were learned in the Pilot and passed on to the Demonstration Plant. This included piping modifications for condensate issues and to prevent the future buildup of mineral deposits in the gas collection system.
- Feedstock testing, including feed rates, recipes, and material consistency was also conducted using several different parameters during the Pilot phase which were continued and utilized successfully at the Demonstration Plant level.

Pilot Plant Conclusions

The Pilot Plant testing, data collection and analyses confirmed the positive results from incorporation of the VERDE pre-digestion system that had been predicted from previously completed laboratory studies completed by VERDE and Brigham Young University. The conclusions are summarized below. The results of the Pilot were presented in the Critical Review Meeting Report to the CEC in a May 25, 2021, report by BYU professor Zachary T. Aanderud.

Conclusions

- Verde pre-digestion definitely improved carbon conversion to methane.
- Pilot studies predict 46 percent increased methane output.
- 48-hour retention time is adequate for pre-digestion.
- Adding dairy manure to green wastes improves pre-digestion.

Demonstration Phase

The Pilot Plant phase was followed by the design, construction, commissioning, and operation of the Demonstration Plant. Please see below for a summary of the goals and objectives of the Demonstration Pilot Project phase.

Goals and Objectives

- Demonstrate that the VERDE pre-digestion technology is technically, economically, and environmentally feasible at a commercial scale.
- Process more feedstock with higher rates of biomethane production and lower digestive output with VERDE
- Determine cost effectiveness and increased RCNG output with VERDE for our commercial-scale AD system processing 250 tons per day of organic waste
- Demonstrate how VERDE technology reduces local criteria air pollutant and greenhouse gas generation

Demonstration System Design, Construction and Commissioning

The Demonstration System (DS) is comprised of two parts:

- VERDE feedstock pre-digestion sub-system
- Anaerobic digestion subsystem

Table 1 provides the design basis input of the Demonstration System.

Table 1: Daily Expected Input Feedstock

Parameter	Value
Total Organic Waste Mass (lbs.)	~3,000-4,000
Total Solids (lbs. TS)	~1,000-1,500
Volatile Solids (lbs. VS)	~850-1,300
% TS	~6-8%
% VS of TS	~85-95%
Potable Water (gas/day)	~1,200-1,700

Source: California Grinding Inc.

Based on these input design parameters, the VERDE Pilot Demo Plant is expected to yield between 5-7 SCFM of biogas, which is equivalent to 2,000 – 2,300 MMBTU/yr or about 36 – 45 DGE's/day as shown in Table 2 below.

Table 2: Expected Output Parameters

Parameter	Value
Biogas Production (65%)	5-7 SCFM
Energy Output (DGEs)	35-45
Biosolids (#/day)	275 – 325
NOx Emissions (ton/year)	0.12

Source: California Grinding Inc.

Assembly and Installation of VERDE Pre-digestion Technology Equipment

The VERDE pre-digestion tanks are made from carbon welded steel and are fabricated at the manufacturer's shop where they are built and custom sized for our design. The carbon welded steel tanks follow the design and fabrication standards of the American Water Works Association, Section D100-11 for welded carbon steel tanks.

The carbon welded tanks are fabricated to last with strict quality control procedures and oversight. Specifications of these custom-built tanks include:

- Interior NSF61 & wastewater Epoxy Coatings to ensure the longest tank life possible.
- Meets or exceeds NSF61, NFPA22, CBC2010, ACE#7 and AWWA, UL 142, API 650 for all storage tank applications.
- Carbon Welded Steel Tanks are built to exact engineered designs.
- Multiple fittings and appurtenances.
- Exterior 646 Colored Epoxy

Mixing for the pre-digestion tanks is provided by pump mixers. The fluid is propelled by the pump through the lower nozzle, creating a defined current and flow pattern that keeps the tank completely mixed. The two VERDE pre-digestion tanks are each mixed with a single pump.

Two VERDE pre-digestion tanks are designed in parallel for batch feed operation from the feedstock equalization tank. This keeps the feed flow through the pipes into the VERDE pre-digestion tanks at a sufficient velocity to minimize solids settling. The VERDE tanks will have approximately 2-5 days of combined hydraulic retention time (HRT).

The total heat demand was estimated to be 150,000 BTU/hr for the VERDE demonstration project. The process heating system for the Demonstration Plant consists of a tankless hot water boiler and internal tank coils. For the low heat demands required by this size of Demonstration Plant, shell and tube heat exchangers, which would be used in a full commercial scale application, are not ideal as the flow and pressure demands would promote clogging and operational issues.

The installed boiler is capable of high temperature output (200ºF). As most residential and commercial tankless heaters only generate up to 160ºF water temperatures, a more robust hot water boiler was installed as shown below. Units of this size have a hot water heating output capacity of up to 240,000 BTU/hr and can be turned down to 50% load as needed.

Certification of Completion of Construction and Installation Activities

Figure 12 provides the signed Certification of Completion of Construction and Installation Activities from CGI's engineering, procurement and construction contractor-Stellar J Corporation.

Figure 8: Construction Certification of Completion

CONSTRUCTION CERTIFICATE OF COMPLETION

PROJECT: Grant ARV 18-021 FROM California Energy Commission ("CEC")

STELLAR J Certifies that the work under the above named project including all appurtenance thereto, has been satisfactorily completed. The demonstration facility located at 3077 S. Golden Gate Frontage Rd., Fresno, CA 93725 has been completed and the facility is ready to commence operations.

Stellar J Rep. Signature

9/29/2021
Date

1363 Down River Drive
Address

Woodland, WA 98674
City, State & Zip

Source: California Grinding Inc.

Demonstration Plant Operations

The Demo Plant ran for over 8 months, operating an estimated 4,120 hours. 3,240 of these operating hours were over a 6-month period. We started initial, trial operations on December 13, 2021, and ran for approximately two weeks through December 28th, 2021, and then continually from February 14 through April 6th and again from May 16 to November 23rd, 2022.

There were operations and testing personnel at the site as detailed on the daily inspection reports and the testing. Testing was done consistent with the Data Collection Plan previously submitted to the CEC.

Data was collected for each of the parameters in accordance with the Data Collection Plan. When the Demo Plant was operating, the data was recorded daily and provided on detailed weekly tabs in the data summary spreadsheet. Each sheet shows the daily data, issues, flow and feed rates.

We also logged in the results of all testing performed for the established parameters. Testing was typically done 3X a week for samples drawn at each of the seven-unit processing measurement points including the feed tank, Verde Tank 1, Digester 1, Verde Tank 2, Digester 2, Biogas port and Digestate Tank.

Normal Operating Hours were 24-hours a day, 7 days a week. Up and down time were as follows:

- Up-time from December 13 - 28, 2021, was approximately 75% of the 24 hours a day, 7 days a week. We shut down due to weather from December to February 2022.
- For the period from February 14 - April 6, up-time was approximately 85% of the 24 hours a day, 7 days a week.
- From April 7 – May 15 we worked on mechanical and process changes such as new boiler, insulating tanks and pipes, etc. to assist with more consistent heating and performance, including changing of the gas supply from the utility. We reseeded the digesters prior to restarting.
- Between May 16 and November 23, 2022, we had uptime of about 93% of the 24 hours a day, 7 days a week. We did have several periods of lowered feed rates due to plugging, pump issues where we kept the system running, and operations going.

Sustainability: From Organic Waste to Biomethane

Sustainability

The Project objectives preserve and enhance the use of natural resources in California in following ways:

- Increase the cost-effective supply of renewable natural gas (RNG) as a substitute for fossil fuel derived transportation, power plant and other usage,
- Enable waste generators to divert organic wastes from landfill disposal to productive use,
- Reduce greenhouse gas emissions that would have resulted from continued fossil fuel and landfill disposal practices.

The results of these Project objectives are summarized in Chapter 4 of this report.

Project Implementation and Responsible Parties

To successfully complete the Project, CGI assembled and worked with a highly qualified project team consisting of experts in project management, financial management, engineering, design, construction management, feedstock supply, RNG marketing, facility operation and maintenance, and data collection and analysis. As summarized below, the collective qualifications, skills, abilities, and technical and business experience

of this project team aligned well with the needs of the Project and ensured its successful completion.

Project Team Qualifications

Our Team is comprised of the following highly experienced and capable companies:

- **California Grinding Incorporated (CGI)** - Project owner, operator and developer
- **Aqua Engineering (AQUA)** – Anaerobic digestion system engineering and consulting, commissioning and startup specialists
- **Baker Tilly** – Financial analyses
- **Clements Environmental** - Technical and environmental consulting and permitting
- **DBG Energy** – Technical support
- **MDB Engineers** - Project management, technical and economic analysis, grant administration and report preparation
- **Stellar J Corporation** – Contractor, operator, data collector, reporting and laboratory analyses
- **Verde LLC** – Technology founder; providing complete technology oversight
- **West Coast Waste** - Feedstock and utilities supply and technical and administrative support

Highlights of the project team's qualifications (including relevant expertise, experience, and skill sets) are provided as follows.

California Grinding Incorporated (CGI)

CGI has been the largest processor and providers of woody biomass for combustion fuel and compost in the Central Valley. Founded in 2010, CGI has serviced seventy-five customers, handling up to 200,000 tons per year. With the closure of the biomass power plants in a reasonable haul distance and the phase out by 2020 of CGI's ability to provide this material as Alternative Daily Cover (ADC) to landfills, CGI is implementing an AD Project as the primary outlet for the green waste and other organics materials needing beneficial use in the Fresno area that it is obligated to process.

Aqua Engineering

AQUA Engineering (AQUA) was founded in 1992 and is providing technical and engineering expertise to the CGI Team. Aqua is a civil engineering firm specializing in anaerobic digestion for transport fuel recovery, municipal engineering, water resources, water and wastewater treatment design, and environmental services. They have provided engineering services to clients in California, Utah, Wyoming, Nevada, Idaho, Arizona, New Mexico, Colorado, and Hawaii since 1991. Aqua has particularly relevant

experience through the recent design and construction of the Wasatch Front Resource Recovery and OES San Bernardino AD projects as they are similar to the CGI project. They also have worked on numerous anaerobic digestion projects in both the municipal and agricultural arenas.

Baker Tilly US

Baker Tilly US LLP is a public accounting and consulting firm, headquartered in Chicago, Illinois. Baker Tilly brings specialized expertise in financial modeling of biomass anaerobic digestion facilities and monetizing tax credits associated with this type of project.

Clements Environmental Corporation

Clements Environmental Corporation is an environmental engineering and consulting firm located in Los Angeles, California. Since 1987, the firm has specialized in solid waste engineering and management, project development, regulatory compliance, and permitting. Clement's clientele includes private industry and city and county government agencies. Specific expertise includes integrated solid waste management planning and program implementation; transfer station and material recovery facility planning, permitting, and design; composting and anaerobic digestion (AD) facility development; renewable energy project development; regulatory compliance evaluations; zero waste strategic planning; and feasibility analysis.

DBG Energy

DBG Energy LLC is a development consulting firm specializing in bioenergy and waste to energy projects. Founded in 2015 by Joe Ramirez and Annie Kipp, the firm's focus is adding value, support and technical assistance to developers, consultants, finance and legal partners relevant to developing projects in the bioenergy/waste to energy space. Current projects include gasification, advanced ethanol and cellulosic ethanol of the west coast and Central America.

MDB Consulting Engineers

MDB Engineers is a consulting firm specializing in the evaluation and implementation of organic waste management and renewable energy (RE) projects. MDB has provided California State Agencies (including the CEC, CalRecycle, Department of Corrections and Department of General Services), local governments and private sector clients over 40 years of continued service. MDB staff has hands-on experience with all forms of waste processing and renewable energy technologies, including solar, wind, geothermal, hydro, landfill gas, MSW and other waste conversion technologies. In addition to the firm's technical expertise, it has extensive experience with the regulatory opportunities in California related to siting and permitting facilities, marketing of electricity and biogas, renewable energy and waste management project financing, federal and state subsidies and structuring public/private and other partnerships to enable project

implementation. MDB's experience also includes grant administration and management and extensive work with anaerobic digestion of food and green waste, biosolids and other organic materials.

Stellar J Corporation

Stellar J is a Contractor with over 30-years' experience and works in a broad range of industries and types of construction. Stellar J has an infrastructure division that specializes in Municipal Construction including Water and Wastewater plants and infrastructure, municipal digesters, solid waste, marine, terminals, bridges, tunneling among many other construction areas. Stellar J also has a national renewables division that specializes in the creation of renewable energy. Stellar J utilizes numerous processes and feedstocks in the creation of Renewable Energy. Most of this renewable's work is performed under the Engineering, Procurement, and Construction model similar to the work performed on the CGI project. The renewable energy work by Stellar J includes Food-Waste Digestion to electrical power, Landfill Gas (LFG) to electrical power, LFG to Renewable Natural Gas (RNG), Dairy Manure Digestion to RNG, Green and Brown Hydrogen fuel production and green waste to RNG.

Verde LLC

The Verde Team has worked together for more than seven years and has patented and commercialized several technologies. With four successful and well-published PhD's and an expert in project management and finance, the multi-disciplinary Team possesses a very unique skill set. The unique combination of expertise embodied within the Team made it very capable of successfully accomplishing the project objectives and proving the technical feasibility of bacterial pretreatment of green waste biomass. More than 35 years' experience designing, commercializing, and operating anaerobic digesters is represented on the Team. Experts in microbiology, engineering, and chemistry with decades of experience in these fields are also involved in this project. Dr. Lee Hansen (Prof. Emeritus, BYU Department of Chemistry and Biochemistry) and Dr. Conly Hansen (Prof. Emeritus, Food and Nutrition USU, and research scientist at Verde, LLC, Inc.) served as researchers on the project and focused their decades of AD-related expertise in operating the Pilot and Demonstration system. Dr. Zach Aanderud, in the Life Sciences College at BYU, directed and supervised collection, identification and the culturing of the microbial systems. Dr. Aanderud routinely cultures and identifies both bacteria and fungi in nearly all his publications to-date. In addition, Dr. Lee Hansen regularly publishes on the thermodynamics and kinetics of biological systems. Mr. Jason Miller, Manager of Verde, LLC, has an undergraduate degree in biology with considerable research and laboratory experience. He also has an MBA which emphasized finance. As noted, the Team has worked together for many years. This is demonstrated by the work which has already been completed in the successful effort to prove the technical feasibility of bacterial pretreatment.

West Coast Waste

West Coast Waste, Inc. (WCW) services the entire Central Valley which includes, but is not limited to Fresno, Clovis, Sanger, Madera, Kerman, Kingsburg, Dinuba, Hanford, Chowchilla, Visalia, Tulare, and Lemoore. WCW focuses on urban and agricultural waste, green and wood waste recycling, and currently produces mulches. They work closely with the agricultural community and provide orchard removal and chipping services. WCW also partners with landfills and other businesses and communities, to provide chipping and grinding services for greenwaste. WCW has a contract with the City of Fresno to receive and process roughly 50% of the City's daily collected greenwaste.

Chapter 2: Activity Report

Project Schedule

The Project performance period began December 26, 2019, and ended December 31, 2022. Table 3 below provides a schedule of activities completed.

Table 3: Project Schedule

Task #	Task Name	Start Date	Completion Date
1	General Project Tasks	December 2019	December 2022
2	Feedstock, Off-take & Economic Analysis	January 2020	October 2022
3	Design & Engineering	June 2020	May 2021
4	Procurement & Site Preparation	October 2020	April 2021
5	Construction	March 202	October 2021
6	Commissioning	July 2021	September 2021
7	Data Collection & Analysis	December 2021	December 2022

Source: California Grinding Inc.

Demo Project Budget

The original Project budget was $4,000,000, made up of a $3,000,000 grant from CEC and $1,000,000 from the CGI team as matching funds. Actual totals were as follows:

- CEC grant - $3.0 Million
- CGI Matching Funds – $1.2 Million
- Total - $4.2 Million

Business Plan/Total Project Cost

As previously mentioned, the Purpose of the Demo Project was to verify that application of the VERDE system was commercially viable. This was accomplished comparing the Project costs of the commercial scale AD plant being implemented at the same Fresno site (the Commercial Plant) in both its conventional mode and with the incorporation of the VERDE pre-digestion technology.

As described below, implementation of the VERDE system has a very positive impact on all aspects of the Commercial Plant project's economics.

In its conventional configuration, the Commercial Plant is planned to digest approximately 90,000 tons per year of green, food and dairy manure wastes, producing

an estimated 190,000 MMBTU annually, With the VERDE system added to pre-digest and recirculate the conventional system's liquid digestate, an additional 30,000 MMBTU/year will be produced each year.

A comparison of the proposed Commercial Plant with and without the addition of the VERDE pre-digestion system is presented as follows:

Project Capital Cost

Adding the VERDE System to the conventional version of the Commercial Plant as described above adds approximately $5.5 million in capital cost as indicated in Table 3.

Table 4: VERDE Capital Cost Estimate

Capital Cost Estimate	Amount in dollars
Equipment	$ 3,500,000
Installation and Site Work	$1,000,000
Engineering/ Construction	$500,000
Miscellaneous and Contingency	$500,000
Total Capital Cost	$5,000,000

Source: California Grinding Inc.

Operating costs

Operating costs will increase by approximately $300,000 per year as shown in Table 5.

Table 5: VERDE Annual O & M Cost Estimate

Capital Cost Estimate	Amount in Dollars
Labor	$ 52,000
Maintenance	$200,000
Utilities	$15,000
Miscellaneous and Contingency	$33,000
Total Annual O&M Cost	$300,000

Source: California Grinding Inc

Revenues from Feedstock Tipping Fees, Renewable Transportation Fuel Sales and Environmental Attributes Monetization

Revenues from tipping fees will not change with the addition of the VERDE system as the plant input capacity remains the same. Revenues from sale of the renewable transportation fuel and the additional transportation fuel sales coupled with the monetization of environmental attributes earned from the increase in RNG output, will increase by approximately $1.8 Million per year.

Based on the net revenues (additional revenues less O&M expenses), pay back the $5.5 million capital cost in less than four years, making this a very worthwhile investment. This is shown in Table 6 below.

Table 6: VERDE Simple Payback Analysis

Capital Cost Estimate	Amount in Dollars
Additional Annual Revenues	$1,797,663
Additional O&M Cost	$300,000
Net Additional Annual Revenues	$1,497,663
Capital Cost	$5,500,000
Simple Payback (Years)	3.67

Source: California Grinding Inc

Chapter 3: Project Assessment

This chapter provides an assessment of the Project, specifically with respect to important system improvement goals to be achieved through the addition of the VERDE pre-digestion system with respect to productivity, greenhouse gas reduction/carbon intensity, and economics. This chapter also summarizes lessons learned during the Project operations that will be incorporated into the next phase of commercialization.

As described below, the Project was extremely successful in demonstrating the effectiveness and benefits of the VERDE pre-digestion system.

Goals and Results

Productivity

Three important productivity measures were tested:

- Conversion of carbon contained in the organic waste feedstock into methane
- Production time to convert the feedstock carbon into methane
- The reduction of process residuals requiring further processing or disposal

The results of this Project demonstrated the productivity effectiveness of the VERDE pre-digestion system in all three.

Carbon Conversion to Methane

The purpose of an organic waste AD project is to produce methane for conversion to Renewable Natural Gas (RNG). The more efficiently the system can convert the carbon in the feedstock into methane, through a process such as VERDE pre-digestion, the more marketable transportation fuel that can be produced. This is the most significant factor affecting the project's economic viability.

Our Pilot Plant testing of the VERDE pre-digestion system indicated an overall methane production increase of 47%. The demonstration plant, with its better process controls and operability, improved this productivity increase to 55%.

Applying the VERDE pre-digestion system to a conventional AD plant's digestate, as described in Chapter 2 and illustrated in Figure 14, which is the recommended next step in commercialization, is projected to increase methane output from the same feedstock by 27% regardless of the blend of organic waste feedstock materials (green waste, manure and food waste) used as feedstock. This increase is summarized in Table 6 below.

Production Time to Convert Feedstock Carbon into Methane

The time it takes to the anaerobic system to digest the organic waste feedstock (known as "hydraulic residence time" or "HRT") is a very important productivity measurement.

It determines the sizing of the AD system. The longer it takes, the larger the system must be sized, increasing both capital and operations/maintenance costs.

The conventional AD system replicated by the Demonstration Plant had an HRT of 20 days, meaning that the system was sized to hold 20 days of the planned feedstock input rate at all times during plant operation. When the VERDE pre-digestion system was added, the HRT dropped to 16 days (4 days for pre-digestion plus 12 days for anaerobic digestion. This 20% improvement will allow either a corresponding decrease in the size of the commercial AD plants or a 20% increase in the amount of feedstock that can be processed, that it is applied to.

Reduction of Process Residuals Requiring Further Processing or Disposal

One of the most significant on-going costs of operating an organic waste anaerobic digestion system for RNG production is management of the solid residues remaining after digestion. This material must either be composted or disposed of by land-spreading or sanitary landfill. By pre-digesting the incoming feedstock, the AD system is able to digest more of the organic material, reducing the number of digested solids requiring expensive further treatment or disposal.

Based on the results of this Project, an 8 to 12% reduction of residue is expected to be achieved by applying the Verde pre-digestion system in the Project's next Phase, as described in Chapter 2 and illustrated in Figure 14 - commercial demonstration. This reduction is shown in Table 7.

Table 7: Increased Methane Production

	Case 1 90% GW/10%Manure (DGE/Year)	**Case 2 60% Green Waste/30% Manure/10% Food Waste (DGE/Year)**
Conventional	813,949	986,969
With VERDE	1,083,700	1,256,719
Net Increase (DGE/PY)	220,723	269,751
Net Decrease (%)	27%	27%

Source: Zero Waste Energy

Greenhouse Gas Reduction and Carbon Credits

By producing more methane for use as transportation fuel, the VERDE pre-digestion process increases both the annual tons of greenhouse gas reduced and the Carbon Intensity score estimated for the planned Phase 2 commercial AD Project. This is summarized in Table 8 below.

Table 8: TABLE 8 - RCNG Output, CI Score & GHG Reduction

	RCNG Output		CI Score	GHG Reduction
	MMBTU/YR	**DGE/Yr**	(gCO2e/MJ)	Metric Tons of CO2
Case 1 - 90% GW/10% Manure				
Conventional	112,325	813,949	-49.8	16,162
With VERDE	149,551	1,083,700	-44.4	20,753
Net Increase	33%	33%	11%	28%
Case 2 - 60% Green Waste/30% Manure/10% Food Waste				
Conventional	136,201	986,964	-113.1	27,769
With VERDE	173,427	1,256,715	-106.8	34,324
Net Increase	27%	27%	6%	24%

Source: Zero Waste Energy

Economics

One of the key purposes of this Project was to verify that application of the VERDE pre-digestion system would improve the economics of conventional anaerobic digestion of organic wastes viable. This was accomplished by comparing the expected Project costs of the commercial scale AD plant being implemented in the next Phase at the same Fresno site in both its conventional mode and with the incorporation of the VERDE pre-digestion technology.

As described in Chapter 2 of this report, implementation of the VERDE pre-digestion system has a very positive impact on all aspects of the project's economics.

Specifically:

- The 220,000 to 270,000 DGE increase annually in RNG produced by the pre-digested feedstock produces an equivalent increase in the Project's RNG sales,
- The similar increase in GHG reduction increases the value of the Project's Environmental Attributes,
- The decrease in HRT provides a proportional decrease in system capital costs, and
- The reduced quantity of digestate solids requiring expensive further treatment or disposal provides on-going operation savings.

Project Challenges

Lessons Learned and Project Replicability

The Project Team learned a lot from conducting this Project, both from the Pilot and Demonstration Plant operations. These lessons learned will be incorporated into the design, construction, and operations of the commercial plant.

The key issues included:

- The C-Bessii was much more resilient in the actual field application than was first thought. When there were initial VERDE pre-digestion system mixing mechanical difficulties in the ASB\Verde Tank, we were able to transfer, store at ambient temperature, and then subsequently reinstall the full contents of the Verde Tank and resume operations after the mixers were repaired,
- The nature of the green waste feedstock requires near constant mixing of the feed tank to prevent plugging. This included piping modifications for condensate and improved mixing issues and to prevent the future buildup of mineral deposits in the gas collection system. Equipment selection, including higher horsepower pumps, increased valve and pipe sizing and variations in the inlet and outlet points were all modified during the Project. With this knowledge we will be able to install proper equipment and process in the Commercial plant with increased operability,
- Optimal feedstock material types, sizing and configuration requirements were learned in the Pilot and Demonstration plant operations. This knowledge will be used in the Commercial Plant with respect to feedstock selection and processing system design,
- Feedstock testing protocols, including feed rates, recipes, and material consistency was also conducted using several different parameters during the pilot and demonstration plant operations. This experience will be incorporated in the design, construction and operation of the commercial plant,
- As a thermophilic (high temperature) process, the VERDE pre-digestion system required greater heating capacity than originally anticipated. A larger and more efficient heating system, coupled with better heat transfer and increased insulation will be incorporated into the design and construction of the Commercial Plant,
- Precise and automated temperature, pH and other key parameters control is necessary to optimize the effectiveness of the VERDE pre-digestion system. This information will be used to improve the monitoring and control system design of the Commercial Plant.

GLOSSARY

Specific terms and acronyms used throughout this scope of work are defined as follows:

AD—Anaerobic Digestion

ADC—Alternative Daily Cover

ARFVTP—Alternative and Renewable Fuel and Vehicle Technology Program

CAM—Commission Agreement Manager

C. bescii—Caldicellulosiruptor bescii

CNG—Compressed Natural Gas

Commercial Plant—The 250 ton per day organic waste AD plant being planned for implementation in Fresno, California

DGE—The pre-commercial plant designed, constructed, and operated to test the VERDE pre-digestion system

DGE—Diesel Gallons Equivalent

EPC— Engineering, Procurement and Construction

GGE—Gasoline Gallons Equivalent

GPD—Gallons per day

HRT—Hydraulic Retention Time

IS/MND—Initial Study/Mitigated Negative Declaration

LCFS—Low Carbon Fuel Standard

MGD—Million Gallons Per Day

MSW—Municipal Solid Waste

PAD—Pilot Anaerobic Digester

PIIRA—Petroleum Industry Information Reporting Act

PLC—Programmable Logic Controller

PON—California Energy Commission Program Opportunity Notice

RCNG—Renewable Compressed Natural Gas

Recipient—California Grinding, Inc. (CGI)

RFS—Renewable Fuel Standard

RINs—Renewable Identification Numbers

RNG—Renewable Natural Gas

SCADA—Supervisory Control and Data Acquisition

SCFM—Standard Cubic Feet Per Minute

TWAS—Thickened Waste Activated Sludge

U.S. EPA—United States Environmental Protection Agency