Energy Research and Development Division
FINAL PROJECT REPORT

CLEANWORLD'S FERTILIZER PRODUCTION SYSTEM

Technical, Economic and Commercial Evaluations

Prepared for: California Energy Commission
Prepared by: CleanWorld

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PREFACE

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Transportation

CleanWorld's Fertilizer Production System-Technical, Economic and Commercialization Evaluations is the interim report for the CleanWorld Fertilizer Production System Project (contract number PIR-12-007, grant number PON-12-506) conducted by CleanWorld. The information from this project contributes to the Energy Commission's Transportation research program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

CleanWorld designed, built and tested an innovative Fertilizer Production System to produce fertilizer products from digester waste. The Fertilizer Production System, constructed at the South Area Transfer Station in Sacramento, California enhances the existing commercial digester by converting the residual solid and liquid stream (which has historically been discarded) into high value natural fertilizer products. This custom designed Fertilizer Production System is capable of processing 72,000 gallons per day of effluent and producing up to 9,600 pounds of solid fertilizer and 25,000 gallons of liquid fertilizer daily.

Tasks included fertilizer research and market review, engineering design and site layout, constructing and commissioning, data collection and analysis, technology transfer, and production readiness. From August to December 2014, CleanWorld sold more than 75,000 gallons of liquid fertilizer to Northern California farmers. In addition, CleanWorld created more than 1,500 pounds of high-value vermicompost and more than 30 tons of solids to be used as a soil amendment.

Keywords: Anaerobic digestion, Biodigester, Fertilizer Production System, Effluent

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

California is the nation's second largest consumer of fertilizer (next to Iowa). In 2007, California farms spent $1.3 billion on fertilizer, lime and soil conditioners used on 6.7 million acres of agricultural land. Fertilizers are used with almost every vegetable crop in the state and nitrogen application makes up the majority of the fertilizer applied. Fertilizers are broadly classified as either organic or conventional. Organic fertilizers are derived from natural sources, such as mineral deposits or plant and animal matter, using extraction or manufacturing processes that do not excessively damage the environment. Conventional fertilizers are typically based on industrial chemical manufacturing processes, many of which carry heavy environmental burdens.

The U.S. Department of Agriculture statistics indicate that nationally the agriculture industry has been applying approximately 20 million tons per year of the primary macronutrients -- nitrogen, phosphate, and potash -- since the mid-1970's, about half of which was nitrogen. By comparison, natural and organic fertilizer use in the United States is relatively small at 0.5 – 0.7 million tons per year.

Organic fertilizer use, however, is on the rise as people are returning to environmentally friendly or "green" products. California has a larger share of organic farms than any other state with almost 20 percent of the nation's organically certified farms and 13 percent of the organic acreage, making the state one of the largest markets for natural and organic fertilizers in the United States.

The following analysis looked at the fertilizer market both nationally and in California, with a special focus on the market situation in Yolo and Solano counties, which are home to large numbers of farms located in close to the Sacramento Biodigester. CleanWorld, in collaboration with the University of California, Davis; Otto Construction; Frank M Booth, Vasko Electric, Peabody Engineering, TSS Consulting, and Evergreen Recycling designed, constructed and tested an innovative Fertilizer Production System (FPS) that produces fertilizer products from digester effluent (waste) created by CleanWorld's Sacramento BioDigester and Renewable Natural Gas (RNG) production facility at the Sacramento South Area Transfer Station. This commercial-scale prototype was engineered as a tank and skid system with automated loading and process controls to reduce on-site management requirements. The FPS system can be configured to create multiple fertilizer products which may be customized to meet local market demand.

Project Purpose

Anaerobic digesters biologically break down the structure of food waste to generate methane for use as vehicle fuel and/or heat and electricity, and the residual nutrients are released in simple, plant available forms through the digester effluent. Using digestate (nutrient-rich substance produced by anaerobic digestion that can be used as a fertilizer) for soil and fertilizer products is co-benefit of anaerobic digestion and few American companies have been able to unlock the full promise of digestate as a contributor to higher value organic products. In recent years, however, consumers in the retail fertilizer sector have increased their demand for organic and natural fertilizer and soil amendment products Natural and organic fertilizers open up a significant potential market opportunity for anaerobic digesters, considering the volume of liquid and solid fertilizers that might be produced from the 100 million tons of organic and food waste material currently being landfilled or otherwise disposed. That amount of material represents more than half a million tons of nitrogen per year being thrown away and wasted, or 4 percent of the total nitrogen use in the United States. At the same time, more farmland is being converted to organic production every year.

In 2011, more than 3 million acres of organic cropland had been certified nationwide. Anaerobic digester residuals are a new form of organic fertilizer in the United States. In 2013, OMRI added digester effluent (waste) to the list but restricted its use on organic farms in an apparent effort to control pathogens. OMRI has determined that any digester effluent from a system loaded with "manure or other animal materials" cannot by applied to organic crops less than three to four months before harvest (depending on whether the crop touches the soil). Waste from a digester treating "plant materials" has no restrictions.

CleanWorld appraised the fertilizer market both nationally and in California to:

- Understand the market potential for fertilizers made from anaerobic digester residuals.
- Develop a plan to produce, market and distribute fertilizers with market potential.
- Evaluate the overall economic and financial impact of creating and selling fertilizers from Clean World anaerobic digesters.
- Focus on the market in Yolo and Solano Counties which have numerous farms located close to the Sacramento Biodigester.

CleanWorld collaborated with the University of California, Davis; Otto Construction; Frank M Booth, Vasko Electric, Peabody Engineering, TSS Consulting, and Evergreen Recycling to design, construct and test an innovative Fertilizer Production System (FPS) that produces fertilizer products from digester effluent (waste) from the CleanWorld's Sacramento BioDigester and Renewable Natural Gas production facility at the Sacramento South Area Transfer Station. This commercial-scale prototype was engineered as a tank and skid system with automated loading and process controls to reduce on-site management requirements. The FPS system can be configured to create multiple fertilizer products which may be customized to meet local market demand.

Project Process

The research began by evaluating the market for natural fertilizers and understanding the market demands for fertilizer products, then, developing the technology to create marketable fertilizers from digester effluent. CleanWorld successfully executed a detailed and in-depth evaluation of the natural fertilizer market, including interviews with farmers, leading agronomists, and agricultural extension workers from the top agricultural research university in California.

Field research was also performed by applying a variety of fertilizer products made from CleanWorld's digester residuals. Approximately 75 to 85 percent of all material entering the anaerobic digester emerges at the back end as a liquid effluent with typical nutrient values of nitrogen, phosphorous and potassium. These nutrients provide an alternative supply of nutrients for farmers – as well as beneficial micronutrients and microbes – that can replace and reduce the using more costly and environmentally damaging synthetic fertilizers. Discoveries made during this phase of the grant prompted changes to the technological development of the FPS system.

Most significantly, the technology was divided into two subsystems: a solid/liquid separation system and a liquid fertilizer production system. The former became a skid-mounted prototype that successfully extracted more than 30 tons of solids from commercial CleanWorld digesters and became an integral component of digester operations. In addition to extracting solids, CleanWorld also successfully created high-value worm castings from the solids by generating more than 1,500 pounds of digester-derived vermicompost.

The liquid fertilizer production system was modeled on the original concept designed by CleanWorld, but the final product was simplified and made modular to allow for "plug-and-play" of additional pieces for scale-up when and if the market demanded liquid fertilizer products. The base system was designed to allow shipment of minimally pretreated liquid digester effluent to use on farms. CleanWorld successfully used this version of the liquid fertilizer production system to sell more than 75,000 gallons of fertilizer to farmers during this project.

As the study progressed, it became clear that additional work was necessary to resolve some of the questions related to fertilizer market potential before selecting a specific product. More of the work became focused on analyzing the market and economics for a broad range of potential fertilizer products, rather than detailing a production and marketing plan for a particular product. Subsequently, CleanWorld acquired quantitative and qualitative market intelligence, as well as market and industry-level feedback, about the potential market acceptance, demand, and economics for digestate use in California and the United States.

Marketing and sales of fertilizer products continue at CleanWorld's BioDigester projects in the Greater Sacramento Area. In addition, research and developing new fertilizer products and manufacturing technologies and techniques are ongoing and will continue after the end of the current project.

Project Results

CleanWorld successfully completed these technical goals:

- Processed up to 30,000 gallons per day of liquid digester effluent
- Reduced the volume of liquid effluent to 7,500 gallons per day using vapor compression evaporation for fertilizer production with nutrient condensed effluent
- Created up to 10,000 gallons per day of marketable liquid fertilizer product created up to 8,000 pounds per day of marketable solid fertilizer product
- Demonstrated commercial scale effluent processing for revenue generation at a successful biodigester and RNG production facility
- Improved process-related effluent processing economics
- Reduced GHG emissions by up to 80 percent -- 2,270 tons of CO2 equivalents per year – by offsetting nitrogen based fertilizers with natural and organic fertilizers

- Reduced petroleum dependence by improving economics for a renewable natural gas project and fueling station for public use
- Stimulated economic development in California by developing a replicable plan for fertilizer production at California anaerobic digestion projects
- Provided natural fertilizer products at competitive market costs to local growers

The results of the project will enhance CleanWorld's business and anaerobic digestion technology for years to come. In addition, California rate payers will benefit from this research as CleanWorld digester projects will become more technically and economically viable and will, in turn, provide rate payers with clean, renewable fuel from a material currently clogging landfills and generating harmful greenhouse gasses. In addition to the public health and environmental benefits, economic benefits to the public will include increased tax revenues, expanded employment, additional investment in California businesses, and additional property taxes through redeveloping underused land.

CHAPTER 1: Project Overview and Management

This report is the Final Report for the CleanWorld Fertilizer Production System project carried out by CleanWorld for the California Energy Commission. The grant was executed in June 2013 and completed in December 2014.

1.1 Initial Project Goals and Final Project Goals

The original technical goals for the project were:

- Process up to 30,000 gallons per day of liquid digester effluent.
- Reduce the volume of liquid effluent to 7,500 gallons per day using vapor compression evaporation for fertilizer production with nutrient condensed effluent.
- Create up to 10,000 gallons per day of marketable liquid fertilizer product.
- Create up to 8,000 pounds per day of marketable solid fertilizer product.

CleanWorld successfully met these technical goals. However, the path to achieving the stated objectives changed during the course of the project. The first task executed for this grant involved a detailed economic and marketing feasibility study, the results of which indicated that the technology used for condensing the liquid per the second technical goal may not be financially feasible. Therefore, evaporation was tested at the lab and pilot scales, but the full-scale technology was not utilized for this grant. In addition, other technologies—such as membrane filters, rotary presses, and centrifuges—were also evaluated for their ability to achieve this goal.

The Fertilizer Production System (FPS) system, as originally conceived, included multiple steps which involved both removing suspended solids from the mixed slurry resulting from anaerobic digestion and further processing of the liquids. The sequence of solids removal and liquid treatment as well as the requirements of each process differ significantly, which led to the development of the FPS as two separate but integrated systems described as the Solid-Liquid Separation (SLS) System and the Liquid Fertilizer Production (LFP) System. Another benefit to separating these processes was that the SLS system may be used independently of the LFP system for certain tasks, such as solids removal directly from a tank, with the resulting liquid being returned to the tank where it can continue to be used in the Anaerobic Digesters (AD) process. The SLS system could also be used either as a pretreatment for the LFP system or as a post-treatment process, depending on the type of product desired. Mobility in the SLS system allowed it to be used where needed instead of being embedded statically within the FPS system. Although the SLS system was originally built and tested at the Sacramento BioRefinery to improve the physical and financial performance of the AD system producing RNG as a vehicle fuel, it was also tested and developed at other CleanWorld AD facilities in the Sacramento region which will demonstrate the applicability of the technology to a wider customer base. Although this was not a part of the original concept, it was well within the scope of work for the grant and it helped meet the technical goals. The SLS system can process over 100 gallons per minute of liquid digester effluent and extract up to 2,000 lbs of solids per hour. This gives the system the capacity of processing 30,000 gallons in five hours to generate up to 10,000 pounds of solids, which meets goals one and four. During a three-day intensive testing period, the SLS system was operated for 900 minutes, processing over 55,000 gallons and extracting over 250,000 pounds of solids. Since then, the SLS system has been running on average three – six hours per day, at least five days per week.

The LFP system was also modified from its original design concept without affecting the ability to meet the technical goals. This was also well within the original scope of work. The LFP system was modeled on the original concept designed by CleanWorld, but the final product was simplified and made modular to allow for "plug-and-play" of additional pieces, which would be added when and if the need arose based on the market demands for liquid fertilizer products. The base system was designed to allow for shipment of minimally pretreated liquid digester effluent for use on farms. The capacity of the LFP system as installed was nominally 30,000 gallons which, if utilized to its fullest extent, would exceed the third goal.

1.2 Tasks and Objectives

In support of this project, CleanWorld successfully completed the following tasks:

- Fertilizer Marketing, Procurement, and Economic Feasibility Report
- Engineering design and site layout
- Construct, install, and commission fertilizer production system
- Collect, analyze, and report on data
- Technology transfer activities
- Production Readiness Plan

1.3 Key Contractors and Subcontractors

The prime contractor on this grant was CleanWorld, who owns and operates several anaerobic digesters in the Greater Sacramento Area. CleanWorld also sells its anaerobic digester technology to customers and developers. CleanWorld provided the project manager for the grant as well as all administrative services (with significant assistance from parent company, Synergex Ventures) as well as engineering design, operations, and market research.

The lead construction subcontractor was Otto Construction, Inc. The lead electrical engineering subcontractor was Vasko Electric, Inc. The lead civil engineering subcontractor was Peabody Engineering, Inc. The lead controls and instrumentation subcontractor was Frisch Engineering, Inc. The lead mechanical engineering subcontractor was Frank M. Booth, Inc. The lead environmental consultant was TSS Consultants. These firms provided critical engineering and environmental services in support of the project construction.

The University of California, Davis (UC Davis) performed research on the creation and use of effluent products, which benefitted both the marketing and engineering related tasks on this grant. Evergreen Recycling performed market research on natural fertilizers and helped review digester effluent treatment technologies.

CHAPTER 2: Fertilizer Marketing, Procurement, and Economic Feasibility

This chapter describes the activities conducted related to marketing and financial feasibility analysis. The results of those activities where appropriate and provide details about ongoing strategies and activities that are expected to continue into 2015 as this system is run and replicated. The goals of this report were to:

- Understand the market potential for fertilizers made from anaerobic digester residuals.
- Develop a plan for creating, marketing, and distributing fertilizers with market potential.
- Evaluate the overall economic and financial impact of creating and selling fertilizers on CleanWorld's anaerobic digesters.

As the study progressed, it became clear that additional work was needed to resolve some of the questions related to fertilizer market potential before selecting a specific product. Therefore, more of the work became focused on analyzing the market and economics for a broad range of potential fertilizer products, rather than detailing a production and marketing plan for a particular product. Subsequently, CleanWorld acquired quantitative and qualitative market intelligence, as well as market and industry-level feedback about the potential market acceptance, demand, and economics for digestate use in California and the United States. The following sections are the results of that analysis.

2.1 General Background on Fertilizers

Fertilizer is any material that is added to soil to promote the growth of plants. Fertilizers come in various forms, the most typical being granulated or powdered solids. The next most common form is concentrated liquid fertilizers, while the least common form is pre-mixed dilute liquid fertilizers. Liquids have the advantage of being immediately available to plants and microbes as they soak deeper into the soil without the need for mechanically turning the soil. They can also be applied along with irrigation water through an existing drip irrigation system or through sprayers, allowing for wide and even coverage. The disadvantage of liquids is that the presence of water adds significant weight, which increases the cost of transportation. Some solid fertilizers can be formulated to be soluble when mixed with water, allowing for less expensive transportation while maintaining the application advantages of liquid fertilizers.

Fertilizers are broadly classified as either organic or conventional. Organic fertilizers are derived from natural sources, such as mineral deposits or plant and animal matter, with extraction or manufacturing processes that are not excessively damaging to the environment. Conventional fertilizers are typically based on industrial chemical manufacturing processes, many of which carry heavy environmental burdens. Whereas conventional fertilizers consist of specific chemical compounds formulated for rapid plant uptake, organic fertilizers are derived from natural sources containing complex mixtures of materials with complicated physical, chemical, and biological effects on plants, soils, and the soil microbiome. Some of the compounds in organic fertilizers can be immediately absorbed by plants; some are released slowly as the organic matter decays; while other compounds may persist in the soil for much longer. These compounds can alter the soil's physical structure, which can improve its moisture and nutrient holding capacity over subsequent growing seasons. Organic fertilizers often have much lower concentrations of plant nutrients and thus are more costly to collect and distribute than conventional fertilizers. However, this also prevents harsh chemicals from harming the plants. They are also difficult to produce at the same scale as conventional fertilizers since they ultimately derive from slower biological processes.

Before organic or conventional fertilizers, mined inorganic fertilizers were used for many centuries, whereas chemically synthesized conventional fertilizers were only widely developed during the industrial revolution. Nevertheless, conventional fertilizer use has significantly supported global population growth. It has been estimated that almost half the people on Earth are currently fed as a result of synthetic nitrogen fertilizer use. However, increases in productivity have been accompanied by damage to the environment in the form of greenhouse gas emissions associated with the production of synthetic fertilizers and eutrophication of waterways due to excess nitrate runoff.

More recently, organic fertilizer use is on the rise as people are returning to environmentally friendly or "green" products. The organic agriculture movement, started in the 1970s, has grown exponentially in the last two decades, resulting in the formation of several certification organizations that provide standards for what is and is not considered part of the "organic" agriculture movement. The OMRI is the largest and most respected certification agency in the United States. These agencies publish guidelines that dictate the specific kinds of fertilizers that can be used as inputs on certified organic farms. In California, the Department of Food and Agriculture (CDFA) created its own registry of acceptable inputs called Organic Input Materials. Because conventional fertilizers are omitted from these lists, the market for organic fertilizers has grown with the industry.

Anaerobic digester residuals are a new form of organic fertilizer in the United States. Therefore, until recently, the lists of acceptable input materials did not specifically include digester effluent. In 2013, OMRI added digester effluent to the list, but restricted its use on organic farms in an apparent effort to control pathogens. OMRI has determined that any digester effluent from a system loaded with "manure or other animal materials" cannot be applied to organic crops less than three to four months before harvest (depending on whether the crop touches the soil). Effluent from a digester treating "plant materials" has no restrictions. The CDFA has not reached a final determination on the use of solid and liquid digester residuals on organic farms, but they are likely to follow the OMRI model.

2.2 U.S. Fertilizer Manufacturing Industry

To better understand the United States fertilizer manufacturing industry, it is important to differentiate between the three major types of fertilizer nutrients that are produced and consumed in the United States: nitrogen (N), phosphorus (P), and potassium (K). Many fertilizers are manufactured using chemical processes to provide only one of these essential plant macronutrients. Some fertilizers are extracted from naturally occurring, inorganic sources. Blends may then be created by mixing the primary synthetics in different proportions of the ratio of nitrogen to potassium to phosphorous in soil (NPK) based on the needs of the plants. Organic and natural fertilizers typically contain a blend of NPK in a proportion based on the natural characteristics of the source. As opposed to synthetic fertilizers, which are extracted and manufactured utilizing highly energy intensive methods, digester effluent derived fertilizers are more sustainable than their synthetic counterparts. The nutrients do not disrupt natural cycling of carbon or N, P, and K, and the lower energy intensity of the manufacturing process means that using CleanWorld's fertilizer products reduce life-cycle greenhouse gas emissions. There are numerous differences between traditional and natural fertilizer manufacturing processes.

2.2.1 Traditional Nitrogen Manufacturing

A primary building block for all organisms, nitrogen is found in abundance in the earth's atmosphere. However, the majority of plants cannot absorb nitrogen from the air and thus rely on nitrogen from the soil, which is usually added through fertilizers, since natural replacement rates cannot support the high levels of growth required in modern agriculture.

Anhydrous ammonia is the source of nearly all the nitrogen fertilizer used in the United States. It is synthesized through the Haber-Bosch process, a chemical process that combines atmospheric nitrogen with hydrogen. Nitrogen can be obtained from the air, but the hydrogen is derived predominantly from natural gas. Anhydrous ammonia may be applied directly to the soil or converted into other nitrogen fertilizers such as urea, ammonium nitrate, nitrogen solutions, and ammonium sulfate.

The United States nitrogenous fertilizer manufacturing sector has decreased production over the past several years and imports now provide over 55 percent of the nation's supply. A total of 26 United States ammonia plants have closed since 1999, representing 42 percent of the United States nitrogen fertilizer production capacity.

2.2.2 Traditional Phosphorus and Phosphate Manufacturing

Phosphorus is found in every living cell and plays vital roles in shaping deoxyribonucleic acid (DNA) and providing energy for cell activity. It is not found in its elemental form in nature. To produce phosphoric fertilizer, phosphate rock is mined and treated with sulfuric acid. This creates phosphoric acid, which is the basic material for most phosphoric fertilizers. The reliance on phosphate rock means that the sector is heavily integrated with phosphate mining and plants are mostly located near reserves of phosphate rock. The United States is home to only about 2 percent of the world's phosphate rock reserves (behind Morocco, China, and four other countries) and in 2012 had 14 percent of the world's production.

2.2.3 Traditional Potassium and Potash Manufacturing

Potassium is an essential nutrient for plant growth, especially water utilization and the regulation of photosynthesis. It is found in potash, a name for various mined and manufactured salts that contain potassium in a water-soluble form. Despite significant consumption of potash in the United States, the domestic potash manufacturing sector is smaller than those for nitrogenous and phosphoric fertilizer. The majority of potash consumed in the United States must be imported, primarily from Canada, the world's largest potash producer. The potash manufactured in the United States is produced in New Mexico, Utah, and Michigan.

2.2.4 Organic and Natural Fertilizer Manufacturing

Non-conventional fertilizer manufacturing as an industry is relatively immature. Other than use of animal manure and compost, alternative natural and organic fertilizers have been mostly manufactured at relatively small scales from local specialized waste streams. Fish waste may be hydrolyzed to liquefy the proteins and generate an organic liquid fertilizer. Overseas, some larger scale production of liquefied fish waste has appeared on the market. Biosolids—the residual bacterial biomass left at the end of the wastewater treatment process—have been utilized as a natural soil amendment, although many states, including California, restrict the use to non-food crops. Animal rendering plants make granular meals from residuals of the rendering process. These include meat meal, bone meal, and blood meal. While typically used as animal feed, which is usually a higher value than fertilizer, they may be converted to fertilizers high in nitrogen and phosphorous.

While the goal of organic farms is to create sufficient crop nutrients from on-farm resources, such as green manure (that is, fertilizers made from nitrogen fixing crops specially grown for fertilizer), compost, and animal manure, as the size and number of organic farms expand, it will become more difficult to sustain the farms using locally available nutrients. Imported nutrients are already becoming an important part of organic farming practices, especially for farmers used to applying a product to their fields to enhance crop yield. As a result, the manufacturing process for natural and organic fertilizers will need to become more efficient and industrial, while maintaining the environmental benefits touted by the organic label. As such, digester residuals have the potential to become an important industrial source of organic fertilizer.

The carbon intensity of digester-based fertilizer is much lower than conventional fertilizer manufacturing. Ammonia, ammonium nitrate, and urea manufacturing can release one to nine kg of carbon dioxide (CO_2) into the atmosphere per kg of N produced, according to the International Energy Agency, with ammonium nitrate at the high end and urea at the low end. Urea ammonium nitrate (UAN), an increasingly commonly used nitrogen fertilizer in the United States, has a carbon intensity of two to six kg CO_2 per kg N. These emissions result from the use of fossil fuels both as a chemical feedstock (that is, natural gas is reformed to produce hydrogen for ammonia) and as an energy source. These carbon intensities do not include the greenhouse gas emissions or other environmental impacts associated with applying conventional fertilizers in the field.

Digester-based fertilizers are generated from renewable feedstocks with much lower energy inputs, and the energy used often comes from the anaerobic digestion process itself rather than fossil fuels. In addition, the application of digester-based fertilizers in the field does not contribute as much nitrous oxide emissions or nitrate runoff as conventional fertilizers. The lifecycle carbon intensity of digester effluent as a fertilizer has not been calculated in any formal studies, although it should be very low since the only source of carbon emissions is from the transportation of the fertilizer to the field (assuming the digester and effluent treatment equipment are self-powered). Although the fertilizer offset credit gained by land applying digester effluent has not been enumerated in a formal research study, it has been calculated for compost. As part of the Low Carbon Fuel Standard for the High-Solids Anaerobic Digestion pathway, the California Air Resources Board estimated that each ton of compost used reduced greenhouse gas emissions by the equivalent of 0.26 metric tons of CO_2. CleanWorld's Sacramento BioDigester was estimated to be capable of producing 2,000 tons of compost annually, offsetting emissions of 520 metric tons of CO_2 equivalents. Since 1,000 gallons of digester effluent contains 19 kg of N, and the carbon intensity of UAN is two to six kg CO_2 per kg N, then the carbon offset for the digester effluent is 38 – 114 kg CO_2 per 1,000 gallons of effluent applied. The Sacramento BioDigester was estimated to produce 6.5 million gallons of effluent per year when operating at its maximum capacity. If all of the effluent from this single facility were used as a UAN substitute, it would offset an additional 247 – 741 equivalent metric tons of CO_2.

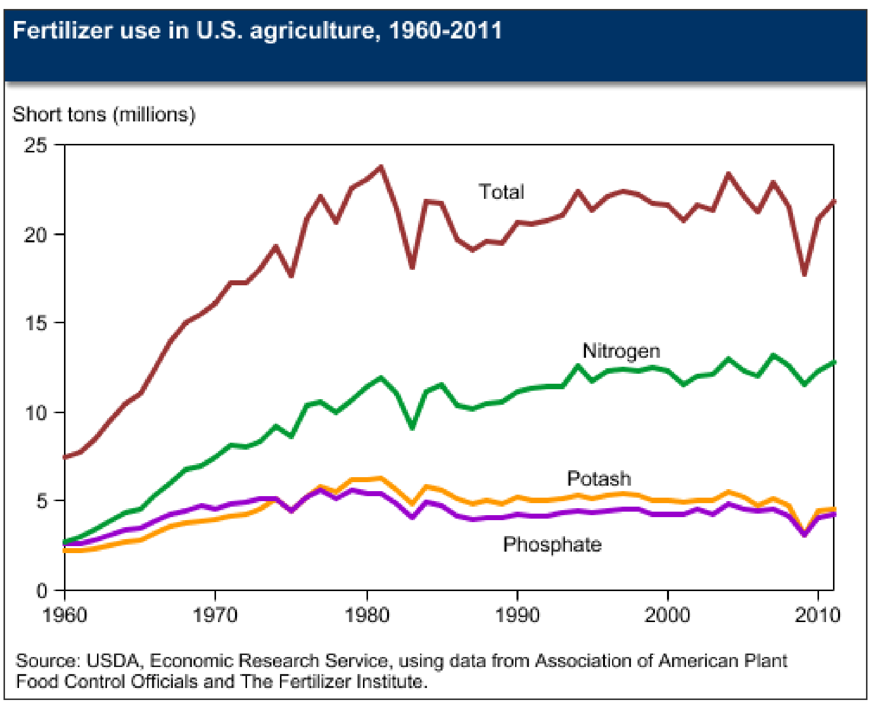
2.3 Fertilizer Market Analysis

There are 1.2 billion acres of agricultural land in the United States, 400 million of which are dedicated to growing crops. California contains eight to nine million of those acres (down from 11 million just a few years ago), but productivity is still higher in California than any other state. Along with high productivity comes high demand for fertilizers. However, California also has a larger share of organic farms than any other state with almost 20 percent of the nation's organically certified farms and 13 percent of the organic acreage. This puts a large share of the market for natural and organic fertilizers in California. The following analysis looked at the fertilizer market both nationally and in California, with a special focus on the market situation in Yolo and Solano counties which are home to large numbers of farms located in close proximity to the Sacramento Biodigester.

2.3.1 U.S. Fertilizer Markets

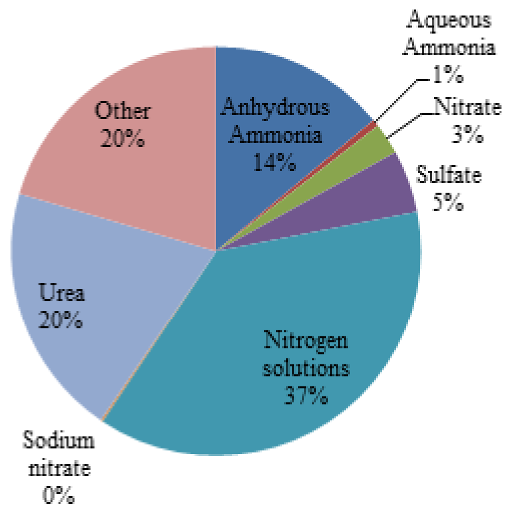
The United States is a mature market for fertilizer, but it is also still an evolving market and can even be volatile. Statistics on United States fertilizer usage are collected by the U.S. Department of Agriculture. These statistics indicate that the United States agriculture industry has been applying approximately 20 million tons per year of the primary –macronutrients—nitrogen, phosphate, and –potash—since the mid-1970's, about half of which was nitrogen (see figure below).

Figure 1: Nutrient Use over Time in the U.S. Agriculture Industry



In 2011, approximately 30 million tons per year of ammonia, urea, nitrates, and blends of these were used to supply the nitrogen needs of the nation's farms. The majority of farms used blended solutions for their fertilizer needs. Ammonia made up 15 percent of the nation's nitrogen demand, but only 166,000 tons of nitrogen was applied in the form of liquid ammonia solutions.

Figure 2: 2011 U.S. Consumption of Selected Nitrogen Materials

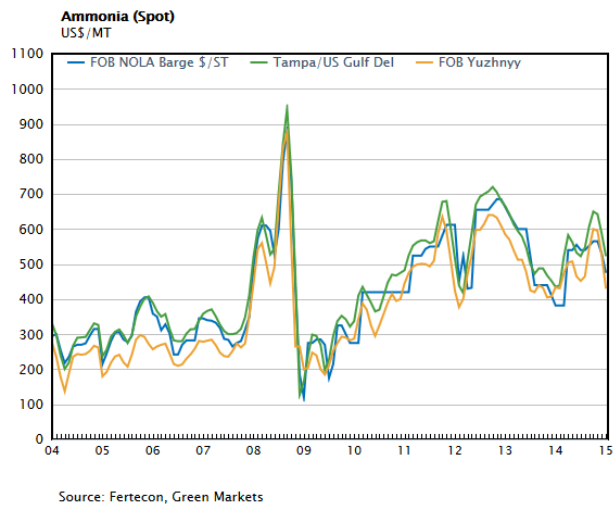


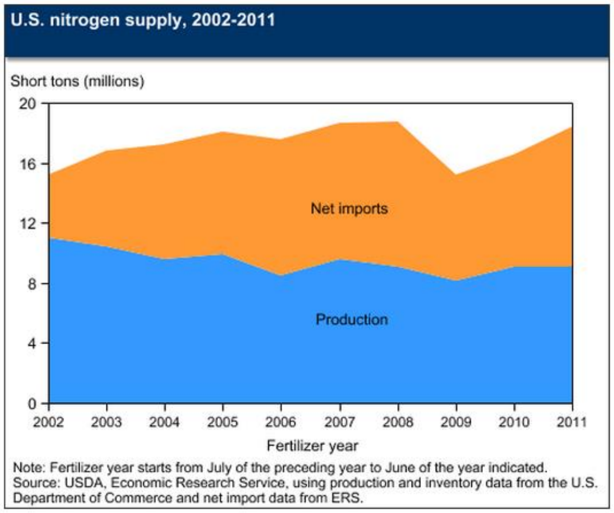
Source: USDA, Economic Research Service, TVA (Tennessee Valley Authority), AAPFCO (Association of American Plant Food Control Officials), TFI (The Fertilizer Institute).

Fertilizer markets have become more expensive and volatile recently. Volatility in the market can occur due to fluctuations in the supply of natural gas and the ingredients used to make fertilizers. In the commercial agricultural and turf sectors, annual changes in fertilizer use and price are typically driven by drought cycles, changes in planted acres based upon crop prices, the supply and price of natural gas, and the competition for nitrogen fertilizers worldwide. Because natural gas is used in the manufacture of fertilizer, it plays an essential role in the fertilizer industry and, by extension, the agriculture industry as a whole. The rise and fall of the natural gas market over the last decade has caused the price and availability of nitrogen fertilizers to swing wildly. Between 2000 and 2008, high natural gas prices and limits in the domestic gas supply forced fertilizer prices to historic highs.

In conventional fertilizer manufacturing, natural gas is used to produce the hydrogen necessary for making ammonia. This ammonia is used as the feedstock for other nitrogen fertilizers, such as anhydrous ammonium nitrate and urea. Between 2000 and 2006, United States ammonia production declined 44 percent and ammonia imports increased 115 percent. In 2011, according to the United States Department of Agriculture (USDA), the United States imported a record 54 percent, or 10.79 million tons, of the nitrogen fertilizer for farming. Starting in 2012, however, increases in the domestic natural gas supply, triggered in part by the proliferation of fracking, has led United States fertilizer plants to reverse the trend of the past decade and begin increasing production of nitrogen fertilizer for major crops. At the same time, ammonia prices have remained relatively consistent despite the increase in domestic natural gas production, although the sharp rise in ammonia prices between 2009 and 2012 was curtailed in the last couple years.

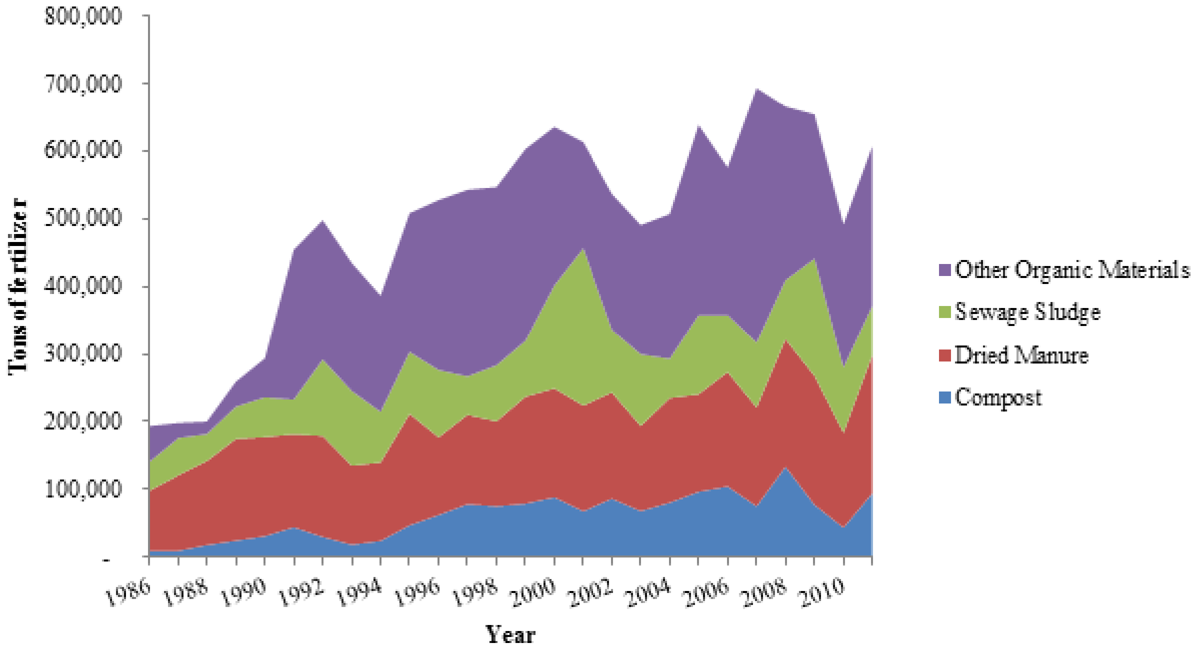
Figure 3: Domestic Production vs. Foreign Import of Nitrogenous Fertilizers in the U.S (left) and Historical Spot Prices for Ammonia Over the Last 10 Years (right)





By comparison, natural fertilizer use in the United States is relatively small at 0.5 – 0.7 million tons per year. Assuming the nitrogen content of these materials is about 10 percent, this represents an application of less than 100,000 tons per year of nitrogen from organic resources, which is less than 1 percent of the total amount of nitrogen applied through use of conventional fertilizers in 2011. However, the use of organic materials has increased over the last 20 years, particularly fertilizers other than biosolids, manure, and compost.

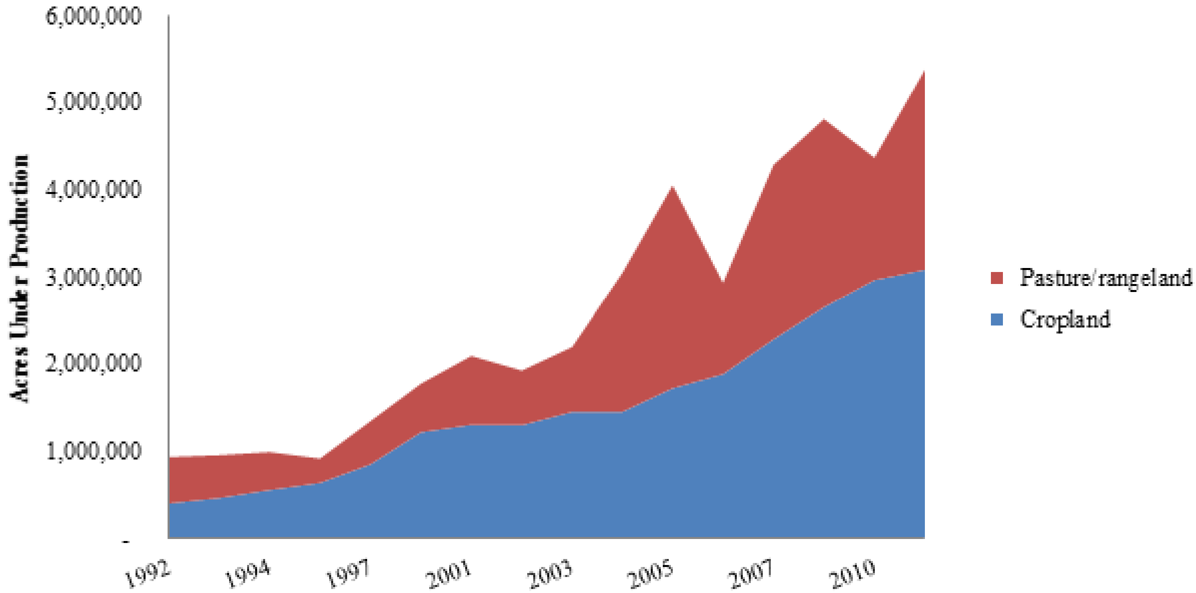
Figure 4: Non-conventional (organic and natural) Fertilizer Use in the U.S. by Type



Source: ERS, TVA (Tennessee Valley Authority), AAPFCO (Association of American Plant Food Control Officials), TFI (The Fertilizer Institute).

Using digestate for soil and fertilizer products is an oft-heralded benefit of anaerobic digestion. However, few American companies have been able to unlock the full promise of digestate as a contributor to higher value organic products. In recent years, consumers in the retail fertilizer sector have increased their demand for organic and natural fertilizer and soil amendment products. This opens up a significant potential market opportunity for anaerobic digesters, considering the volume of liquid and solid fertilizers that might be produced from the 100 million tons of organic and food waste material currently being landfilled or otherwise disposed. That amount of material represents over half a million tons of nitrogen per year being thrown away and wasted, or 4 percent of the total United States nitrogen use. At the same time, more farmland is being converted to organic production every year. In 2011, over 3 million acres of organic cropland had been certified nationwide.

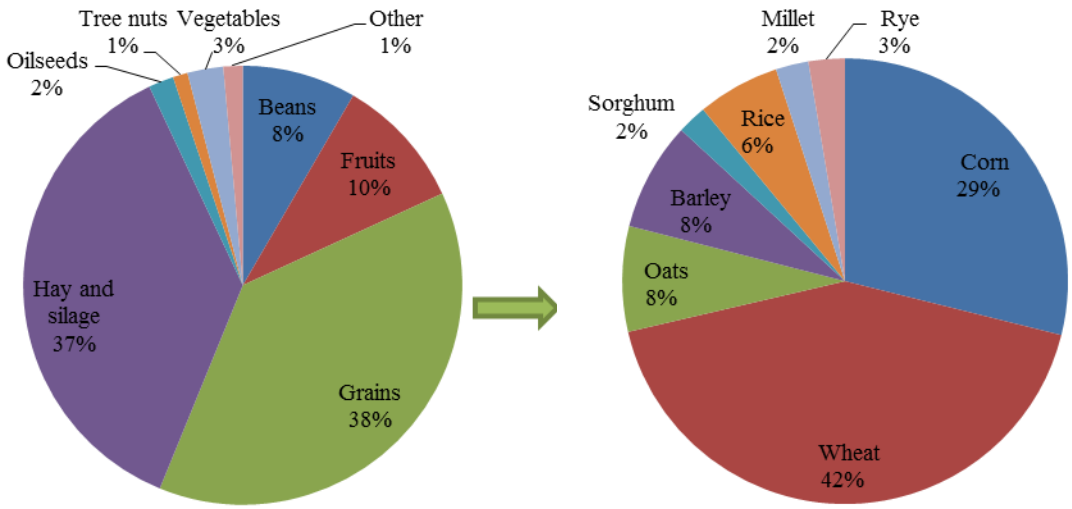
Figure 5: U.S. Certified Organic Farmland Acreage, 1992-2011



Source: USDA, Economic Research Service, based on information from USDA-accredited State and private organic certifiers.

The majority of land certified for organic production in 2011 was used for growing hay/silage and other grains (primarily wheat and corn). Corn production also required as much as half of the nation's nitrogen usage in 2011.

Figure 6: Share of U.S. Certified Organic Crop Acreage in 2011 by Crop Type (left) and Within the Grains Category (right)



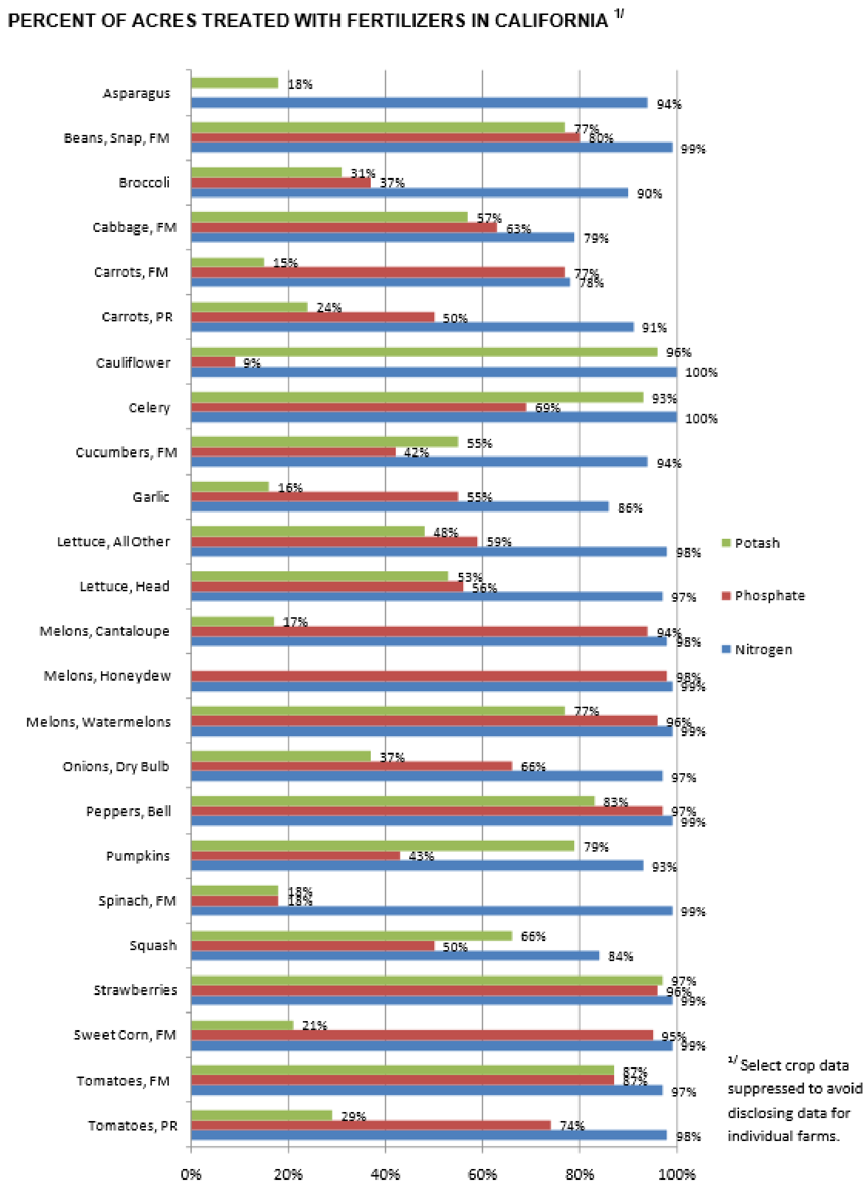
Source: USDA, National Agricultural Statistics Service, www.nass.usda.gov.

The potential for utilizing digester effluent as a substitute for conventional fertilizer on organic farms in the United States is large, and the biggest impact will be on hay and silage, grains (particularly wheat and corn), as well as fruits and beans. Corn may be a good target crop, since its cultivation requires large quantities of nitrogen, it makes up over 10 percent of the United States certified organic crop production, and the edible portion is not in contact with the ground. There is clearly room for growth in the use of organic materials on farms in the United States.

2.3.2 California Fertilizer Markets

As a state, California is the nation's 2nd largest consumer of fertilizer (next to Iowa). In 2007, California farms spent $1.3 billion on fertilizer, lime, and soil conditioners used on 6.7 million acres of land. Manure was also applied to 645,300 acres of farmland in California in 2007. Fertilizers are applied to almost every vegetable crop in the state, and nitrogen application makes up the majority of the fertilizer applied. Over 20 out of 24 vegetable crops in California apply nitrogen to over 90 percent of the vegetable cropland (see table below).

Figure 7: Percentage of California Vegetable Cropland in 2010 Treated with Fertilizers, by Vegetable and Nutrient



Source: USDA, National Agricultural Statistics Service, www.nass.usda.gov.

In addition to consuming significant quantities of fertilizer, California is also the largest crop producer (with double Iowa's crop output) and the largest organic agriculture producer. With large concentrations of population, California is ideal for anaerobic digestion of organic waste because there are inputs for the digester (food and food processing waste) outputs for the energy (population and industrial centers) and outlets for the organic fertilizer.

California boasts over 25 million acres of farmland (3.7 percent of the nation's total), 9.5 million of which is dedicated to growing crops. Of these 9.5 million acres, 0.4 –million—or 4 percent of the total crop –land—were certified for organic crop production in 2011. This represents 13 percent of the nation's organically certified cropland. California also has 24 percent of the nation's organic pasture and rangeland and 20 percent of the total number of organic farms in the country. There are approximately 80 thousand farms in California and approximately 2,500 of them are certified organic. These 80 thousand farms generated over $48 million in sales in 2012, $32 million of which (67 percent) was from crop output.

California farms lead the nation in the production of 79 products, including over 99 percent of the nation's almonds, artichokes, dates, figs, raisin grapes, kiwi, olives, clingstone peaches, pistachios, prunes, pomegranates, sweet rice, clover seed, and walnuts. California produces 23 percent of the nation's greenhouse and nursery products. California also ranks first in the nation's export of tree nuts, fresh and processed fruit, and processed vegetables. Between them, Fresno, Tulare, Kern, Merced, and Monterey Counties accounted for 54 percent of the state's agricultural sales, which totaled $26 billion in 2012.

Figure 7: Highest Grossing Agricultural Products in California

Source: CDFA, Agricultural Statistics Review 2013-2014

2.4 Competitive Analysis of Digester Based Fertilizers

Anaerobic digester facilities have several advantages over other fertilizer manufacturers. First, the overall manufacturing process is a net producer of energy, creating significant revenues from the sale of energy in the form of biogas, electricity, or compressed natural gas. This is in contrast to traditional fertilizer manufacturing, where energy is consumed in the process. In addition, the raw ingredients from which AD fertilizers are derived are neither mined nor manufactured. They are waste products from such sources as grocery stores, restaurants, food processors, and municipalities. These waste products can typically generate additional revenues through tipping fees from haulers. The actual fertilizer products are considered byproducts of the digestion process and are typically underutilized by anaerobic digestion facilities. In reality, most digester facilities pay a cost for disposal of digester residuals if they cannot utilize them. This may factor into the value of the residuals and help keep the cost of digestate very low compared to other natural fertilizer products.

2.4.1 Factors Impacting Valuation

The challenge for digestate-based fertilizers and soil amendments is to identify solutions that overcome collection, transportation, and distribution barriers, while keeping the resulting product organic and cost competitive. One problem with assessing the value of fertilizers made from digester residuals is that the anaerobic digester is not strictly a fertilizer manufacturing facility. It is also an energy production facility and a waste treatment facility. Therefore, assessing the cost of production for fertilizer is difficult, as the costs are split between multiple product streams.

Another issue is how to factor in the cost of transporting the fertilizer product. Transportation costs vary depending on the distance and hauler, and hauling distances vary depending on the customers. Digester effluent has a moisture content of 97 to 99 percent with a nitrogen content of 0.5 to 0.8 percent. One gallon of digestate weighs 8.4 lbs. Consequently, a major factor in determining the overall competitiveness of digestate fertilizer is shipping cost. Transportation of liquid in tankers over short distances (less than 50 miles) generally costs around $0.10 per gallon, which is equivalent to $2.40 per pound of nitrogen in liquid digester effluent. The average cost of conventional fertilizers is around $0.60 per pound of nitrogen, including shipping. Therefore, shipping alone will make undiluted digester effluent more expensive than conventional fertilizers.

Processing the liquid effluent to increase the concentration of nutrients would reduce the shipping cost. For example, concentrating the nitrogen in digester effluent by four times to 2 percent reduces the shipping cost to $0.60 per pound of nitrogen, but this would require removing 75 percent of the water. The cost of removing this water could be significant. Simply boiling off the water would require about 7,000 BTU per gallon of effluent treated. At $15 per mmBTU, this would add $0.42 per gallon or $2.50 per pound of nitrogen to the cost of producing the concentrated liquid. However, this is oversimplified since it does not account for heat transfer inefficiencies or the loss of ammonia during the boiling process. There may be more cost effective ways to concentrate nitrogen, but they would have to cost less than $2.50 per pound of nitrogen recovered to be cost effective. Furthermore, to compete with conventional fertilizers, the transportation cost would have to be much less than $0.60 per pound of nitrogen, which means that the concentration of the final product would have to be higher. This will cost more, however, thus there will be a minimum transportation cost which may not be low enough to compete with conventional fertilizer. Understanding the cost of the available concentrating equipment will help pinpoint this minimum transportation cost and a price point at which digester-based fertilizers can compete with conventional ones.

An alternative strategy is to capitalize on the natural and organic nature of the digester as well as the microbial benefits by finding a niche market like organic farms that will pay a premium for natural or organic fertilizers. Organic liquid fertilizers on the market retail for as little as $4.40 per pound of nitrogen and as much as $187.50 per pound of nitrogen. The range of prices depends on the quality, form, and type of organic fertilizer as well as the supply and demand for the product and whether transportation costs are included. For example, on the cheaper end of the scale are fish emulsions whose odor reduces demand and high volume of production increases supply, leading to the low price. Furthermore, these are often produced overseas, and shipping costs are not included in the retail price. Alternatively, at the high end are some specialty organic fertilizers that are highly sought after and are produced by hand at very small volumes, and these are sold in retail outlets where the transportation cost is included in the price.

There may be an opportunity to sell a non-certified “natural” fertilizer to the non-organic market, if there are farmers and gardeners willing to pay more for the natural alternative even though they cannot sell their food as certified organic. The price of the fertilizer would be higher than conventional fertilizers, but lower than organic fertilizers. The demand would have to be from farmers interested in natural fertilizers. However, it remains to be seen how they would monetize the fact that they are using natural fertilizers. New labels touting the environmental benefits unique to anaerobic digesters and the closed-loop nature of the fertilizer could help in this regard. However, such new labels would have to be accompanied by a promotional campaign and associated expenses. It is part of the strategic marketing plan to learn how to go about with the promotional campaign and other marketing approaches.

2.5 Strategic Fertilizer Marketing Plan

The strategy for marketing fertilizer products based on digester residuals depends on a thorough understanding of the market potential, as described in the preceding section. CleanWorld undertook efforts as part of this grant to better understand the local market needs, to develop new markets, and to access the existing demand for natural fertilizers based on digester residuals. The majority of these efforts were conducted with the help of UC Davis researchers and third-party consultants.

2.5.1 General Market Access Strategies

California offers a variety of fertilizer outlets, including conventional and organic agriculture, horticulture, turf industries, landscaping, and retail markets. Targeting all potential markets will allow manufacturers of novel fertilizer products to determine which market will be the best suited for each product.

The agriculture and horticulture industry is by far the largest consumer of fertilizer products. Most fertilizers are sold to the end user by fertilizer distributors and brokers, with only a handful of distributors controlling the majority of the market. Targeting these distributors is critical for getting access to the end user. Distributors focus on product price point, quality, and shipping costs while end users focus on ease of use, price point, and quality. The turf and landscape markets work in much the same way as the agriculture and horticulture markets. There are distributors that focus primarily on turf and landscaping, but many of the agriculture distributors also market in the turf and landscape market.

The retail market works on a totally different set of principles than the commercial markets. The retail market in California is divided into three categories: hydroponic stores, big box stores, and garden centers. The market for fertilizers in hydroponic growing systems, which provide all of a plant’s growing needs through nutrient solutions in water, has a large number of small- and medium-sized distributors that focus on retail hydroponic stores. There is a large variety of products with a focus on specialized plant response characteristics, so products must have high-quality, targeted packaging and branding to succeed in this market. The market for big box stores, such as Walmart, Home Depot, and Costco, is controlled by a small number of manufacturers that sell directly to the stores. These stores market products at a highly competitive price point. Stores may have their own special requirements for packaging, palletizing, and shipping. The garden center market includes characteristics of both the hydroponic and the big box markets. Garden centers carry a variety of products—some specialty, some general—which come from both direct sales and distributors. They market on price point and variety. In all three of these retail fertilizer markets, it is essential that products be properly branded for the specific market.

2.5.2 Market Development and Outreach Efforts

Marketing fertilizers in California presents challenges because the market is already saturated with dozens of products from various producers. In addition, the multi-billion dollar California fertilizer industry contains a small handful of companies who distribute a majority of the products. To maximize market penetration, a dynamic marketing plan is required.

The conventional fertilizer industry is oversaturated, making it difficult for digester-based products to compete on either volume or price, especially considering the low price per gallon necessary to compete on price per pound of nitrogen. Digester-based fertilizers can compete, however, in a niche market for natural, biological, and ecologically friendly fertilizers. Since the organic fertilizer industry has already been developed to access this niche, CleanWorld is looking into organic certification. However, gaining acceptance for previously unknown fertilizer types in the organic industry takes time and considerable investment of financial and human resources. In the meantime, CleanWorld has been attempting to access a non-organically-certified niche that still values the environmental benefits of a natural fertilizer over a conventional one. This is the niche being targeted for sales of CleanWorld's proprietary 3-3-3 all-purpose liquid fertilizer as discussed below.

CleanWorld conducted meetings with farmers and others in the agricultural community in Northern California to assess acceptance and potential use of digestate-based fertilizer products. CleanWorld hosted an industry roundtable on December 12, 2013 in conjunction with the UC Davis California Institute for Food and Agricultural Research that was attended by food processors, farmers and other agriculturalists, and researchers. The purpose of the meeting was to share information about CleanWorld's digestate and products developed from the digestate thus far and to collect input from prospective users and researchers on where they see the most market potential for digestate. As a result of the meeting, CleanWorld developed a research initiative with several UC Davis researchers who have novel concepts for the utilization of digester effluent. Leads were also generated for beta testers and users of fertilizer products.

CleanWorld has been focused on demonstration opportunities to prove that a range of products from their facilities' digestate can be produced, distributed, and marketed. Developing new technical approaches to processing and conditioning the material to produce new products is also an area of study. The following are examples of research and demonstration activities CleanWorld has undertaken while attempting to demonstrate the value of digester co-products:

- Identification of demonstration partners for composting solid residuals.
- Development of a proprietary system for producing CleanWorld 3-3-3 All-purpose Liquid Fertilizer and other blended and upgraded fertilizers from digester liquids.
- Registration of the liquid digester effluent (as "CleanWorld's SoilTea") and three blended products based on liquid effluent as commercial fertilizers with the CDFA.

- Creation of a partnership with a major national fertilizer distributor that has registered CleanWorld's liquid all-purpose bio-based fertilizer under its own label for retail distribution in all 50 states.
- Demonstration of the use of residual fibers as a high-value input material for the manufacture of fiber boards and building materials.

CleanWorld is working with Evergreen Recycling on a farmer outreach program in the counties surrounding the Sacramento and UC Davis BioDigesters. The purpose of the outreach is to solicit farmers' input on the feasibility of using liquid digester effluent on their crops and to enlist some of them to participate in field trials.

CleanWorld developed a promotional sales and marketing awareness campaign that will involve retail stores, fertilizer distributors, and other public and private stakeholders committed to organic diversion and closed-loop economy practices. The purpose of the campaign is to promote awareness of CleanWorld's 3-3-3 liquid fertilizer product, which is currently sold online through their distribution partners and is currently being marketed directly to their retail distribution channels (that is, Emigh's Hardware, Target, and super store outlets such as Home Depot). This partnership will assess consumer acceptance of CleanWorld's bio-preferred, all-purpose liquid fertilizer product through online and retail distributors as well as regional agriculture and "Farm-to-Fork" events that target the appropriate customer base.

A campaign was conducted from June 1 through September 30th, 2014 that included both an online and ground retail strategy. It was marked with a series of press releases, field event show attendances, social media stories, and television spots aimed at promoting the ecological benefits of carrying the 3-3-3 product line, which include landfill diversion, offset of conventional fertilizers, and reduced carbon footprint, and the closed-loop appeal of the product, which is the "farm to fork to fuel to farm" appeal. The campaign also engaged fertilizer distributors in spreading awareness to retail businesses to help them recognize the brand and promote the closed-loop benefits of natural fertilizers for consumers.

CleanWorld also successfully registered three of its products with the USDA Certified Biobased Product program. Biobased products are commercial or industrial products that are composed in whole, or in significant part, of biological products, renewable agricultural materials, or forestry materials. Federal and state agencies give preference for products certified under this program. The designation is a significant marketing tool for CleanWorld products.

2.6 Fertilizer Testing and Demonstration

End users of fertilizers need to feel confident that CleanWorld's fertilizer products—which are new to the marketplace—will provide benefits. They need to understand how to use the products and feel confident that the products are safe. Controlled, university-sponsored research trials, as well as farmer-backed field trials, are essential to providing the type of data that will make it possible to instill this level of confidence in users, thereby providing access to the fertilizer markets at large. To this end, CleanWorld contracted with horticultural researchers at UC Davis to design and conduct greenhouse tests while simultaneously seeking out local farms at which to conduct field trials.

2.6.1 Greenhouse Testing

The greenhouse research focused on testing liquid fertilizers, since the solids are much more accepted in the market already and compare closely with compost.

Three liquid products were tested: untreated liquid digester effluent, aerated liquid digester effluent, and CleanWorld 3-3-3 All-Purpose Liquid Fertilizer. The aerated liquid came from an active CleanWorld digester and had been aerated for three days in a lab aeration reactor.

The research consisted of three parts. First, the liquids were applied to a test crop at various concentrations to determine the effect of application rate on the growth potential for the crop. This helped determine the effect of applying high concentrations of salts, such as sodium, and also helped determine maximum allowable application rates not only for farmers, but also for subsequent experiments. However, a non-food crop was used (Chrysanthemum) and the time frame for the test was short. Second, a nitrogen mineralization test was performed in which fertilizers were applied to soils where no plants were growing, in order to determine the rate and extent of conversion of ammonia and organic nitrogen to nitrate and nitrite. Microbes in the soil mediate this crucial mineralization process that determines how long it will take plants to respond to the fertilizer. This also helps determine how long the fertilizer will last and whether any nitrogen will be lost due to off-gassing of ammonia and nitrogen gas. Third, the fertilizers were tested for their ability to grow lettuce both as the sole source of nitrogen and in combination with varying quantities of conventional fertilizers. The growth test measured both above and below ground plant mass.

The results of the greenhouse research are still being processed. Initial results indicated that excessively high application rates may inhibit plant growth, but appropriate application of the fertilizer products can substitute for the use of synthetic fertilizers. The experiment ran for ten weeks, but the week before harvest was scheduled over 50 percent of the plants became infected with a fungus that appeared to originate from an adjacent experiment. Harvest was cancelled and no yield or root growth data were analyzed. With time running out, a second smaller experiment was run using only one application rate, but at the end of the experiment, yields from the treated plants were lower than the control. The application rate appeared to be too high. A better application rate test should be carried out on the crop of interest over a sufficiently long period of time before conducting any further greenhouse trials, and the initial experiment should be repeated with closer attention paid to the hygiene of the plants. CleanWorld and UC Davis researchers anticipate continuing these efforts when funding becomes available.

2.6.2 Field Trials

Several farms willing to test filtered digester effluent on a trial basis are also conducting field trials. No rigorous experimental design has been used for these trials. Rather, the goals of the trials were to introduce farmers to a new fertilizer product and record their experience with it. Yield data were collected from farmers as a benchmark, although those data were not scientifically meaningful. All of the farms that are participating applied filtered liquid from the digester without aeration. Farms tested the fertilizer on plots ranging from 10 to 75 acres, planted with processing tomatoes, tree crops (walnuts, pistachios, and almonds), and forage crops. One farm tested the fertilizer in its nursery. In addition to crop yields, the farmers were also asked to report any problems with drip irrigation systems and irrigation filters, odors, and crop damage.

Initial results appear promising. Several farms have signed up for a second season of field applications. One farmer experienced low yields in the treated field, but the cause of the decline could not be attributed to any specific factor. CleanWorld is working with the farmer to better understand all of the factors that may have contributed to the low yield and to conduct a more rigorous field trial with the farmer.

2.6.3 Biological Testing

Samples of digester effluent have been collected for DNA extraction in order to identify the spectrum of microbes present in the starting material. In addition, samples of the digester contents and feedstocks were collected for future experimental analyses. The list of microbes present in the digester was cross-checked against a list of microbes with known benefits for plants and crops, but none were found given the limited coverage of the DNA test. Additional DNA testing may reveal the presence of additional species. If any of the species discovered are on the CDFA list of approved beneficial microorganisms, CleanWorld will apply for a CDFA label identifying the presence of those beneficial microbes. This will provide a marketing tool for informing potential customers about the possible microbial benefits of the effluent. In addition, samples are regularly tested for potentially harmful microbes that can be cultured and quantified in labs, such as coliforms and *Salmonella* species. None have been found to date.

The DNA testing is ongoing in a collaboration between CleanWorld, UC Davis, and the USDA Western Regional Agricultural Research Center in Albany, California. This research will entail further coverage of the microbiome in each tank of the digester and a comparison of the organisms found at each stage. Based on this research, DNA-based techniques for identifying the presence of beneficial and harmful microbes can be explored for future development and the genomes of the organisms in the reactors can be better understood in conjunction with application of the microbes to cropping systems.

2.7 Economic Feasibility of Anaerobic Digester Based Fertilizers

To accomplish significant market penetration in California, fertilizer products will need to compete on price point, quality, and availability. CleanWorld determined that the best strategy for accessing the markets includes creating niche markets, partnering with industry specialists, brokers, and distributors, and selling direct to local farmers first whenever possible.

For unprocessed and dilute liquid fertilizer like the digester effluent, selling directly to local commercial farmers has benefits over using a distributor. The number of potential customers is smaller, which allows for a smaller sales team to access the market. Word of mouth works well in a local market, especially for accessing a niche of ecologically-conscious early adopters. Direct sales also allows for lower costs by eliminating the distributor markup. This is essential to controlling the cost to the farmer, especially in light of the relatively high transportation cost for the product. CleanWorld has been developing networks with local transportation companies to reduce transportation costs in order to reduce the price premium over conventional fertilizers.

Due to the advanced configuration of the CleanWorld digester system, two effluent streams with different characteristics can be collected separately. The first effluent stream is discharged daily to a temporary holding tank and consists primarily of water (greater than95 percent) with some suspended particulate matter (mostly active bacterial cells), some dissolved compounds (for example, ammonia, sulfides, phosphates), and some mineral elements (for example, magnesium, calcium, manganese, zinc, copper, and iron). The holding tank has to be drained regularly to allow room for new loads entering the digester. If the tank is discharged to the sewer, the stream may be called wastewater, but the liquid could also be used to irrigate and fertilize fields, hydroponic gardens, lawns, orchards, and other planting systems. As such, the liquid and its constituents have value as a fertilizer product.

The second effluent stream consists primarily of larger solid particulates that have been screened from the second stage of the digester and squeezed to reduce the water content to 50 - 75 percent. Most of the undigestible and largely carbonaceous fibers will end up in this effluent stream, along with some grit and food particles that do not have time to degrade. This solid cake also has value as a soil amendment, compost, or as a feedstock for high value products.

These solid and liquid co-products derive value from their constituents. The solids contain organic carbon that improves soil structure, nutrients and minerals that enhance plant growth, and bacteria that accelerate the conversion and transport of these nutrients in ways that benefit crops. However, the solids also contain some active compounds that can contribute to odor emissions and may actually inhibit plant growth initially as they continue to break down in the field. Therefore, it may be necessary to treat the solids prior to land applying them or ensure that they have sufficient time to stabilize after being land applied. They may also contain low levels of inorganic contaminants such as plastic and metal. At low levels, these contaminants may be insignificant, but at higher levels they may require additional processing (that is, screening). If the contamination level is high enough, the cost of processing may eventually become higher than the alternative cost of landfill disposal, at which point the material must be treated as a waste stream. Therefore, preventing excessive intrusion of contaminants is essential for preserving the value of the solids. CleanWorld’s pre-treatment equipment already prevents intrusion of the majority of the contaminants. Preliminary testing has shown that the level of contamination of the solid residuals is less than one-percent by weight. Additional testing of the residual solids and contamination rates is ongoing.

The liquids also contain nutrients, minerals, and active biological organisms and compounds that can enhance plant growth and replace the use of chemical fertilizers in irrigated cropping systems. However, the liquid may also contain high levels of compounds that can inhibit plant growth such as volatile fatty acids and salts such as sodium. If sodium levels are high enough, it may limit the amount of the liquid that farms can safely apply to their land. Furthermore, on farms in areas already afflicted by problems resulting from high salinity in the soil and groundwater, it may prohibit the use of the liquid as a fertilizer. There may also be enough suspended particulates in the liquid to clog emitters and foul sand filters in drip irrigation systems. Furthermore, the beneficial compounds are diluted with large quantities of water, making the liquid costly to store and transport over long distances in agronomically relevant quantities.

There are treatment options that overcome these limitations, but these treatments add cost to the production of the products. Understanding the full spectrum of treatment options, costs, and values of the resulting products, as well as the quantities of products produced and sold, allows for a more thorough analysis of the economic feasibility of creating, selling, and distributing these products.

2.7.1 Types of Solid and Liquid Fertilizer Products

The solid and liquid fertilizers produced from digester effluents can be categorized by the production approach. The marketability of these different products requires a separate analysis. Both solids and liquids may be used as they are extracted from the system without any additional processing so long as the disadvantages mentioned above are tolerable to the end user. Otherwise, the solids may be dried to prevent additional degradation or composted (although this may also degrade some of the useful compounds).

For the liquid, there are three general approaches resulting in several different treatment options and resulting products. The first approach is to remove the undesirable compounds from the liquid, while retaining the desirable ones. This results in treatments like aeration to remove volatile fatty acids and odors, filtration to remove suspended solids, reverse osmosis for desalination, and even evaporation for removal of unwanted water. The second approach is to extract the beneficial compounds from the liquid. This results in treatments like ammonia stripping and recapture, struvite precipitation, and ion exchange. The third approach is to add more beneficial compounds to the liquid to further increase its value.

CleanWorld has researched all three approaches and has even created commercially available products utilizing the third approach. The manufacture of these products has been developed by CleanWorld's Research and Development team from the bench-scale, through pilot-scale, to commercial-scale, and a fully-engineered process has been developed. As part of this grant, researchers at the UC Davis have also developed a multi-step filtration scheme utilizing various sized membranes. This process produces several potential products, each of which was analyzed separately. Consultants at Evergreen Recycling also helped evaluate technologies for suspended solids filtration, ammonia stripping and recapture, and struvite precipitation, as well as several others.

All of the research helped develop estimates on capital, installation, operations, maintenance, and input costs as well as production quantities, which were used to create a detailed financial analysis and comparison of the various technologies. As the understanding of each process improves, the assumptions in the models will be adjusted and more details added. For now, the researchers have focused on the following products that have reliable information:

- Liquid effluent without additional processing
- Aerated liquid effluent
- Proprietary 3-3-3 blend
- Concentrated liquid effluent
- Ammonium sulfate
- Solid residuals without additional processing
- Composted solid residuals
- Dried solid residuals

2.7.2 Fertilizer Ingredient Procurement Plan

The primary ingredient for CleanWorld's fertilizers is the digester effluent itself. Procurement issues for digestate include storage, post-processing, and transfer.

The digester design includes an effluent storage tank that buffers mismatch between production and offtake rates. The buffer tank can typically hold two to three days of effluent production. If offtake occurs less frequently, either some form of additional storage would be required or the excess liquid would have to be discharged into the sewer. Storage options include empty tanker trailers, stackable bulk containers (IBCs), tanks, and ponds. Ponds are the least expensive but most susceptible to contamination. IBC totes are the least susceptible to contamination when not re-used, but this makes them significantly more expensive than other options. Dedicated tanks are a good choice when the quantity of storage needed is well defined and consistent; however, underutilized capacity can make tanks very expensive. At the Sacramento BioDigester, stackable IBC totes have been utilized to store from several thousand to tens of thousands of gallons of product in a readily shippable package.

Post-processing can reduce the volume of product to be stored by concentrating or selectively removing the most valuable constituents (that is, nitrogen and/or phosphorus). In this case, storage may not be as much of an issue since the product can be shipped as it is produced. For products such as the 3-3-3 all-purpose liquid fertilizer, bulk quantities of the product can be shipped to a bottling plant (by truck or rail) and the final package acts as the storage medium.

If the digestate is further processed, additional ingredients may be required. As a part of the development of liquid fertilizer products based on digester effluent, formulations were selected by analyzing the most readily available and least expensive sources of the constituents needed. For example, nitrogen sources included urea, ammonium hydroxide, UAN32, and protein hydrolyzate based on organic protein sources from agricultural byproducts. Phosphorus sources included phosphoric acid, rock phosphate, bat guano, and other phosphate rich materials.

CleanWorld created a list of all of the possible ingredients needed for each proprietary fertilizer formulation and then compiled a database of those ingredients that includes the source, shipping cost, price, and chemical composition. This database allows for selection of the fertilizer formulation based on the lowest price ingredients. Sourcing low cost inputs is critical to keeping the overall price of these fortified fertilizer products down. Maintaining the database of fertilizer ingredients can also allow for substitution of lower cost options, when available.

Developing strategic relationships with various distributors and commodity brokers will assist in locating the most competitive sources of each ingredient. These relationships can also provide valuable insight into price variations and availability of raw materials. One issue with these types of fertilizer products is the susceptibility to volatility in the commodity price of the ingredients. This is one of the reasons that CleanWorld is looking into alternatives that use fewer ingredients. In addition, because the fertilizer market is highly seasonal, supply quantities have to be estimated long before the demand occurs. Raw ingredients need to be sourced early in the season and alternative ingredients need to be identified in the event that a certain commodity becomes unavailable due to unforeseeable circumstances. Alternative products without large input requirements avoid these issues altogether.

2.7.3 Economic Potential of Fertilizers

CleanWorld has conducted a detailed analysis of the costs, both startup and ongoing, for creating a broad range of fertilizer products. A matrix was created to track the costs and benefits, as well as potential revenues, for all of the commercially available technologies needed to produce the fertilizers identified. In addition, CleanWorld created an analytical tool that allows for comparative analysis of projects with known costs and revenues. The analytical tool was used to evaluate several potential fertilizer products over a 10-year project life.

The quantity of wet solids extracted from a digester can vary depending on the digester feedstock, how biodegradable it is, and the extraction efficiency of the equipment used. For the BioDigester treating 35,000 tons per year of food waste, extracting 1,500 – 2,500 tons per year of solids is estimated at approximately 60 percent moisture content. For the baseline analyses, a production rate of 2,000 tons per year of wet solids is assumed. Drying was assumed to only remove water to a moisture content of 20 percent. Composting was assumed to involve a slight decrease in moisture content along with a 10 percent mass loss due to the degradation process.

The quantity of liquid removed to make room for a given quantity of feedstock is more predictable. However, additional water may be required in some cases in order to control ammonia concentration. In the case of the Sacramento BioDigester, no additional water has been required to control ammonia or to dilute incoming feedstock. Therefore, for this analysis, it was calculated that 6.5 million gallons per year of liquid would be extracted from the digester. Furthermore, this analysis assumed that 85 percent of the liquid would be available for sale. Mass losses through oxidation were assumed to be negligible. For the blending process, materials were added and then extracted, resulting in zero net change to the production volume. A side-stream of this process is a solid extract that was included in the revenue stream for this analysis, but not in the production volume. The concentration process resulted in net loss of volume which was derived through a careful mass-balance calculation. The ammonium sulfate production quantity was based on the stoichiometry of the chemical reaction, based on the quantity of ammonia in the 6.5 million gallons of liquid effluent, and a reasonable recovery factor for the equipment being used.

Capital costs for each process were derived from budgetary quotes for turnkey systems where possible. When this was unavailable, quotes for individual system components were obtained, and balance of plant, installation, and other construction costs were estimated. Non-standard equipment was added to the capital costs, but standard equipment used for other purposes at existing plants was not included. Examples of standard equipment include front-end loaders, fork-lifts, scales, and trucks. A 10 percent contingency factor was added to systems without a turnkey quote. A 5 percent contingency was added to turnkey quotes that did not include contingency factors.

Many of the products in this analysis could be sold on the organic market. However, there is a significant cost associated with the organic certification process. This cost is unknown and could vary widely depending on the demands of the certifying agencies. There is a time cost as well due to the long wait for certification. CleanWorld is in the process of assessing the true cost of organic certification.

Production costs include the cost of labor, inputs such as chemicals and washing agents, heat and power, testing and data analysis, and standard maintenance costs. The latter was assumed to be 2 percent of the cost of capital when better estimates were not available. Heat and power costs were based on retail rates even when on-site energy was available to avoid any miscalculations due to the unforeseen costs of redirecting on-site energy. The labor rates used were based on existing unskilled labor currently being used at CleanWorld facilities. Additional production costs were estimated for the additional testing and registration required for certified organic products.

The sale price of the products was evaluated relative to other similar products on the market. When commodity pricing was available, the best substitute price was utilized with a 5 percent markup added for the environmental benefit. For fertilizers with the potential for organic certification, a separate analysis was run based on the price of similar organic products.

The quantity of product sold was assumed to be equal to 100 percent of the available material after two years. In the first two-years, the revenues were adjusted by a factor to account for a ramp up of the market.

2.7.4 Results and Conclusions of the Economic Analysis

The detailed results of the analytical tool, as well as the basis of the analysis, are proprietary. However, the following products were found to have the most economic potential:

- Filtered liquid effluent
- 3-3-3 proprietary blend
- Composted solid residuals
- Concentrated liquid effluent

The filtered liquid effluent is the most economical process, as long as storage is not included in the capital costs. The only capital expenditure required is a filtration and dispensing system, which has a minimal cost. Operating expenses include a small amount of labor for scheduling and filling of trucks and some costs for record keeping and sample analysis. Equipment maintenance costs were included for cleaning, repair, and replacement of filters and pumps. The primary cost of the filtered liquid effluent is the transportation cost for sending the product to a farmer. Since transportation costs are variable, it was assumed that the only customers that would be accepted would be those for whom transportation would be less than the value of the product—in other words, some net revenue could be realized. This revenue was used as the sales revenue for the purpose of calculating the project viability. Due to the low costs, a very small margin between sale price and transportation cost was found to still be cost effective. Therefore, setting up a digester with the ability to filter the liquid effluent and pump it into a receiving tanker is highly recommended. However, due to the large unknowns of price and transportation cost, this would not be recommended as the sole source of effluent offtake. In addition, since supply is relatively consistent and demand is highly variable, there could be large mismatches between the two. On-site storage of three to seven days' worth of effluent production was designed into the digester. Additional storage may be economical if the markets for the product materialize and the margins become more concrete.

The 3-3-3 blended liquid fertilizer could be highly economical, provided that the market is large enough to absorb the quantity of product and justify the large capital and input costs. At the price previously negotiated with a retail distributor, a fertilizer system capable of producing 100,000 gallons per week would generate over 100 percent return on investment and $6 million per year for the digester. However, the distributor was only willing to commit to small volumes at that price. A more realistic bulk price that would be more cost competitive could generate 35 percent returns and over $800,000 per year. However, the retail market for liquid fertilizer may be saturated at 5.5 million gallons per year. At the price negotiated with the distributor, CleanWorld would need to sell approximately 260,000 gallons of the liquid fertilizer in order to generate 15 percent return on investment. This does not include revenue from the sale of the solid co-product, which would add $0.10 - $0.25 per gallon in extra revenue, depending on the price of the solid co-product and the cost of any additional processing required. At best, this would reduce the amount needed to be sold to 220,000 gallons per year. While this is only 4 percent of the total volume produced by the digester, it is more than the market has yet borne. It is, therefore, difficult to justify the capital expenditure until the market size is better understood and has been developed. Organic certification could open up the market and increase the selling price, but at a currently unknown cost. The organic market potential for a 3-3-3 NPK liquid fertilizer product is also uncertain.

The compost project is marginally feasible when processing only the digester solids. Compost values of $20 - $30 per ton are typical for compost made from municipal waste. Horticultural grade compost can sell for $45 - $90 per ton, especially if certified organic. Based on a quote received from a reputable compost technology provider, $45 - $50 per ton could provide a reasonable return on investment. There are high replacement costs for compost covers, and compost turning can be a labor intensive and expensive process. Permitting a composting facility in California can add significantly to the cost, and if there is any water discharge, the regulatory restrictions would completely prevent the project from progressing. The primary uncertainty in the project surrounds the value of the compost produced on the local market. A demonstration facility would help significantly in determining the overall financial benefits of the project. A proposal for a demonstration facility was obtained.

An alternative to traditional windrow composting is vermicomposting, which uses worms to degrade the organic material. The advantages of vermicomposting are that it is a continuously fed process, rather than a batch process; it is regulated as an animal husbandry process rather than a waste treatment process; it requires no pile turning; and it generates very little leachate, which is liquid run-off that can be difficult to manage and highly odorous. The primary disadvantage is the slow speed of degradation, which results in a much larger footprint. In addition, there is a risk of losing the worm population due to mismanagement. The project could be economically viable with a 40 percent return on investment and significant net annual revenues for the project on the order of $400,000. Even with only $150,000 annual revenues, the project could still generate a reasonable rate of return, assuming the project costs are accurate. It would be beneficial to estimate the project costs more accurately.

Concentrating the liquid effluent could be a financially feasible method of treating large quantities of effluent and simultaneously creating a viable product. However, there are many competing factors that need to be optimized. For example, as the concentration increases, the quantity of product decreases, and thus the price per gallon required to make the project viable goes up. At the same time, increasing the concentration requires a higher treatment cost. On the other hand, the market demand for the resulting product increases and the cost of transporting the product increases as the concentration goes up. Also, unless sodium can be selectively reduced, increasing sodium concentration reduces the value of the product. All of these competing factors need to be understood and quantified in order to understand how to optimize the concentration equipment. Nonetheless, the project could generate over 40 percent return on investment, assuming the market can absorb the entire production. However, even with only 60 percent of the predicted revenues, the project would still be feasible.

The technologies identified can increase the plant revenue for the full-scale digester facility by between $50,000 and $1 million annually. However, the liquid and solid products can be produced simultaneously. Vermicomposting produced the most revenue from the digester solids, and it was predicted to add $150,000 – $400,000 per year to the facility. Liquid filtrate sales would add $15,000 – $100,000 per year to the digester revenues, depending on the price received. Concentrated liquid could add $300,000 – $1,000,000 in additional revenues.

Assuming a conservative value, the solid and liquid products together could add $0.5 – $1.5 million per year to the digester's bottom line. This would significantly improve the digester *pro forma* and could mean the difference between a project being financially feasible or not. However, there are significant risks and uncertainties in all of the options identified. These must also be weighed against the potential disposal costs for the solid and liquid residuals. When considering these offset costs, the financial feasibility of the overall project would improve significantly. However, disposal costs have to be factored into the digester project financials in order for the offset cost to appear to be a benefit to the project.

CHAPTER 3: Engineering Design and Site Layout

The original concept of the Fertilizer Production System (FPS) system included integrated equipment for liquid fertilizer manufacturing and solid/liquid separation. More recently, it was decided that a mobile solid/liquid separation system would be a more cost-effective solution for extracting solids from the digester, while the liquid fertilizer production system would require separate stationary equipment. This report details the design and site layout for the stationary equipment as well as the engineering design for the mobile solid/liquid separation system.

Each of these unit operations (that is, solid/liquid separation, aka SLS and liquid fertilizer production, aka LFP) has a separate set of design drawings. The site layout for the LFP plant includes a placeholder for the position of the SLS system, even though the unit itself is mobile. The SLS does not have a site layout since it is a mobile unit. However, design drawings, equipment, and odor and spill mitigation are included for the SLS

3.1 Piping and Instrumentation Diagrams (P&ID)

The P&ID is the basis of the engineering design for any new process. A full P&ID for the FPS system was developed and later, the SLS and LFP portions of the FPS system were separated into two different P&IDs. These three P&ID's are discussed in sections 3.1.1, 3.1.2, and 3.1.3 below.

3.1.1 Full FPS System P&ID

The original FPS system design started with the development of a process architecture diagram. This diagram included all of the unit operations but none of the valves and instrumentation. Development of this document allowed for simple revision without considering how the revisions affect valves, piping, and instrumentation. Once this document was finalized, it helped greatly to inform the development of the full P&ID, which included all valves and instrumentation.

Based on the final process architecture diagram, the major equipment components were specified to meet the flows and process sizes indicated. After finalizing the equipment specification, a full P&ID was developed for the integrated FPS. The flows and directions were checked for prevention of backflow, ease of operation and maintenance, and expandability. Valves, additional piping and pipe size and material specification, and fully specified instrumentation was added. A complete equipment list was generated, including the specs for each component, a valve and fitting count, and an estimate of piping lengths was created.

The equipment list and specifications were developed based on the P&ID. They were later refined for the final set of equipment. Some of the equipment in the original P&ID was omitted from the final design, but the interconnections were retained for the sake of expandability of the system in the future.

3.1.2 Solid/Liquid Separation System P&ID

The solid/liquid separation portion of the full P&ID was later broken out as a separate system. The P&ID was supplemented with a vertical arrangement to describe how the equipment feed into each other, where gravity flow can be used in place of active pumps, and where the equipment should be placed on the portable skid frame. The overall skid was sized to contain the equipment in a single unit with safe access that can be mounted on a trailer and moved from site to site. This diagram is not included in this report because it contains confidential information.

3.1.3 Liquid Fertilizer Production System P&ID

The liquid fertilizer production system was modified to include spare ports for future addition of the chemical additive and bulk solids loading equipment. The steam/hot-water circulation system was removed, although the heating jacket was retained in the tank specification[1]. The revised liquid fertilizer production system reduces the system's cost without sacrificing flexibility. The full P&ID for revised fertilizer production system was created by CleanWorld engineers. The drawing included a fully specified instrument, equipment, and valve list. This diagram is not included in this report because it contains confidential information.

The pilot filtration system will allow for in-line processing of the liquid prior to processing in the above reactor system. The P&ID for the pilot filtration system was provided by the system manufacturer (although it is not included in this report because it contains confidential information). The pilot system may consist of a microfiltration unit followed by a reverse osmosis unit, which would consist of two filtration units in series. The SLS system may also be used as a pre-filter for the pilot filtration system.

3.2 Site Layout

The site layout for the full FPS system was drawn by civil engineering subcontractor, Peabody Engineering. In the original FPS layout, the SLS system was integrated with the rest of the facility. The final system installation will omit some of the equipment in the original layout. The layout may change in order to accommodate the additional equipment in the future if needed. The new mobile SLS can be located at the same position as shown in the site layout, or it can be placed in a more convenient location if needed by extending flexible tubing to the SLS inlet and outlet ports.

After modifying the FPS system and creating the new P&ID drawings, the CleanWorld team changed the layout of the LFP portion of the FPS system, leaving room for connection of auxiliary equipment such as the SLS skid and the microfiltration system. The civil engineer re-drew the site plan to incorporate these modifications as well as a few additional changes made in the interim. The site layout drawings are not included in this report because they contain confidential information.

[1] Ultimately, the tank purchased did not have a heating jacket. It was determined that the added expense was not justified. Direct steam injection is a suitable alternative if and when the tank contents need to be heated, in which case insulation would be applied to the tank exterior.

3.3 Equipment List and Specifications

The equipment list and specifications were developed for the LFP and SLS systems separately. The equipment was categorized by subsystem and expense category for the purposes of tracking costs.

3.3.1 Liquid Fertilizer Production System Equipment List

The following equipment was included in the liquid fertilizer production system:

- Liquid receiving tank
- Mechanical mixer
- Discharge pump
- Programmable AC Motor Speed Control
- Instrumentation
- Control programming
- Air blower
- Variable Frequency Drive (VFD) controller
- Diffuser assembly
- Valves and fittings
- Vacuum Distillation Pilot System
- Industrial Grade Microfiltration Pilot System

3.3.2 Mobile Solid/Liquid Separation System Equipment List

The following equipment list includes the major components of the mobile solid/liquid separation system:

- Screw press
- Vibratory separator
- Manifold
- Instrumentation
- Valves and fittings
- Hose and piping
- Frame
- Replacement parts
- Transfer pump
- VFD controllers for the pumps
- Motor starters
- Emergency stop switch

3.4 Odor Mitigation and Spill Containment Plans

Odor and spill control and mitigation are important considerations when designing, constructing, and operating FPS systems. The best spill and odor control method is the one that is utilized regularly. Therefore, the standard operating procedure (SOP), which is described in more detail below, was designed to include procedures to minimize spills and odors.

3.4.1 Odor Mitigation and Control

Many of the materials, while not hazardous, can be odorous and even noxious. When a system is in close proximity to sensitive receptors (that is, businesses, homes, schools, pedestrian traffic, and so forth) there is a significant risk of complaints, including undesirable attention from regulators, neighborhood groups, and even the press. While 100 percent elimination of all spills and odors is unrealistic or even impossible, the control of odors to meet acceptable levels is both possible and a priority.

In order to minimize or eliminate this risk several good design, build and operation practices are employed:

1. Select operations and equipment that can be sealed or closed during normal operations.
2. Use drip tight fittings and design any removable components to seal the inside surfaces, reducing the chance of drips or leaks on exterior surfaces.
3. Whenever possible, run systems under slight negative pressures.
4. Limit positive pressure discharges and route such flows to less sensitive areas. If odors persist, consider the use of anti-odor agents and/or flow odor containing air through a filter and/or bio-filter.
5. Train personnel in good hygiene methods and proper operation of equipment in order to keep systems clean before, during and after operations.
6. Periodically inspect systems for leaks and repair accordingly.
7. Conduct engineering reviews on all new systems and actively aim for continuous improvement.

For the SLS system, odors were limited by adding fully closed soft connections wherever there are connections with the piping. The press was covered with a removable access port for periodic inspection and cleaning without allowing odors to escape continuously. The primary source of odors from the SLS system is the extracted solids, which is controlled by confining the solids to a closed receiving vessel. In extreme cases, the whole SLS system, which is mobile, can be located in an enclosure for complete odor containment.

The LFP system was designed with closed-top reactors with ventilation ports that allow for the diversion of fumes to a filtration system as needed. This is particularly important if aerating the liquids, as the forced air can carry more odors than the passive diffusion of gasses from the surface of the liquid.

3.4.2 Spill Containment Plan

Reducing the risk of spills and containment are accomplished by a combination of good design practices and disciplined operation methods and hygiene. Vessels and tanks are never operated above 100 percent capacity, and instrumentation is used to report levels and flows with redundant safeties to prevent over-filling. On automated systems, process parameters including total system volume are constantly monitored to calculate when the risk of spill is high. Automated processes automatically shut pumps down when spill risk is detected. Systems are positioned away from sewer and storm drain inlets, and gutters divert spills to the spill containment pit in the case of an accident. When hazardous chemicals are included in the process, isolated secondary containment systems are added to reduce the risk of spills in critical areas. Regardless of the source, all spills are cleaned up as soon as they are discovered, and all vessels, hoses, and equipment are checked for leaks and spills as well as any damage that could lead to leaks and spills daily as part of the SOP. Personnel are trained in the identification and proper response to leaks, including both internal and external reporting requirements. Each CleanWorld site has a running incident log that is maintained by the site lead and accessible by the appropriate CleanWorld personnel. Regular reports are created from the logs detailing any incidents and follow-up actions that were taken.

3.5 Controls and Instrumentation

All instrumentation and controls were limited to those necessary for safe operation. Rather than develop a fully automated system, the prototype was used to determine the needs for automation which could be added later. Ports for sampling and spares for additional instrumentation were included to provide locations for instrumentation needed in the future for full automation.

3.5.1 Liquid Fertilizer Production System Controls and Instrumentation

The LFP system has a small integrated control system for starting and stopping motors either manually, on a timer, or according to feedback from certain sensors. Initially, the system was run manually in order to better understand how to automate the system. In the future, instruments may be added and the controls may be expanded to reduce the need for operator oversight. Data collection of key variables may also be incorporated to provide valuable information on the performance of the system.

3.5.2 Solid Liquid Separation System Controls and Instrumentation

The SLS system was intentionally designed without the integration of automation because it was critical for the unit that it be manned and monitored while it was running. This allowed for training of the operators and an in-depth knowledge of how the system is controlled in the field. Although it was not integrated into the system, plans have been developed to add a flow meter with a small feed-back controller that can regulate the pump speed to maintain a consistent flow through the system. This would also provide the ability to trigger an alarm when the pumps stop running or flow declines or stops. CleanWorld is trying to understand the best way to operate and control the system and will incorporate new instruments and controllers as needed. In the short term, there is a strong need for data logging which may be added first. Variables such as flow rates, motor speeds, solids extraction rates, and motor runtimes provide important information about system efficiency.

3.6 Standard Operating Procedures

A set of consistent procedures for setting up, running, monitoring and collecting data, shutting down, and cleaning equipment are necessary to ensure proper safety, equipment integrity and longevity, and consistency. Many safety precautions are standard and included in the general corporate safety training—such as lock out/tag out, ergonomics, avoiding heat exhaustion, and so forth—and are therefore, not specified here. The SOPs outlined below include those steps that are specific to the unique equipment utilized. SOPs are updated regularly as familiarity is built over time.

3.6.1 Liquid Fertilizer Production System SOP

A detailed SOP was developed to establish the fertilizer manufacturing processes, procedures, safety guidelines, and quality control measures needed to produce the CleanWorld proprietary blend of liquid fertilizer products. The production process consists of multiple steps described in detail in the SOP. Briefly, the steps are as follows:

1. Setup and Pre-Check
2. Material Receiving and Loading
3. Material Processing
4. Clean Up
5. Product Storage and Delivery
6. Sampling and Quality Control

Setup involves inspecting and cleaning the reactors, pumps, and hoses to ensure proper operation and eliminate leaks, followed by connecting any hoses that had been disconnected and ensuring the connections are secure. Manual valves are checked to ensure they are in their proper positions. Wiring is checked for loose or missing connections. Levels are checked as the system fills to the desired set point.

Processing may then begin following a set of SOPs for the specific fertilizer being produced. The simplest fertilizer that the system can produce is effluent direct from the digester. For this, the reactor is filled to the desired set point. This may be part of a regular discharge schedule. The liquid is then filtered through the SLS system with the proper size screen in place. Additional processing may be included prior to filtering the liquid, including any combination of the processes listed above. The SOP for the specific fertilizer being produced reflects the steps included and any associated safety measures.

Clean-up of the system generally involves washing down the area and any additional equipment used. Provided that there are no leaks in the hoses, pumps, or reactor, clean-up needs are minimal. The hoses may be disconnected and rinsed with fresh water into the spill containment pit.

The reactors also serve as storage vessels, until the material is pumped into tanker trucks or intermediate bulk containers for shipment.

3.6.2 Solid Liquid Separation System SOP

The SLS System is built on a frame so that the entire system is self-contained and easily transported. The system is inspected from top to bottom before operation to ensure that all connections are secure and no damage is apparent. In particular, the screens are inspected for tears before and after each day of operation. During operation, the equipment is monitored regularly for proper function and lack of leaks or spill. Two emergency shut-offs were included: one adjacent to the vibratory screen where the operator typically stands to oversee the process, and the other in the main electrical panel. Escape paths are kept clear around the equipment, and all railings and ladders conform to safety codes. After operation, all equipment and hoses are emptied of their contents and flushed with fresh water prior to shut-down. The equipment is cleaned and rinsed, and the screens are removed and thoroughly cleaned. Spare parts are kept on-hand in case the equipment requires adjustment. A checklist of initiation, operation, and post-operation items is used each time the equipment is operated.

Data collection is important for monitoring the performance of the SLS skid. The operators are provided with the SLS Log Sheet on which to record all necessary data pertaining to the operation of the unit as a whole. Log sheets are collected daily and data are entered into an online database for analysis.

CHAPTER 4: Construction, Installation, and Commissioning of the FPS System

The FPS system, as originally conceived, included multiple steps which involved both removing suspended solids from the mixed slurry resulting from anaerobic digestion and further processing of the liquids (and possibly the solids, although this was outside the scope of this grant). The sequence of solids removal and liquid treatment as well as the requirements of each process differ significantly, which lead to the development of the FPS as two separate but integrated systems described as the Solid-Liquid Separation (SLS) System and the Liquid Fertilizer Production (LFP) System. In addition, the SLS system may be used completely independently of the LFP system for certain tasks, such as solids removal directly from a tank, with the resulting liquid being returned to the tank. The SLS system can also be used either as a pretreatment for the LFP system or as a post-treatment process, depending on the type of product desired. This modularity allows for the solid-liquid separation system to be used where and when it is needed instead of being embedded statically within the FPS system.

This report describes the construction, installation, and testing of the LFP and SLS systems as separate entities as well as the integration of the two systems. Furthermore, the LFP system was designed and built to accommodate future expansion for use in the creation of a wide range of fertilizers. However, it was immediately designed to process, hold, and distribute liquid pretreated by the SLS and/or another pretreatment unit, several of which were piloted for this grant. The SLS system was originally built and tested at the Sacramento BioRefinery for improving the physical and financial performance of the AD system producing RNG as a vehicle fuel. However, it was also tested and developed at other CleanWorld AD facilities in the Sacramento region which ultimately will improve the ability to disseminate the technology to a wider customer base. The LFP system was installed on-site at the Sacramento BioRefinery facility as a fixed processing system, wholly integrated with the digester. This included site preparation (that is, grading and installation of electrical service, drainage, and direct access to the digester fluids) as well as installation and testing.

4.1 Liquid Fertilizer Production (LFP) System

The LFP system is the portion of the FLP that consists of the stationary equipment laid out on-site to allow easy access for operations including maintenance, vehicle access, rainwater runoff handling, solid separation, pilot testing, and any other operations that may be needed in the future for the creation of higher value fertilizer products.

4.1.1 Construction and Site Preparation

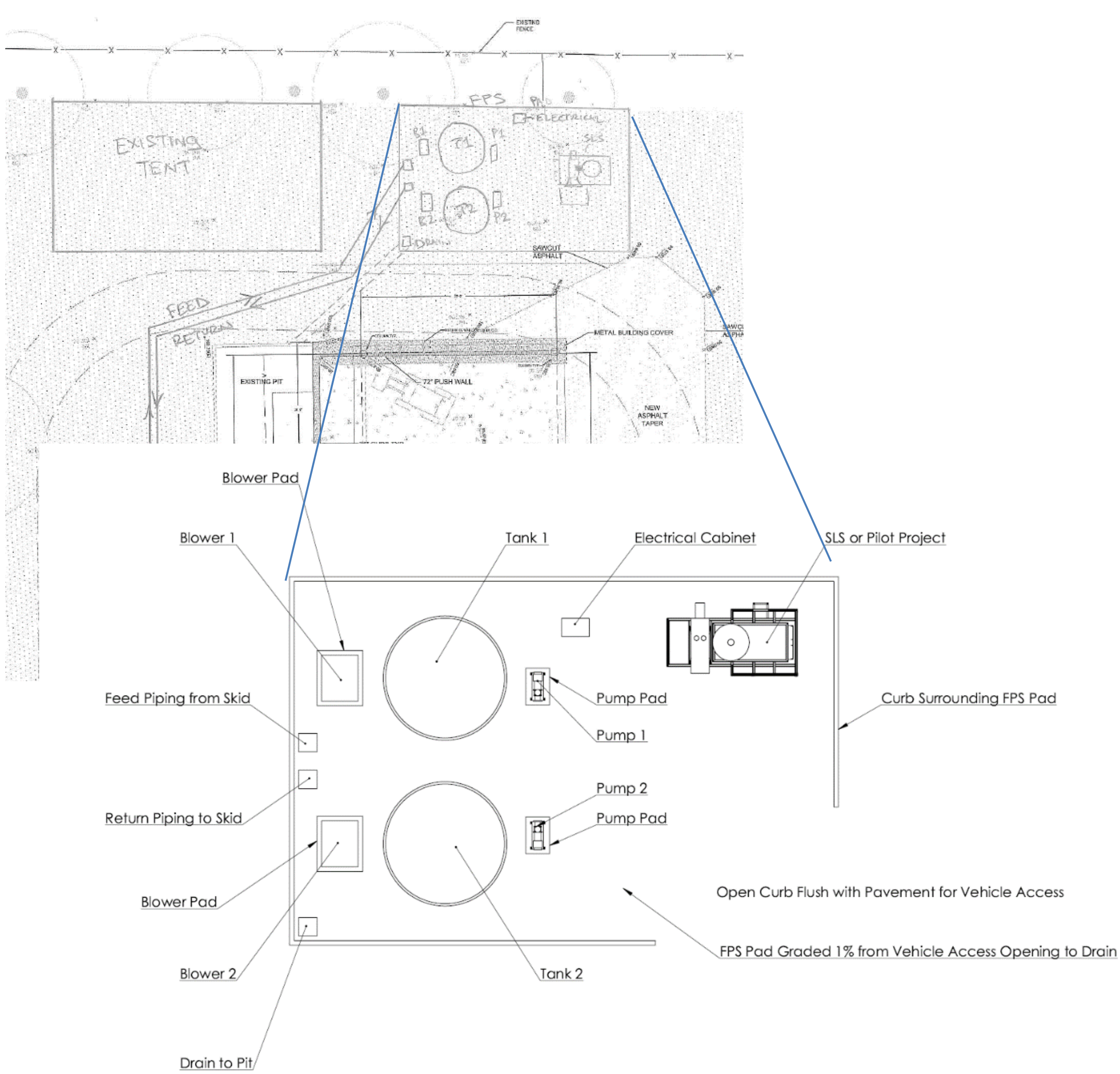
The construction of the LFP site included moving existing infrastructure and equipment to clear a space for the system, installing additional infrastructure such as piping and electrical service, and pouring a concrete slabs as needed for mounting all of the major components, including tanks, pumps, blowers, and electrical/control panels. The siting and location of the system was selected to be convenient for access without interfering with existing operations. Testing of additional equipment in the future was also factored into the site prep work. Therefore, the area and electrical service was slightly oversized to accommodate additional, as yet unspecified equipment in the future.

Preparation for the site began with moving existing equipment so that the desired location of the LFP was clear for construction of the system. The feed and return piping to and from the LFP needed to be built into the existing site layout to connect to the digester's fluid transfer skid. Furthermore, the piping needed to allow for continued vehicular access to the area. The digester's existing pumps and controls can still be used to fill the LFP system's tanks directly. Additional pumps were added for transferring material through the rest of the process.

In addition to feed and return piping from the digester, the LFP system was designed with the ability to wash any spills directly to the digester's existing containment pit from which the liquid can be pumped back into the AD system. This will serve as a secondary containment system for the LFP system and will simplify the cleanup of the site. Additional modifications to the area were made to avoid excessive storm water runoff into the pit during rains.

Electrical service was also extended from the master control cabinet to a secondary electrical cabinet, which was located near the control cabinet. The design and installation of a 100 amp, 480VAC service line was executed by CleanWorld's electrical contractors. The electrical cabinet was installed to feed the electrical needs of the LFP system as well as the SLS system and any additional system requiring 480VAC service. The breakers were sized to allow for double the expected current draw from the existing equipment. A small transformer was also installed to turn the 480VAC service into 120VAC for smaller components such as lights, control systems, tools, and other equipment. The proper connections were installed for the SLS system with additional outlets for future expansion.

Figure 8: Site Layout with Detail of Liquid Fertilizer Production System



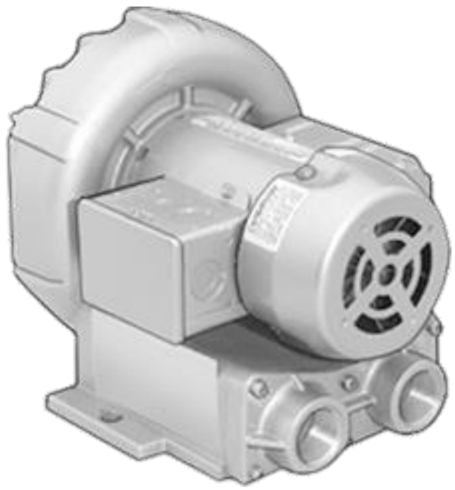
Source: CleanWorld

Once the site preparation was completed and the equipment pad in place, the major components were installed. Each was bolted to its final location with sufficient space between them for servicing. Conduit was then laid out to supply the components with power and the electrical installation was completed. Each component was fitted with quick disconnects initially. Flexible hose and tubing was used to plumb the parts together until a permanent configuration has been finalized.

4.1.2 Major Equipment Components

Blowers

Figure 9: Reciprocating Blower



Source: CleanWorld

Part of the liquid fertilizer production process may involve aerating the liquid to oxidize some residual organics and/or ammonia. The blowers were sized to provide enough air to completely oxidize the residual organics as measured via the biological oxygen demand (BOD) of the digester effluent. The blowers were selected for their cost-effective performance within a small footprint. A single-stage regenerative blower design was chosen for its ability to provide high air flow rates under reasonable head pressure with low noise. The model selected use a 10 HP motor which will be driven by a variable frequency drive to allow for variation of aeration flow rates. These are standard blowers utilized for aeration at wastewater treatment facilities.

Pumps

Figure 10: Pump for Filtered Digestate

Source: CleanWorld

The pumps used for discharging the liquid fertilizer were selected to handle high enough flows to quickly fill tanker trucks with sufficient head to pump the liquid long distances if needed. Since the liquid fertilizer will not contain large suspended solid particulates, a pump design was selected which can handle up to 3/8" diameter particles. The pump motor selected is a 7.5 HP totally enclosed fan-cooled motor. It drives a cast-iron pump head that is self-priming with a stainless-steel self-cleaning impeller. While this pump is not as heavy duty as the pumps used to pump the digester slurry, it is more cost effective and is expected to handle the liquid fertilizer which has had the majority of the large suspended particles removed, since they would clog sprayer and drip nozzles on most farms. The pump size will be capable of filling a 6,000 gallon tanker trunk in less than 30 minutes.

Tanks

The two tanks purchased were made of stainless steel with a 15,000 gallon nominal capacity. Each tank was equipped with an agitator/mixer powered by a motor with a variable speed controller. Additional ports for sensors that determine temperature, pH, dissolved oxygen, and level were added to the tanks. Each tank also included multiple ports for process connections and valves to allow the configuration and reconfiguration of the piping layout for research and development of new and different fertilizer production strategies and methods. The tanks contained a standard manway at the bottom of the tank for cleanout and maintenance of the tanks and a coned roof with a connection for diverting gaseous emissions to a biofilter.

Figure 11: Liquid Fertilizer Production Tanks as Delivered to SATS

Source: CleanWorld

Each tank was also equipped with a blower for aeration and a pump for moving the process liquid out of the tank. The blowers were connected to a diffuser assembly that was inserted into the tank. The diffuser assembly was custom designed for the tank to allow for testing of different bubble sizes and diffuser heights and orientations. The air pressure and flow rate through the air diffuser assembly was monitored between the blower outlet and the diffuser distribution manifold inlet.

For future expansion, the tanks were fitted with ports that will allow for the injection of chemicals for pH control, additional ingredients, and steam for heating the tank contents. In the event that steam is used for heating, insulation will be added. For this project, only the ports to allow for such expansion were included. In addition, a scaffold with a ladder and walkway to allow access to the sides and top of the tanks were installed. A worker stationed on the walkway through a port atop the tanks can load solid additives by crane.

4.1.3 Installation of Tanks and Field Equipment

The tanks were delivered by truck and lifted onto the concrete pad with a crane. The pumps and blowers were placed on the pad and positioned relative to the tanks prior to the final mounting. This allowed for the ideal positioning of the equipment prior to mounting in order to reduce the field piping requirements. Once the equipment was sited and oriented as desired, the pumps and blowers were bolted to the pad. Pipe connection fittings were installed on the tank and pump inlets and outlets along with control valves, and piping runs were measured for installation. Flexible tubing was utilized when the materials were suitable for the application (that is, when temperature and pressure ratings for the tubing met the expected conditions of the liquid fertilizer). Carbon steel pipe was used for the air supply from the blowers which can exceed reasonable temperatures for plastic and rubber. Chlorinated polyvinyl chloride plastic pipe was used for the air distribution manifolds inside the tanks as well as for field runs where hard pipe was required.

The electricians installed an electrical cabinet and a controls cabinet. Field conduit was laid from the main disconnect to each pump, blower, and tank. The tank conduit supplied power to the mixers and instruments. A junction box was installed adjacent to each tank with wire terminals to allow for future instrumentation. Conduit was also laid for field instruments such as flow and pressure meters on the air supply lines. The transformers and electrical sockets needed for all of the required power service were installed by the electrical contractors. They also installed all of the variable speed controllers and electrical starters in the control cabinet and made sure they were connected to their respective motors.

Future expansion will allow for addition of controls and programming of the control panel for added automation. Initially, all of the equipment will be manually controlled. A controls contractor was hired to begin planning the controls systems for the liquid fertilizer production system. However, until the use of the equipment is finalized, the controls design will be generic. Ultimately, a fully integrated and automated system will be possible with some advanced programming.

4.1.4 Pilot testing of filtration and suspended solids removal

Farmers tested unfiltered and filtered digester effluent as a liquid fertilizer during the course of this grant. The filtered effluent was filtered by the SLS system described here with the smallest feasible screen which removed particles of 50 μm or greater diameter. Based on the analyses, this should remove up to 25 percent of the total solids remaining in the liquid effluent. Dissolved solids made up 30 – 50 percent of the total solids. This implies that 25 – 45 percent of the solids in the liquid are suspended particulates of less than 50 μm. The data recently found that one-third of the total suspended solids (over 0.45 μm) were less than 75 μm. To ensure that these small suspended particles do not clog drip irrigation emitters, irrigation sprayers, or other downstream processing equipment, an additional piece of equipment is needed to remove these suspended solids.

The candidate technologies identified for suspended solids removal were membrane filters, rotary filter presses, belt presses, and centrifuges. Three microfilter designs, a rotary press, and a centrifuge were pilot tested and lab testing was performed on using polymers to cause the small particles to agglomerate to form larger particles that could be removed with the existing 50 μm screens. The results of the pilot testing are presented in Table 1. Ultimately, one membrane filtration technology was selected as the most likely candidate for integration with the overall LFP system. A centrifuge may also be pilot tested as well.

BioEnvironmental Engineering laboratory at UC Davis performed the initial research on membrane filtration. The goal of the feasibility test was to determine if the biodigester effluent could be sufficiently clarified using membranes to produce permeate suitable for direct use as a fertilizer or for passage through additional nano-filtration/reverse osmosis membranes for salt reduction and nitrogen concentration. The researchers used a commercially available tubular membrane with an 800 kDa molecular weight cutoff. This resulted in –96 – 98 percent removal of total suspended solids (TSS) without any significant loss of ammonia. This technology was determined to be suitable for the desired application and additional testing was conducted.

Table 1: UC Davis BioEnvironmental Engineering Microfiltration Results

Solution	TS (%)	TSS (g/L)	NH_3-N (mg/l)	Na^+ (mg/l)
Without aeration				
Effluent	4.3	11.85	4220	1880
Permeate	1.6	0.29	4150	1820
Reduction	*63%*	*98%*	*2%*	*3%*
With aeration				
Effluent	3.3	7.75	3200	1950
Permeate	1.4	0.31	3150	1912
Reduction	*58%*	*96%*	*2%*	*2%*

Figure 12: Raw Digester Effluent (left) and Permeate from Microfiltration (right)

Source: CleanWorld

Other microfiltration technologies performed similarly. A third-party membrane supplier conducted a similar trial using their membranes. They tested 50, 100, 400, and 800 kDa cutoff flat-sheet membranes. They found that the turbidity of the permeate samples was greatly reduced compared to the feed. However, all permeate samples were still heavily pigmented, and the results of this feasibility test indicated that none of the tested membranes produced permeate suitable for passage through Nano-filtration/Reverse Osmosis (NF/RO) using their spiral wound membranes without additional pretreatment to improve the flux further reduce the turbidity. As a result, these membranes were not selected for further testing. Ultimately, a different membrane design was selected for additional pilot testing.

Table 2: Results of Third-party Spiral-wound Membrane Filtration Bench Testing

Membrane Size	Feed Turbidity (NTU)	Permeate Turbidity (NTU)	Turbidity Reduction
800 kDa	22,000	1.0	>99.9%
400kDa		0.7	
100kDa		5.4	
50kDa		1.92	

Figure 13: Flat-sheet Membrane Bench Test Setup for Microfiltration of Digester Effluent

Source: CleanWorld

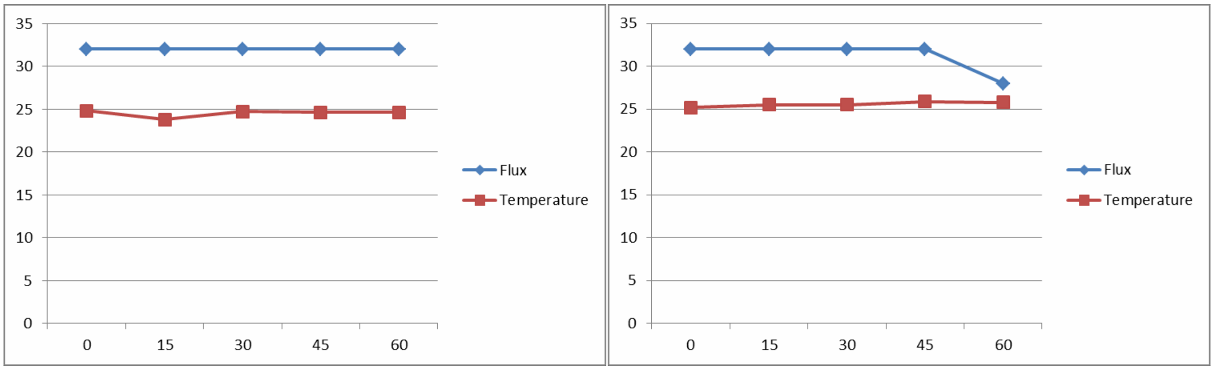
The membranes selected for further testing were based on a self-cleaning design as pictured in the figure below. They found they their technology could be used as a pretreatment for reverse osmosis or for use as a product without further treatment. Pilot testing commenced in October, 2014 with additional on-site testing of the pilot unit scheduled for January, 2015.

Figure 14: Self-Cleaning Membrane Pilot Equipment

Source: CleanWorld

The equipment manufacturer initially ran an in-house pilot test to investigate the potential to remove TSS, reduce BOD, and reduce Total Kjehldahl Nitrogen levels from the digestate which contains very fine particles and has very high TSS levels. The levels of TSS in the digestate sample were reduced from 8,490 mg/L in the feed to below detectable levels for two of the three membranes tested. The membrane system also lowered nitrate levels by 98 percent and reduced turbidity to 1.79 and 8.65 NTU, which was similar to the levels achieved with the spiral wound membranes. Unlike the spiral wound membranes, the pilot unit was able to maintain a relatively high flux for a sustained period of time. The resulting permeate was translucent and free of suspended particulates. The final dissolved solids content was still relatively high at 10,500 and 12,000 mg/L for the two membranes tested, indicating that the majority of the useful dissolved compounds such as ammonia and micronutrients were still present in the permeate. Additional concentration by reverse osmosis and evaporation were tested in the BioEnvironmental Engineering lab and pilot testing of these technologies was scheduled as well.

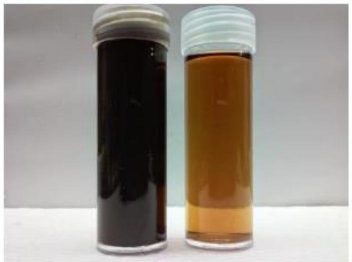
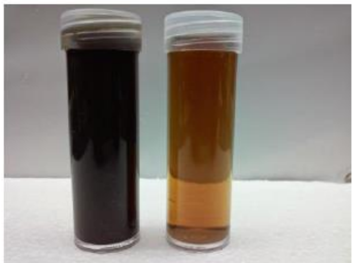
Figure 15: Results of Bench Testing of Two Membranes



Source: CleanWorld

The Y-axis represents temperature in degrees Celsius and flux in liters per meter-hour, and the X-axis represents time in minutes.

Figure 16: Photos of Raw Digester Effluent (feed) and Permeate Resulting from the Bench Test of the Self-cleaning Membrane System

Membrane	FU-N05	FU-N150
Comparison: Photos of sample vials	 Feed, Permeate	 Feed, Permeate

Source: CleanWorld

In the lab, RO resulted in a 16 percent volume reduction with 73 percent recovery of ammonia. The concentrate from the RO treatment doubled the ammonia concentration, bringing the final nitrogen level in the concentrate to 1 percent. Nanofiltration membranes were also tested because they can achieve higher flux rates at lower pressures while still retaining ammonia.

However, nanofiltration only increased the ammonia concentration by –32-58 percent. Therefore, nanofiltration was not found to be a useful treatment for creating valuable products from digestate.

In addition, concentration of the resulting permeate was tested in the lab in a vacuum evaporation chamber which can evaporate liquid at 122°F (50°C). Samples volumes were reduced by 50 percent, which should double concentrations as long as nothing but water is evaporating. However, without adjusting the pH prior to evaporation, the ammonia concentration only increased by 10 percent, while sodium concentration increased by 88 percent. Ammonia evaporated. After adjusting the pH to less than 4.0, evaporation of 50 percent of the volume increased the ammonia concentration by 46 percent. For the pilot tests, pH adjustment will be critical. The pilot equipment also utilizes additional technologies not available to a bench-scale evaporator for preventing evaporation of volatile compounds. However, the bench test provides a baseline for comparison.

Figure 17: Rotary Press Pilot System

Source: CleanWorld

In addition to membrane filters, other technologies were tested for their ability to clarify liquid digester effluent, including a rotary press and a centrifuge. A rotary press (see Figure 18) is a disc filter that progressively increases the pressure on the liquid, forcing it though a screen in the disc. This technology has been used successfully at wastewater treatment plants for dewatering sludge. A pilot unit was tested in November 2014 on liquid effluent from CleanWorld's digester system.

Figure 18: Results of Bench Flocculation Test Revealing Poor Floc Formation

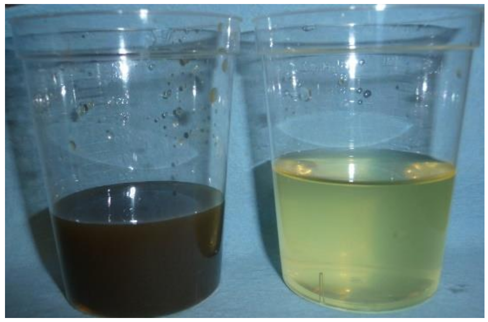
Source: CleanWorld

The company that performed the pilot test tried to flocculate the effluent in order to improve the separation efficiency by adding polymers with and without ferric chloride or calcium hydroxide. They tested five dry cationic polymers, four emulsion cationic polymers, two dry anionic polymers, and one emulsion anionic polymer, but they were unable to generate a press cake with their pilot equipment. The cake formed (Figure 19, right) was wet and did not hold together properly. As a result, no further testing of this technology was warranted. Difficulties with flocculation with other companies was also experienced.

A centrifuge manufacturing company tested two five-gallon samples of digester effluent using their technology. They also found that conventional polymers may not work effectively. They noted that the relatively high pH of the samples is a problem for conventional cationic polymers which work best at a pH of 5.5. Further, attempts to reduce the pH with sulfuric acid produced foam and required a lot of chemical. The samples were initially pre-screened with conventional wastewater polymers and the highest cationic polymer seemed to work the best. The samples were also screened with a wide range of aluminum based coagulants. Several of the coagulants demonstrated foaming similar to acid addition.

They found that they could generate a cake with 30 – 40 percent total solids (TS) from the digester effluent, but they only recovered 10 – 20 percent of the available solids. The resulting liquid was 1.8 – 1.9 percent TS, but it was opaque due to the high level of residual solids. The most cationic polymer had the best results and coagulants did not have any impact on the cake formation or solids recovery rate. Reducing the pH also did not help and it caused excessive foaming. They did develop a technique that improved the quality of the supernatant and raised the solids recovery efficiency via dilution which could be tested on-site if further pilot testing were performed (see figure below). The resulting cake was 22 – 28 percent TS. The supernatant was not tested for ammonia, but the final dissolved solids concentration was 2,800 mg/L. Further pilot testing of this configuration was planned for the beginning of 2015. Additional lab testing may be required prior to the pilot tests.

Figure 19: Results of Centrifuge Pilot Testing



Source: CleanWorld

4.1.5 Testing of the Liquid Fertilizer Production System

Testing of the liquid fertilizer production system began in May 2014 with the first commercial shipment going to a farmer in Woodland. A rental tank was used in place of the final installed system. Effluent was filtered through a small vibratory separator with a 50 μm screen. A temporary pump was used to fill the tank. In all, about a dozen shipments of fertilizer were sent to farmers. This testing period allowed us to size the tanks and filtration equipment as well as the pumps.

After the installation of the tanks and pumps was complete, the tanks were filled with water and checked for leakages. The pumps were used to transfer liquid from one tank to the other as a test of the pumps and their controllers. Pump speed was modulated and the flow rate was checked with a spot check meter. The blowers were tested in water as well. The blower was run as the water level was allowed to increase and the air flow rate was monitored. A blower curve was created to calibrate the flow rate against different fluid level heights. This will be used to test different air flow rates for aeration testing. Testing in clean water also allowed for a baseline to measure the drop in performance since aeration diffusers may clog with solids during testing. In addition to flow rate, back pressures were also monitored by the pressure meter on the air flow line.

Testing of the liquid effluent will proceed when a plan is in place for disposal of the liquid. Farm application of liquid fertilizers is scheduled to resume in March 2015. The new LFP system will be tested further at that time.

4.2 Solid-Liquid Separation System (SLS)

The SLS system was designed as a separate unit from the LFP system for the cost savings and the benefits of modularity. In addition, SLS is a required process for continued digester operation, whereas liquid fertilizer production depends on many other factors. Therefore, it made sense to separate the two processes.

The SLS system was designed as described in the “Engineering Design and Site Layout” section of this report. After an initial prototype was built, the design was revised to improve safety and operability while minimizing the need for user oversight. Also, the initial prototype was built on a stationary skid, while the final design included mounting of the skid on a mobile trailer to allow the unit to be transported between different locations on-site as well as to different sites.

4.2.1 Construction and Site Preparation

Before mounting any of the components on a skid, each individual component was tested independently. The vibratory screen was tested first at the lab scale before purchasing a larger unit for the full-scale operation. The lab unit was run under a variety of conditions to understand how material flows through the device, which helped understand how to integrate it into the full system design. The screw press was tested in the field independently from the vibrating screen. Flow rates and solids extraction rates were measured before the units were integrated. Low solids production rates were largely the impetus for the integrated design. The two subunits were then arranged such that they could be operated in series. This helped determine heights and measures for the frame, which was built later.

A steel frame was designed with assistance from the engineering consultants and built in a welding facility off-site. The frame was then transferred to the site, and the operational components were added in the field with some welding performed as appropriate. The equipment was mounted to the frame, and fittings and piping were added to convey material to the equipment. The initial piping was later changed to eliminate spills and better contain odors.

Initially, the pumps on-site were used along with gravity feed to transfer fluid from the digester into the separation system. Temporary tanks were used as sumps and flexible hose was used to make the majority of the connections. Later, independent pumps were tested. However, these air-operated diaphragm pumps produced pulsating flows that reduced the system's efficiency. This helped drive the selection of the final pumps to be used which are centrifugal chopper pumps similar to those used by CleanWorld previously. They have been shown to be very robust when handling the kinds of thick slurries encountered at CleanWorld's digester facilities.

The sump tank initially used was replaced with a custom-designed manifold which joined inlets from the vibratory screen and screw press discharge to a common header with a reducer connected to the discharge pump inlet. A large clean-out port was added to the manifold to eliminate the issues with solids accumulation that had plagued the sump and prompted its replacement. This manifold was mounted to the frame and connected to the outlets from the screen and press.

Figure 20: Field Fabrication of the Solid/Liquid Separation Skid

The inlet and return pumps were added to the frame in a spill catchment with drains, and the pumps were located and oriented for ease of access near the back of the skid. Custom fittings were designed and installed to allow for interconnection of the different components while minimizing the chance for pipe clogs. The process flow was designed to allow the fluid to bypass the screen or to bypass the entire process so that the pumps could run at full speed and allow a slip stream to enter the processing system. This should keep the pipes clear of clogs and prevent settling of solids. It also will allow for fine adjustment of the flow with valves rather than trying to control pump speed, which eliminates the need for costly VFDs and controls. Eventually, the valves can be automated and controlled based on sensor readings on the equipment. Initially, flexible hose was used for interconnecting the components within the skid, which will help with cleanout and portability. After extensive field testing, hard piping can be installed as needed to replace the flexible tubing,

Several adjustments to the skid design were also made to improve safety and operability, including toe guards, rails, a new ladder, a second emergency shut-off located near the ladder, quick connect fittings, storage segments for transporting hoses, fork removable frames for servicing the sub-units, and improved connection and discharge points for liquids and solids.

The electrical distribution along with starters and emergency shut-off buttons for each piece of powered equipment (vibratory screen, screw press, inlet pump, and return pump) were built into a certified, weather resistant, steel enclosure by the electrical contractors. A single power junction was added with a long electrical cable for field connection to a serviceable 480V standard outlet to provide power to each piece of equipment. A stand-alone emergency shutoff switch was placed near the ladder and installed by the electricians.

4.2.2 Operating Area

There will need to be sufficient space around where the system will be placed on site to allow placement and operation of the heavy machinery required to move and/or assist with the operation of the system. The SLS system as a unit is 8’ wide by 14’ long. Additional space of about 3’ was given on all sides to allow access to all parts of the system. The area around the screw press discharge chute should allow access by a forklift to large 4’ by 4’ collection bins or other containment such as roll-off bins. The area should be level and designed to handle the weight of the SLS system, with optional lag bolts for fastening the trailer to the site.

The site will need the proper electrical connector installed so that the system may be plugged in to operate. The plug used was rated for 60A, 3ph, 10HP, 480 VAC. In addition to the proper, conveniently located receptacle, the site must have spare 480VAC, 60A service with independent breaker available. These were added to all of the sites to be used.

The SLS system was designed to be capable of being connected to a tank with 4” cam-lock fittings, independent of the other site equipment. It was designed with autonomous pumps in order to dissociate the operation from the rest of the facility’s needs. However, the site location should be selected to minimize the pipe runs and power cable length. Each site where the skid will be used was evaluated for the best location for the equipment and the distance to all of the connection points (electrical and hydraulic) were noted so that the proper lengths of extension cords and tubing will be available when needed.

4.2.3 On-site Equipment

The digester tanks and skids are integral to the solid/liquid separation process. Therefore, although they are not strictly required for the operation of the SLS system, their location and accessibility are key. The advantage of making the SLS mobile is that it can be placed adjacent to the tanks being serviced.

Because the unit was designed to run autonomously, the only site equipment required (other than the digester) were the bins for collecting extracted solids and a forklift for moving the full bins. In addition, it will be helpful to have a scale for weighing the solids post-extraction and a mechanism for transferring the solids into a vehicle for hauling the solids off-site. Initially, a rotary drum for drying the solids was tested at the lab, but further development of this technology was postponed. Lab testing of vermicomposting of the solids proved successful as did some third-party testing of creating fiberboard and other value-added processes. The final destination of the extracted solids remains to be seen. CleanWorld will continue to work on additional processes or market destinations for the extracted solids outside of the scope of this grant.

4.2.4 Materials and Equipment

A full materials and equipment list was developed for construction of the SLS system. The specs and equipment purchased are proprietary, but the general equipment included in the system are as follows:

Table 3: List of Primary Equipment in the SLS

Equipment Name	Description
Vibratory Screen	Used to first filter liquids from the solids, it can be used to filter to different particle sizes as required via interchangeable screens. A 46" diameter single deck vibratory screen with anti-blinding rings was purchased along with multiple sets of screens of various pore sizes for different applications. Filtration of liquid fertilizer required smaller screens than extraction of solids, and the best screen size depended on the distribution of particles in the slurry being screened as well as the needs of the end user of the liquid product. Multiple size screens were tested for flow and solids extraction rate under different applications. Ultimately, the screens selected provided sufficient solids extraction while maximizing the flow.
Screw Press	A small screw press was employed for this application which was provided by one of CleanWorld's equipment partners. The screw press has an interchangeable screen that comes with variable slit sizes. The screen was made of stainless steel with laser etched slits for extracting the fluid. It also had a pressure plate on the back with variable pressure for optimizing cake dryness versus solids flow rate. Multiple screen sizes were purchased for testing different separation configurations.
Sump Tank/Fluid Collection Manifold	The sump combined the liquid output from the vibratory screen and the screw press and allowed it to be pumped out of the SLS system. This would allow for variable inlet and outlet flow rates. However, in a later design, the sump tank was replaced with a fluid manifold which made more sense given the re-designed process flow.
Pumps	After reviewing multiple pump specifications, the same centrifugal chopper-pump that was employed in the rest of the digester system was used for this application. They have been extremely robust in the face of slurries that clog other pump designs, and they also proved to be more cost effective than other models and designs. Two pumps were employed, one to supply liquid to the screens and one to return screened liquid to the digester. Ultimately, instead of regulating flows by slowing down the pumps, the flows were regulated by installing a bypass valve, which allows the pumps to be run at full speed at all times. This should minimizes settling of solids during processing and eliminate the need for expensive pump speed controllers.
Electrical Control Box	A single panel with one point of contact for the power inlet was installed to distribute power to all of the equipment. In addition, all of the motor starters, safety switches and control panels were included in the master panel. An additional master power emergency stop switch was added to a location near the top of the ladder so that workers on the skid can kill power without having to climb down first.

Mobility Trailer	After testing, development, re-design, and final prototyping, the skid was mounted atop a low flat-bed tow trailer with extendable legs for securing the equipment on site. The trailer made the equipment easily movable within and between sites. A custom trailer was built special for this purpose.
Instrumentation	The full instrumentation package was being determined as of the publication of this report. Ideally, instruments will be added to the system to improve safety and reduce the operational needs of the system.
Additional Equipment	A storage location was built into the skid for transporting the hoses, gaskets, replacement screens and other spare parts, and key tools needed for operating the SLS system.

4.2.5 Skid Assembly

The skid was assembled per the design drawings created by CleanWorld engineers. The frame of the skid was welded and modified in a fabrication workshop as per the design instructions. The major components were mounted in the field. The screen and the press were both mounted on frames that could be easily unbolted and removed for servicing. These were fabricated in the shop and the equipment was then field-mounted. The pumps were mounted on a frame over a catch pan that would contain spills and be easily removable for cleaning and maintenance. Piping was installed in the field. Flexible tubing was used initially for making the required interconnections. Once the final piping configuration was tested and approved, the flexible tubing can be replaced with steel piping if needed. Valves and instruments were used with flange mounts that could be adapted for either pipe material.

Initially, the primary components were tested without a skid to determine the appropriate placement, heights, distances, and orientations. The skid was then fabricated in a shop and transported to the site where the components were then installed onto the skid. Once the configurations and locations were determined, the components were mounted to the frame in the field, but the electrical and fluid piping was connected using temporary connections. Later, an electrical control box was added along with the connection points, safety switches, and starters and room for expansion. The skid was operated under this configuration for several months using external pumps before being re-designed.

Figure 21: Shop Fabrication of the Solid/Liquid Separation Skid on a Mock Frame

Source: CleanWorld

After the re-design, the skid was modified for safety and internal pumps were added. The pumps were mounted on a fork-removable frame for ease of maintenance. The frame was fabricated in a shop along with the new ladder, spill catch pan, fluid collection manifold, and custom fittings. The main equipment pieces were mounted and tested in the shop on a mock-up frame in order to determine the best orientation and heights for all of the components as the equipment were being utilized on-site (see Figure 22 above). Once the configuration of the different connections and components was determined in the shop, flexible tubing was cut to fit the required spacing, and all of the components were brought to the site for installation. The ladder and spill catchment were installed last in case any pieces were found to interfere with their placement. The electricians worked in the field to provide power to the new pumps and install the remote emergency shutoff switch. They also field tested all of the components to ensure they worked.

Once the components were installed, plumbed, and electrically connected, they were tested at length. Minor adjustments were made as needed and may continue to be made as the unit is used for an extended period. At publication, the trailer was being built. After the trailer is delivered, the entire unit will be lifted onto the trailer bed and mounted so that the equipment can be hauled to different locations as needed.

4.2.6 Testing

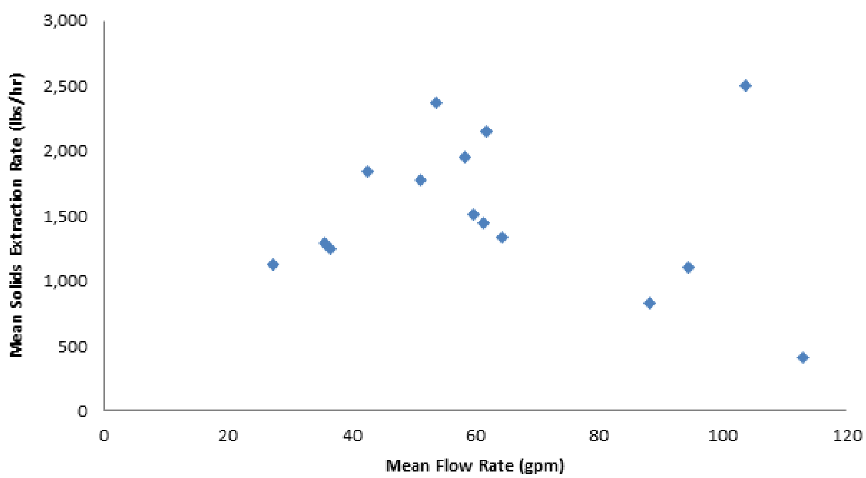
The SLS system was tested over many months in the field. It was tested at multiple facilities. Initially, the vibratory screen alone was tested in the lab on a small-scale unit. The screw-press was then tested independently in the field in September 2013. During this test, it was determined that the solids extraction rates were too slow to make independent use of the screw press feasible. As a result, the vibratory screen and screw press were tested together before the final skid-mounted design was created.

Figure 22: Development of the Solid/Liquid Separation System.

Source: CleanWorld

Once the skid-mounted prototype was built, it was tested at the SATS facility. Rental pumps were used to run long-term, four to eight hour tests to determine flow rates and solids extraction rates. The results of the tests are shown in the graph below.

Figure 23: Solids Extraction Rate as a Function of Inlet Flow Rate for the SLS System.



Source: CleanWorld

In addition, the prototype was transported to CleanWorld's American River Packaging (ARP) facility in April 2014 in order to test the transportability of the system as well as to test it on a different effluent stream (see Figures 25 and 26). The system performed equally well at the other facility, despite the presence of much larger quantities of contaminants in the solid stream.

Figure 24: Transportation (left) and Results of Operation (right) of the SLS System at the ARP Digester Facility

Source: CleanWorld

In November 2014, the unit was transported to the UC Davis Renewable Energy Anaerobic Digester facility for additional testing and use. The device was able to extract over 20 tons of solids from the digester in four weeks (see photo below). The final modifications and fabrication were performed on site.

Figure 25: Testing of the SLS System at the UC Davis READ Digester Facility

Source: CleanWorld

4.2.7 Logic Controls and Instrumentation

CleanWorld contracted controls and instrumentation experts at Frisch Engineering to develop and design the controls schematics for the solid-liquid separation system. The primary control points for the system are the bypass valve and the vibratory screen inlet valve. These will be modulated by the control panel based on sensor readings attached to the vibratory screen. The goal of the controls system is to allow the unit to run unmanned and to shut down pumps in the case of an overflow or a leak. The final instrumentation package remains to be selected and implemented. However, the following concepts are the most likely for controlling the system.

Temperature sensors could be mounted to the pumps in order to prevent them from melting any connecting pipe. The temperature sensors could be connected to a control relay that would shut the pumps off at an adjustable set point. A handheld magnetic fluid flow meter was purchased for monitoring flow rates. In the future an in-line meter could be installed on the main inlet pipe to measure the flow rate into the skid and the controls could allow for alarms triggered by lack of flow. A pair of fluid level sensors may be installed in the upper deck of the vibratory screen and a control scheme written to control the flow into the screen to keep the level between these sensors. A second high-level sensor could shuts down the system in case the level controls fail. For now, the system will be operated manually until the proper control mechanisms are identified.

4.3 Final Testing and Use

Both the SLS and the LFP systems are works in progress. Each will be tested as it is used in real-time, and each will be modified to accommodate new pieces of equipment or instruments that will help improve the performance, usability, and safety are incorporated. For the LFP system, this will likely involve the addition of pre-treatments for removing suspended solids and possibly for concentrating the nutrients in the resulting liquid. For the SLS system, the improvements will most likely come from the installation of automation and controls. In both cases, the systems will be producing valuable fertilizer products and both will have the flexibility to accommodate changes in the needs of both the digester systems as well as the customers using the products.

CHAPTER 5: Data Analysis

This chapter describes the activities conducted related to collect operational data, analyze it for economic and environmental impacts. The goals of this chapter were to:

- Develop a data collection test plan including energy savings and estimated cost savings, greenhouse gas reductions, and other non-energy benefits.
- Provide data on potential job creation, market potential, and economic development, as well as increased state revenue as a result of expected future expansion.
- Provide an estimate of the project's energy savings and other benefits as well as potential statewide energy savings once market potential has been realized.
- Compare project performance and expectations provided in the proposal with actual project performance and accomplishments.

CleanWorld used the pilot FPS system at the Sacramento BioDigester to extract effluent from the tanks, separate the solids from the liquid and then process both for offtake to local farm facilities. During the grant term, CleanWorld shipped more than 75,000 gallons of effluent to farmers in Yolo and Solano County. The team also extracted more than 30 tons of solids for use as fertilizer and proved the capacity to convert them to high quality vermicompost at the lab scale. More than 1,500 pounds of vermicompost was produced from the digester residuals. Each use of the FPS configuration was recorded with data for volume, solids extracted, and characteristics of the effluent material. As the testing progressed, CleanWorld worked to reduce the energy and labor requirements of the system. The final configuration will require periodic manual observation and can be operated in tandem with digester loading shifts, further minimizing additional labor costs. Lab tests were conducted on samples taken from the raw effluent as well as solid and liquid fractions after processing.

This chapter discusses the activities of the data collected during the testing of the FPS system, the results from the lab analysis, The economic and environmental impacts of the system in terms of potential job creation, market potential, and economic development as well as increased state revenue as a result of expected future expansion are also discussed. This chapter also compares project performance and expectations provided in the original proposal with actual project performance and accomplishments.

5.1 Data Collection Test Plan

CleanWorld developed a data collection test plan to evaluate the performance of the FPS system in the following categories. Each metric was measured in comparison to traditional methods of fertilizer production:

- Energy savings
- Cost savings

- Greenhouse gas reductions
- Other non-energy benefits

5.1.1 Energy Savings

The solid/liquid separation system was calculated to use about 20 kWh per ton of solids extracted, based on the pump sizes, power use for the vibratory screen and screw press, and the mean solids extraction efficiency (25 percent). Each ton of solids extracted from the digester was estimated to replaces 0.5 tons of compost due to the difference in moisture content between the solids (60 percent) and typical compost (30 percent). Therefore, the solids require 40 kWh per ton of compost equivalents offset. Compost production was assumed to require 36 kWh per ton of compost produced during windrow composting, 19 kWh per ton of compost produced in a covered aerated static pile, and 69 kWh per ton of compost produced in a rotating drum composter[2]. Therefore, the solids consume about the same amount of energy as compost, while still producing 300 diesel gallon equivalents (DGE) of renewable biomethane per ton of solids extracted, or 150 DGE per ton of compost offset. At the same time, 10,000 gallons per day of liquid effluent containing 550 lbs of nitrogen, 50 lbs. of phosphorus (as P_2O_5), and 250 lbs of potassium (as K_2O) was produced.

For the production of liquid fertilizers, filtration and filling of a 6,000 gallon truck requires 13 kWh, which is equivalent to 0.04 kWh per lb. of nitrogen, 0.43 kWh per lb. of potassium, or 0.09 kWh per lb. of phosphorous, based on the average NPK of the liquid fertilizer during the grant period (0.7 – 0.06 – 0.3).

Traditional anhydrous ammonia production methods consume 0.46 kWh and 24.3 cu. ft. of natural gas per lb. of nitrogen[3] or 33,642 Btu per lb. nitrogen. This is equivalent to 9.9 kWh per lb. N. Phosphate extraction consumes 7,529 Btu per lb. of phosphorous or 2.2 kWh per lb. P. Potash extraction consumes 5,936 Btu per lb. of potassium or 1.7 kWh per lb. K[4]. These energy usages are summarized in the table below, where it can be seen that the FPS system offers substantial energy savings relative to traditional fertilizer production methods.

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[2] Rod Van Haaran. *Large Scale Aerobic Composting of Source-Separated Organic Wastes: A Comparative Study of Environmental Impacts, Costs, and Contextual Effects.* (Diss., MS Thesis, Columbia University, 2009), Page #.

[3] William Lockeretz, *Agriculture and Energy* (New York: Academic Press Inc., 1977) http://store.elsevier.com/Agriculture-and-Energy/isbn-9780323142649/

[4] W. Gellings, Clark and Kelly E. Parmenter. "Energy Efficiency in Fertilizer Production and Use." In *Efficient Use and Conservation of Energy: Encyclopedia of Life Support Systems. Vol. 2*. UNESCO-EOLSS, 2004.

Table 4: Comparison of Energy Use During Fertilizer Production for Conventional and FPS Fertilizers

Nutrient	Energy Required by FPS (kWh per lb)	Energy Required Traditional (kWh per lb)	Energy Savings (kWh per lb)
N	0.04	9.9	9.86
P	0.43	2.2	1.77
K	0.09	1.7	1.61
Total	0.56	13.8	13.24

5.1.2 Cost Savings

The cost of producing fertilizer from anaerobic digester residuals depends on the capital and operating and maintenance costs of the equipment needed as well as the cost of any inputs such as chemicals, added nutrients, and even the digester effluent itself. The latter is highly variable from system to system. In some cases, the digester effluent has no alternate value and is therefore available at no cost. In other cases, there may be a local demand for the effluent for direct land application (for example on a farm where the digestate can be pumped directly into the fields), and it may therefore have some nominal value. However, in most cases the effluent must be disposed at some cost, which means that the value of the effluent as an input for fertilizer production is actually a disposal offset, which could be accounted as a kind of revenue for the fertilizer production system. At the Sacramento BioDigester, the effluent is currently discharged to the county's wastewater treatment system, which charges for the disposal.

The disposal fee is a function of the flow as well as the composition of the wastewater. For the full-scale digester system, the disposal cost is expected to be $0.13 - $0.17 per gallon. This helps to make the FPS system cost effective. However, the cost of producing fertilizer has to be justified relative to the cost of simply treating the wastewater on-site for disposal.

The FPS system is also at an advantage over traditional fertilizer manufacturing because it is a process to refine a byproduct produced at an already profitable BioDigester project. The BioDigester is a net producer of energy and a waste treatment system, and revenue is generated from the sales of energy and tipping fees, making the project profitable before the creation and sales of fertilizer from the effluent. Fertilizer sales become additional profit for most AD systems, therefore the financial incentive for turning digester effluent into fertilizer products depends solely on the alternative uses and costs. In a traditional fertilizer manufacturing process energy, is consumed which increases the cost of the products in order to attain enough revenue to offset the production costs. For the FPS system, the market value of the products is determined by the market. The cost of producing the fertilizer then only has to compete with the alternate uses of the products.

5.1.3 Greenhouse Gas Reductions

The fertilizers produced from the FPS system reduce greenhouse gas emissions by reducing the use of chemical fertilizers in the agricultural market. The International Energy Association's report "A Review of Greenhouse Gas Emission Factors for Fertilizer Production" provides data for chemical fertilizers with an NPK of 15:15:15, indicating that these products release 60-1200

gCO_2 per kg of fertilizer. In the proposal, CleanWorld described the theoretical greenhouse gas reductions that could be achieved with the FPS system summarized below.

Given a very modest factor of 300 gCO_2 per kg of chemical fertilizer (1.135 tCO_2e per 1,000 gallons), then the natural fertilizer produced by the FPS system would reduce CO_2 by 80 percent, or 0.227 tCO_2 equivalents per 1,000 gallons. Using those assumptions, the FPS system's daily production of 10,000 gallons of liquid fertilizer would offset 2.27 tCO_2 equivalents per day or 567.5 tCO_2 equivalents per year (assuming 250 days per year of production). For the highest emissions factor from the International Energy Association paper (1200 tCO_2 equivalents per kg of chemical fertilizer), the offset by the FPS system would be 2,270 tCO_2 equivalents per year.

5.1.4 Other Non-Energy Benefits

Additional benefits that were seen in the data collection of the FPS trials include production of sustainable communities, odor reduction, and reduction of waste and wastewater disposal.

Promoting the recycling of food waste through anaerobic digestion that replaces the effluent's nutrients back into the soil creates an environment that promotes sustainability and efficient resource allocation. Education and awareness regarding sustainability can lead to increased environmentally conscious practices at home and at the work place, including electricity savings (for example, energy efficient lights and switches, and turning off lights when not in use), which reduces overall demand.

By diverting organic waste to anaerobic digestion facilities, odors from decomposition in landfills or at composting facilities are eliminated. The treatment of the effluent with the FPS system reduces the scent of the raw effluent, which reduces barriers to adoption in the agricultural industry that pertain to odor.

By diverting AD effluent to the FPS system the need to dispose effluent into local wastewater systems was reduced, decreasing the BOD and improving wastewater quality before reaching treatment centers.

5.2 Data on Economic Impacts of FPS

5.2.1 Job Creation

The job creation potential from the FPS system can be estimated using several existing data sources. The Tellus Institute with Sound Resource Management reported this year that waste disposal generates the fewest jobs per ton of waste (0.1 job per 1,000 tons) for the various management activities. This is not surprising given that the capital intensive equipment used at disposal facilities can handle large tonnages with few employees. Materials collection also generates relatively few jobs, but more than disposal. Processing of recyclables (2 jobs per 1,000 tons) and organics (0.5 jobs per 1,000 tons) is somewhat more labor intensive. Manufacturing using recycled materials creates a relatively high number of jobs per 1,000 tons, varying by material/sector (for example, about 4 jobs per 1,000 tons for paper manufacturing and iron and steel manufacturing, and about 10 jobs per 1,000 tons for plastics manufacturing). Though relatively small tonnages of material are involved, municipal solid waste reuse and remanufacturing activities are particularly job intensive owing to the labor required for disassembly, inspection, repair/refurbishment, reassembly, and testing.

We can estimate the job creation at an average 100tpd AD facility using the estimate that organics processing demands 0.5 jobs per 1,000 tons and adding the job creation generated by the manufacturing, construction and renewable fueling system, as follows:

- Construction/Manufacturing/Permitting: 30 part time, temporary (or 12 full time annual)
- Fertilizer Production/Distribution: 5 FT
- Facility processing/management/operations: 18.25 FT
- Fueling: 5 FT

Based on this analysis, each typical 100 tons per day (tpd) digester facility can convert 36,500 tons of organic waste to RNG each year, will produce a total of 58.25 jobs. This would potentially add over 580 jobs in California over the next three years if CleanWorld met a modest goal of installing 10 such facilities in that time. These numbers are related to the whole facility, but the FPS system adds an additional two persons per facility as compared with a facility that does not include an FPS system.

Most importantly, the FPS system allows the production of fertilizer to be performed at the site of the digester, allowing the jobs required for operation to be sourced locally. Many of the jobs in the traditional fertilizer manufacturing industry are overseas, even though the United States is the largest importer of nitrogen in the world. The United States also imports the bulk of its domestic potash needs as well[5]. The FPS system brings back both jobs and in-state production of fertilizers to the local economy, and the fertilizers produced are better for the environment. This will be especially important as many digesters are located or planned for siting in rural communities.

5.2.2 Market Potential

Based on its research, CleanWorld believes that there is strong market demand for AD facilities and FPS systems along with them. Recent laws, such as AB 341 (Chesbro, Chapter 476, Statutes of 2011), point toward increased diversion rates in the future that may eventually require alternative disposal methods such as AD. In addition, the general public has begun to make buying decisions based on the environmental impact of companies. All of these factors are driving the demand for commercialization of AD technologies and their ancillary systems such as FPS.

[5] The Fertilizer Institute. http://www.tfi.org/statistics/statistics-faqs

Based on the CalRecycle Waste Characterization study,[6] food waste is the most prevalent type of material in California's waste stream, totaling 6,158,120 tons per year. Over 168.7 MW of base load power (1,404 GWh/yr) could be produced.[7] If the proposed technology were to be applied across the market, the table below shows the potential benefits from various levels of market penetration.

Table 5: Projections of Project Impact for Wide-Spread Application of the FPS System

Market Penetration	Diverted Food Waste from Landfills	Renewable DGE produced	GHG Reductions	Fertilizer Produced
1%	61,320 TPY	3,360 DGE 1.2 M DGE/yr	6,930 MT CO_2e/yr	1,182 TPY solids 16.97 MMgal/yr liquids
10%	613,200 TPY	33,600 DGE 12M DGE/yr	69,300 MT CO_2e/yr	11,827 TPY solids 169.68 MMgal/yr liquids
100%	6,132,000 TPY	336,000 DGE 120 M DGE/yr	693,000 MT CO_2e/yr	118,272 TPY solids 1,696.8 MMgal/yr liquids

California's two new organic waste bills signed into law in September 2014, (AB 1826 (Chesbro, Chapter 727, Statutes of 2014), AB-1594 (Williams, Chapter 719, Statutes of 2014)) were a major step forward for bioenergy resource development in California, and for the pursuit of diverting organics away from landfills more generally. California policy and customer and market signals clearly paints a picture that the state intends to mitigate and adapt to serious climate change impacts through methane reduction, to strengthen the state's fuel security through the development of RNG, to deliver a more stable source of renewable electricity from a more diverse supply mix of bioenergy when the grid demands it, and to create clean and green jobs as part of the new climate economy goals through the capture and recycling of organic waste. New laws, combined with the current incentive and funding structures available, finally allow the market to deliver on the promise of organic waste as a valuable new fuel source for California's transportation and green energy sectors. As a result, based on current market intelligence, it is projected that there will be at least 10 new facilities of the 100 ton a day size class and greater commissioned annually by 2017, with an average per year adoption rate thereafter of over 10 per year, until approximately 350 AD facilities have been built out in California over a 20 – 30 year future projection period.

CleanWorld estimates of the 16 million tons to be diverted, that approximately 75 percent (or 12 million tons) of that stream will be recycled through AD systems made for food and municipal solid waste organic waste streams, as compared to composting, of which CleanWorld expects its technology to capture 40 percent or 3.6 million tons of that market share (based on current competitive analysis and pipeline activity).

In 2014, there are now six food waste AD systems operating in California, three are CleanWorld's. 50 percent of CleanWorld's pipeline of projects that are currently in development

[6] Cascadia Consulting Group. "California 2008 Statewide Waste Characterization Study." *California Integrated Waste Management Board*. Publication Number IWMB-2009-023. August, 2009.

[7] Assumes 95% capacity factor

are in California (more than seven new systems) and it is estimated that pipeline to continue to grow and increase at a rate consistent with the 40 percent projection per year above.

5.2.3 Economic Impact and Increased State Revenue due to Expansion

The FPS system is expected to provide up to $547,000 per year in additional revenue[8] to CleanWorld's existing digester systems in the next year. If this were expanded to 10 new AD systems in California over the next five years, it would add $3.65 Million per year in State revenue. While the exact value of the liquid fertilizer is not yet fully understood and the market potential of liquid fertilizers is not yet known, this estimate provides a reasonable baseline by which to judge the success of liquid fertilizer production from AD systems into the future.

5.3 Energy savings and other benefits

Once the market is fully developed for FPS, the estimated energy savings (based on $0.14/kWh) are approximately $2,500 per year for CleanWorld's existing systems over traditional fertilizer generation. The more important point is that the FPS system allows AD projects to save money over disposal and potentially generate revenue from their effluent streams. While not strictly required for making AD systems economically feasible in California, it would greatly augment the adoption rate for AD technology. The benefits and energy savings to the state are tremendous if the AD industry is successful in capturing the market of organic waste and transforming it into renewable fuels and electricity as shown in the table above.

5.4 Project performance versus expectations

After running the FPS for over six months, the performance of the system was consistent with the expectations provided in the proposal. The table below compares the expectations stated in the proposal to the data collected during trials.

Table 6: Table of Successes of the Current Grant in Meeting Stated Goals

Goal Stated in Proposal	Results from Field Trials	Analysis of Success in Meeting Goal
Demonstration Goals:		
Demonstrate the ability to price RNG at compressed natural gas market prices – eliminating the RNG "premium" – by substantially increasing income from effluent co-products.	CleanWorld used the FPS system to produce 75,000 gallons that were sold for $400 per truckload ($0.07 per gal) as well as over 30 tons of marketable solids.	While CleanWorld demonstrated the ability to charge for offtake of the liquid effluent, which was a huge step in the direction of increasing the economics of AD projects and being able to subsidize RNG for buyers, CleanWorld needs to work on getting higher value for these co-products before the RNG premium can be completely eliminated.

[8] Assuming gross revenues of $0.05 per gallon for liquid fertilizer with a daily continuous production rate of 20,000 gallons from a 100 ton per day facility and 10,000 gallons from a 50 ton per day facility.

Goal Stated in Proposal	Results from Field Trials	Analysis of Success in Meeting Goal
Demonstrate commercial scale effluent processing for revenue generation at a successful BioDigester and RNG production facility.	The FPS systems processed over half a million gallons at CleanWorld's SATS and READ projects, both which are commercial systems.	CleanWorld successfully met this goal. The SATS facility is a successful RNG producing BioDigester facility, and the FPS system was demonstrated at commercial scales for processing effluent which generated revenue for the company.
Improve process-related effluent processing economics.	Operation and design of the FPS system was optimized over the course of the grant, which increased the flow rates and production efficiencies from the equipment selected. Additionally, pilot testing of new equipment further improved process efficiencies.	The current effluent process involves disposal to the county wastewater treatment facility, which is a net cost to the company. Therefore, the development of the FPS improved economics by turning a net cost into a revenue source. Improvements in efficiency for the equipment further improved the economics of effluent processing. There will be additional improvements in the future as well which resulted from the testing. enabled by this grant.
Reduce GHG emissions by up to 80 percent -- 2,270 tCO_2 equivalents per year – by offsetting nitrogen based fertilizers with natural and organic fertilizers.	The FPS system was demonstrated to generate fertilizer from natural products for farms that can offset traditional fertilizers. As stated earlier, the FPS is capable of processing enough co-products per year to offset 2,270 tCO_2 if run continuously.	CleanWorld plans to run the FPS system full time at both the SATS and READ facilities as well as implement them at future AD facilities that the owner is agreeable to incorporating and operating this system. This will greatly increase the GHG emissions that are offset per year. The ability to offset fertilizers and reduce GHG emissions depends entirely on the market demand for the natural fertilizer from AD.
Reduce petroleum dependence by improving economics for a renewable natural gas project and fueling station for public use.	The FPS system was used to generate revenue from co-products that had previously been a net cost to the AD process.	This greatly improves the economics of RNG production. As the market penetration for natural fertilizer improves, the additional revenue for AD will speed up its adoption. Many of CleanWorld's pipeline projects include RNG production, and the more RNG projects there are on the ground, the less dependent fleets will be on foreign oil.
Stimulate economic development in California by developing a replicable plan for fertilizer production at California anaerobic digestion (AD) projects.	The testing done as part of the current grant allowed CleanWorld to select the best processing scheme for the FPS system. CleanWorld will include FPS systems in the plans for all future AD projects where the economics support it.	As CleanWorld's AD projects are deployed, the FPS systems will also be replicated throughout the US. These will also be offered as a product with CleanWorld's consulting services to projects that do not include CleanWorld AD systems.

Goal Stated in Proposal	Results from Field Trials	Analysis of Success in Meeting Goal
Provide natural fertilizer products at competitive market costs to local growers.	CleanWorld provided natural fertilizer from the FPS system to farmers at a cost which was competitive with comparable products.	Compared to organic fertilizers on a nitrogen basis, CleanWorld's co-products created by the FPS system were significantly lower in cost. The products were comparable to compost by this same comparison. When compared with disposal costs for the effluent, the natural fertilizers produced by the FPS system may also be competitive with conventional fertilizers.
Technical Goals:		
Process up to 30,000 gallons per day of liquid digester effluent.	We installed 30,000 gallon capacity tanks and tested equipment capable of processing 100 gallons per minute of liquid effluent, which would process 48,000 gallons per day of liquid effluent in an 8 hour day.	CleanWorld installed equipment that can meet the processing goal on a daily basis. Therefore, CleanWorld successfully met this technical goal.
Reduce the volume of liquid effluent by 7,500 gallons per day using vapor distillation.	A vapor distillation system was tested at a smaller scale, capable of reducing the effluent volume by 50 - 80%, which could meet the stated goal. However, the equipment tested would not process the full 10,000 gal per day effluent production volume.	This technology continues to be vetted based on the results of the testing enabled by this grant as well as market research on the product created. Until more information has been gathered, a purchasing decision cannot be made.
Create up to 10,000 gallons per day of marketable liquid fertilizer product.	The equipment installed utilizing this grant can process up to 48,000 gallons per day of liquid and store up to 30,000 gallons of liquid fertilizer on site. More than 75,000 gallons of liquid fertilizer to farms during the grant were shipped and more than 10,000 gallons per day of liquid fertilizer could be shipped with the existing equipment.	CleanWorld successfully met and exceeded this technical goal. CleanWorld continues to develop markets for these products and to do additional development utilizing the existing equipment as well as new equipment which was piloted under this grant.
Create up to 8,000 pounds per day of marketable solid fertilizer product.	The solid/liquid separation equipment developed and installed under this grant was shown to extract over 2,000 pounds per hour of solids which could be used as a solid fertilizer. During the course of the study, over 30 tons of solids were extracted. Furthermore, over 1,500 pounds of high quality vermicompost were created from the solids generated.	CleanWorld successfully met and exceeded this technical goal. The FPS system could produce the stated goal if run for 4-6 hours per day. The amount of solids extracted regularly from an AD system depends on the rate of solids accumulation in the system. CleanWorld will be utilizing the FPS system for solids extraction on a regular basis at all of their active facilities. In time, the true steady-state solid fertilizer production rate will be determined in the field.

CHAPTER 6: Technology Transfer

This chapter describes the activities conducted related to developing a plan to make the knowledge gained, experimental results, and lessons learned available to key decision-makers. The goals of this report were to:

- Prepare a technology transfer plan that explains how the knowledge gained in this project will be made available to the public. The level of detail expected is least for research-related projects and highest for demonstration projects. Key elements from this report will be included in the final report.
- Conduct technology transfer activities in accordance with the technology transfer plan. These activities will be reported in the monthly progress reports.
- Indicate the intended use(s) for and users of the project results.
- Complete Draft Technology Transfer Plan

There are three broad stakeholder groups critical to the successful execution of anaerobic digestion projects that are discussed below. The three main consumer groups are:

1) Fertilizer distributors and producers – with a long history already in this market, this group has existing customers that they will want to retain as new products emerge. By educating this group about the fertilizers created from byproducts of anaerobic digestion and developing product recognition, the researchers gain access into an existing group of customers and educate the buyers through the channels that sell to them.
2) Producers of organic waste, farmers, waste collectors and disposal facilities – many of these groups have a use for or access to a customer who has a use for the final fertilizer product in addition to the need for disposal of their organic waste. By educating this group on the final product's availability it becomes possible to market a full-circle solution that includes selling the fertilizer product to the original generator of the organic waste that created it. These organizations are looking to increase sustainability performance and use of this material can greatly increase diversion credits and provide revenue opportunities.
3) Policy makers, government agencies and other stakeholders – these organizations want the benefit from AD system developments and continue to make changes to laws that demand for its use (Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006), Renewable Portfolio Standard, and so forth). Project developments like CleanWorld's FPS will help them feel more comfortable with it as an application, allowing them to make changes that will contribute to quicker deployment.

CleanWorld's FPS (and projects like it) are important examples of anaerobic digestion technology use that will help these stakeholder groups be more apt to use the technology to accomplish their organizational goals. Development of AD technologies to create valuable byproducts from anaerobic digestion will need to leverage synergies from these stakeholders for further deployment of the technology.

6.1 Technology Transfer Activities

CleanWorld researched and identified industry associations and stakeholder organizations for possible membership and collaboration to increase exposure of this technology.

CleanWorld will ask to be listed in these stakeholder's databases; posting lessons learned from this study on their websites, as well as making this information available for presentations in future meetings and educational activities, including webinars and in online resource libraries. CleanWorld has created a database of these stakeholders, which is represented in the table below, although additional stakeholders or industry associations may be identified as the outreach activities commence:

Table 7: List of Associations Relevant to the FPS System

Association Name	Acronym	Web Address
Advanced Bio fuels Association	ABA	http://www.advancedbiofuelsassociation.com/
Air & Waste Management Association	AWMA	http://www.awma.org/
American Biogas Council	ABC	http://www.americanbiogascouncil.org/
American Council on Renewable Energy	ACORE	http://www.acore.org/
American Society for Agricultural and Biological Engineers	ASABE	http://www.asabe.org/
Bio Technology Industry Organization		http://www.bio.org/
BioCycle		http://www.bio-cycle.com/
Bioenergy Association of California	BAC	http://www.bioenergyca.org/
Bio-Energy Interagency Working Group	BEWG	http://groups.ucanr.org/BEWG/
Biomass Collaborative		http://biomass.ucdavis.edu/
Californians Against Waste	CAW	http://www.cawrecycles.org/
California Association of Compost Producers	ACP	http://www.healthysoil.org/
California Energy Commission	CEC	http://www.energy.ca.gov/
California League of Food Processors	CLFP	http://clfp.com/
California Resource Recovery Association	CRRA	http://crra.com/
California Restaurant Association	CRA	http://www.calrest.org/
California Refuse and Recycling Council	CRRC	http://www.crrcnorth.org/index.aspx
CalRecycle		http://www.calrecycle.ca.gov/Organics/default.htm
CalStart		http://www.calstart.org/Homepage.aspx
California State Association of Counties	CSAC	http://www.counties.org/
Center for Climate and Energy Solutions-AD	CCES	http://www.c2es.org/technology/factsheet/anaerobic-digesters

Association Name	Acronym	Web Address
Clean Cities Coalition - USDOE	CCC	http://www1.eere.energy.gov/cleancities/
Clean Fuels Development Coalition	CFDC	http://www.cleanfuelsdc.org/
Energy Institute		http://www.energyinst.org/home
Energy-Vision	EV	http://energy-vision.org/
Global Trade & Technology Network	GTTN	http://www.usgtn.net
GreenBiz/Verge	VERGE	http://www.greenbiz.com/microsite/verge
League of California Cities	LCC	http://www.cacities.org/
Local Government Commission	LGC	http://www.lgc.org/
National Gas Vehicles for America	NGVC	http://www.ngvc.org/
National Waste & Recycling Association	NWRA	https://wasterecycling.org
Northern California Recycling Association	NCRA	http://www.ncrarecycles.org/
Regional Council of Rural Counties	RCRC	http://www.rcrcnet.org/rcrc/
Renewable Fuels Association	RFA	http://www.ethanolrfa.org/
Solid Waste Association of North America	SWANA	https://swana.org/
Teru Talk (Michael Theroux)		Mtheroux.com (530) 823-7300
United States Conference of Mayor’s	USCM	http://www.usmayors.org/
US Composting Council	USCC	http://compostingcouncil.org/
Union of Concerned Scientists-BioMass	USC	http://www.greenbiz.com/microsite/verge
US EPA Office of Solid Waste	EPAOSW	http://www.epa.gov/osw/
World Resources Institute	WRI	http://www.wri.org/

CleanWorld also plans to educate decision makers through public forums, workshops, and industry conferences such as the annual BioCycle conference, the Annual Waste Management Conference, the Biomass Collaborative sponsored by UC Energy Week at UC Davis and the United States Composting Council meeting. CleanWorld is planning on attending the American Society for Agricultural and Biological Engineers, the Alternative Clean Transportation Act Conferences, Waste and Conversion Congress (west coast), and the Biogas West Conference in future years to raise awareness for this technology.

This final report will be posted on the CleanWorld website and CleanWorld will encourage the associations they hold membership in to also make the report available on their websites. This will allow the public to learn about CleanWorld’s anaerobic digestion technologies and feasibility determinations from this study. CleanWorld will also have a link on their website for potential customers to fill out a survey with their waste stream information that will allow CleanWorld's engineers to evaluate the technical, financial and economic feasibility of the potential site for an anaerobic digestion system generating transportation fuels with the information they gathered from this study.

6.2 Intended Uses

CleanWorld anticipates that this report will be used to instill confidence in the products that are created using the FPS among targeted audiences described in the introduction of this report. The more knowledge that is transferred among industry stakeholders, the more widely the FPS system can be deployed. CleanWorld envisions the FPS system being deployed not only in tandem with CleanWorld's digestion technologies, but also on existing digestion projects that are looking to recover additional value from their effluent streams—even across other industries and by projects/systems not connected to CleanWorld technologies. Other potential uses for the FPS could include manure lagoon digester effluent, biosolids, wastewater and other projects that have a liquid waste stream associated with their process.

CHAPTER 7: Production Readiness Plan

This report describes a plan to determine the steps that will lead to the commercialization and manufacturing of the technologies developed in this project. The details of the plan have not been fully refined due to the state of the technology, which is still in the prototype phase. However, an effort was made to discuss the equipment, facilities, personnel and support systems needed to finalize the design and begin large-scale manufacturing of the FPS system. The costs for the prototype units will be discussed along with cost reductions during manufacturing as well as additional investments needed in order to launch the commercial product. In conclusion, a plan will be presented with a view toward ramp up to full production.

7.1 Technology Advancements for FPS

Technological barriers are often a major hurdle for renewable energy. In the case of generating co-products from digester effluent, very few products exist specifically designed the AD industry. Therefore, CleanWorld was forced to use equipment developed for related industries such as wastewater treatment, composting, and fertilizer production, as well as unrelated industries such as mining and pharmaceuticals. In some cases, the unique characteristics of the material being processed proved to be unsuitable for the equipment selected, while in other cases multiple pieces of equipment were combined in a unique way to perform the tasks needed. A fully productized system does not currently exist in the market and this has challenged CleanWorld to create a modular turnkey system to improve the economics of their own anaerobic digestion projects as well as others throughout the market. As a result, a number of technologies were tested and piloted, and ultimately, CleanWorld created a unique new technology specifically designed for turning digester effluent into high-value co-products. This equipment and the knowledge gained from the execution of this grant will help promote AD and RNG production from organic waste streams well into the future.

During the process of creating of a mobile solid/liquid separation system, several technologies were integrated after testing of the individual components failed to create a suitable product. The integration of these components involved the development of a unique new process with several custom designed components to assist with the control and functionality of the equipment. These represent significant advances in technology specific to the characteristics of the fluids from the AD process.

For the creation of liquid fertilizers, CleanWorld conducted extensive research on various technologies. This research has revealed, again, that the equipment choices available from other industries may not be ideally suited to the AD industry. Research and development in this sector is ongoing, and ultimately, CleanWorld opted for a simplified set of equipment which can be modified later to adopt whichever technologies ultimately appear to be required for creating the most economically viable product(s) from liquid digester effluent.

7.2 Pathway to Full Commercialization

The FPS system initially envisioned by CleanWorld for processing of digester effluent ultimately became two independent systems that could be applied separately and in combination for the creation of a wide range of fertilizer products. The first system created was the solid/liquid separation (SLS) system, which was designed to create a relatively dry fibrous cake extracted from active digester slurry. The SLS system which is operated intermittently as an integral part of digester operation was conceived as a mobile unit for cost savings. A stationary design was also considered. In practice, the skid was built to be a stand-alone unit that can either be mounted in place or mounted on a trailer for mobility. After several design revisions, a final prototype was built and tested. However, additional design reviews are planned prior to finalizing the system design. These design reviews will resolve any outstanding operations issues that are discovered during field testing as well as automate the system with a full set of instrumentation and controls. In addition, several adjustments to the equipment will be tested to improve the unit's capacity and separation efficiency, which continues to be field proven as it is being utilized. Ultimately, the sizing of the equipment and its capacity will be determined which is critical for commercial application and will vary along with the AD system size and substrate being digested.

The liquid fertilizer production (LFP) portion of the FPS consists of stationary equipment for creation and dissemination of liquid fertilizer. The LFP system was designed to be flexible to accommodate fluctuations in market demand for various fertilizer products. The base system includes tanks for storing and possibly processing effluent from the digester and pumps for discharging the liquid fertilizer to a tanker truck for transportation to the end user. However, the design allows for integration of preprocessing equipment, mid-stream processing of the effluent (that is, aeration of the liquid and/or injection of additives to the liquid), and post-processing equipment. Several of these added components were tested as part of this grant and testing is ongoing as of the publication of this report. Therefore, the final layout of the LFP system has not been finalized. However, the base system can be considered as a commercial system ready for integration with all CleanWorld AD systems where a liquid fertilizer production component is desired.

7.2.1 Commercial Readiness of the Solid/Liquid Separation System

The SLS system will need several months of additional testing followed by at least one additional design review before the system can be deployed commercially. The system was designed and is being tested as a mobile unit, but the final configuration will depend on the solids extraction efficiency and maximum achievable flow rates achieved in the field. Substantial additional work is also required for automating the system and reducing the labor demands for operation.

In order for the system to be ready for commercial deployment, the field testing would need to be complete, automation would need to be installed and tested, the piping layout and system configuration would need to be finalized, and the system would need to be re-designed based on all of these decisions. Finally, the system would be re-tested under the final design configuration prior to creating the final assembly package.

Testing will involve operation by field staff with oversight and data collection by the CleanWorld Research and Development team. Automation will involve creation of a control scheme by instrumentation and controls specialists, installation of the instruments and controls, and additional field testing. Final as-built drawings would be created by mechanical engineers with a parts list and assembly instructions. Custom components would need to be fully specified and drawn for repeatable manufacture.

Manufacturing of the full-scale skid would most likely be performed by a contract manufacturing firm to CleanWorld's detailed specifications and under CleanWorld supervision. The manufacturer would be under a strict confidentiality agreement and all methods, tools, fixtures, software, hardware and firmware required to produce the system(s) would remain the property of CleanWorld.

The prototype system cost about $120,000 in parts and $40,000 in fabrication (with a 15 percent contingency). An additional $20,000 – $40,000 was spent on site-work needed for things like extending electrical service, plumbing the digester for feeding the SLS system directly, and various other site service needs. CleanWorld envisions that the expected cost of the final system could be reduced by 25 – 35 percent by purchasing materials in bulk, eliminating redundancies, and completely assembling the system in a factory setting. Factoring in a profit margin for the company, the final expected price for the SLS system (not including site work) is expected to be in the range of $125,000 – $150,000.

7.2.2 Commercial Readiness of the Liquid Fertilizer Production System

The LFP system was tested at scale under several configurations. Initially, a complex system with integrated heating, cooling, mixing, screening, and filling was tested for the creation of a "3-3-3" natural liquid fertilizer based on a proprietary ingredient blend that included the digester effluent. This product was marketed under a private label and was the basis for the original FPS design. However, the market for this product did not justify expanding the manufacturing process. A market did begin to develop for the liquid digester effluent with minimal preprocessing. Therefore, the process flow was pared down to the minimum needed to create and disseminate this product, but the equipment were designed to allow for adding the required components later to create the same 3-3-3 liquid fertilizer as well as other products under development by CleanWorld.

The final LFP system design consisted entirely of readily available commercial components without any custom parts needed for their integration. As such, this system is ready for commercial deployment without extensive additional testing. However, if any other components are added to the base LFP system or if a particular customer requires the product to be treated to meet their specifications, additional engineering design and testing would be required. In preparation for such, CleanWorld began pilot testing various add-on components as part of this grant, including aerators, pre-filters, and evaporation/concentration equipment. This pilot testing is ongoing.

Operation of the base system requires minimal oversight. Instrumentation and controls were added to monitor tank levels and prevent overflow, so that tanks can be filled to specified level without constant supervision. However, filling and discharging the tanks would not be expected to occur very frequently, so manual operation would be sufficient with minimal operator oversight. However, as additional components are added, the complexity of the processing would increase which could require additional automation to avoid excessive oversight. This would be designed into any changes to the overall system. Filling trucks for shipping would be quick and could be executed with a single on-site operator. A truck filling station was included in the site layout plan. Logging the shipping volumes could be done at the weigh station and backed up with data integrated into the control system. This would be critical for inventory tracking and billing for fertilizer shipments.

The cost of the LFP system in this grant came to $70,000 – $90,000 for the equipment with $20,000 – $40,000 in installation and assembly costs (that is, electrical connections, field plumbing, and tank erection). Site modifications cost $70,000 – $90,000, but most of these costs could be cut significantly by including the LFP system in the original site-prep work for the AD system as it was built. For projects without LFP in the original plans, the infrastructure for adding the LFP could be included in case of future expansion. For this project, the LFP was not envisioned when the AD system was originally designed and installed. Therefore the project incurred higher site-prep costs. Some of these were shared between the LFP and the SLS system, such as electrical service.

As part of the AD system design and without any additional components, a similar LFP system would be expected to add $75,000 – $100,000 to the overall system cost, not including any site changes required, which will be specific to the facility where it was installed. If the most promising piece of pilot equipment for pre-filtering the effluent were included, it would add $150,000 plus some additional cost for integrating the system with the overall LFP and to the LFP system cost. This would have to be justified by the needs of the customer.

In addition to the initial cost, there would be ongoing operating and maintenance costs related to repair and replacement of parts that wear. As CleanWorld continues to test the pilot equipment, a better estimate of these costs will be developed. This is included in the overall production plan.

7.3 System Production Plan

Full implementation of the LFP and the SLS systems will require a dedicated plan to achieve the goals needed moving forward. The details of the plan need to be further refined, but the general plan will require the following steps:

1. *Finalize designs with set sizes for production.*

   For the SLS system, the prototype unit needs to be tested in the field to determine the optimal use and maximum flows and extraction rates and capacities. These need to then be validated relative to regular system operation to ensure that the equipment is appropriately sized. The system design can then be sized to match the needs specific to the AD system.

The base LFP system design has been finalized and can be implemented in its current state. As experience with the equipment continues the design and system layout may be refined, and these refinements can be integrated into new AD systems moving forward. However, the process of refining the system design should not impede the distribution of the FPS system, unless critical safety failures are discovered. A full safety analysis for the equipment was included in the original design. Therefore, such discoveries would not be likely. The design of the LFP system may need to be revised at the conclusion of pilot testing of the various add-on components currently identified. However, the base system design will allow for adding components as they are identified with minimal changes. Nonetheless, a final design should include any extra equipment required as the LFP system is disseminated in the future.

2. *Identify manufacturing partners and/or suppliers for all equipment as well as installation needs and partners.*

   For the SLS system, several components were custom designed. These need to be fabricated in a shop accustomed to custom fabrications. The entire skid should be shop fabricated and tested, including installation of electrical components, instruments, and controls. CleanWorld will need to identify the appropriate partner to contract this work to as manufacture ramps up. This would be similar to the work done for manufacturing the pump skids for the CleanWorld BioDigester system. The same manufacturing partner could be used. All of the commercially available components for the skid have been selected and sourced. There are several options for the vibratory screen and the screw press that need to be selected for the system prior to manufacturing.

   For the LFP system, all of the main components are available commercially without the need for custom designed parts. No shop fabrication or manufacturing is necessary. The components would be ordered and delivered to the site. CleanWorld or one of its contractors would install all of the equipment. Field piping and electrical would be contracted to the same company used to install the AD systems. If an add-on component was needed for filtration or otherwise, it would be ordered as a turnkey system, independent of the rest of the equipment, and integration would be done at the same time as the primary equipment installation.

3. *Continue equipment testing for identification of ongoing operation and maintenance costs, as well as overall technology improvements.*

   In order to provide an LFP or SLS system to its customers, CleanWorld will need to be able to provide realistic estimates for ongoing operating and maintenance costs for these components. Field operation at the Sacramento BioDigester will help provide the needed information on the SLS and LFP running costs. In addition, as field testing continues, periodic design reviews will undoubtedly result in process improvements, often provided by the field staff operating the equipment. These improvements can be integrated into the overall design, and they can also be offered to customers as upgrades to their existing systems. Knowledge of field practices will be an integral part of the marketing strategy for the FPS system as CleanWorld signs up new AD customers.

4. *Conduct further research on fertilizer products to help develop and access markets.*

   In addition to researching and developing the equipment for the FPS, CleanWorld will need to continue researching field application of its fertilizer products. Research started at UC Davis under this grant will continue, and new research programs will be developed as part of the implementation plan. A field research program with farmers was started under this grant as well, and plans are in place to continue and expand the field research into the next growing season.

   Not only will this research be critical for CleanWorld to market its liquid and solid fertilizer products to farms near the Sacramento BioDigester, but building up experience with the fertilizers will also expand the market demand for the products. This will in turn help new customers to develop successful AD to RNG projects moving forward.

5. *Create marketing materials, price sheets, and a sales and marketing plan for CleanWorld fertilizer products.*

   Research on the use of fertilizer products will help to inform the CleanWorld marketing strategy for the products. A set of sales and marketing collateral was developed previously, but the new research will help to improve the collateral and provide farmers with better instructions for use of the materials. As things like nutrient mineralization rates and uptake efficiencies, water use reductions, and application rates and timings are investigated, the marketing and sales documents can be improved to provide better information to farmers on how to best apply CleanWorld fertilizers in various settings. Farmers who are not familiar with the products will also be given the confidence to use them on their crops by knowing exactly how to use them, what to expect, and by seeing that other farmers have successfully used the material. In addition, the environmental benefits to using digester effluent as a fertilizer needs to be quantified to provide a better rationale for using natural fertilizers on conventional crops.

7.4 Expected Investment

The implementation plan outlined above clearly includes steps that will require additional investment. Most importantly, the equipment designed, installed, and tested under this grant will need additional field testing, redesign, and modification before CleanWorld can begin manufacturing the technologies. In addition, the research on the product use and market development for the fertilizer products will be absolutely critical in determining whether the proposed technologies will be financially justified.

CleanWorld estimates that the field testing of the equipment and additional engineering development will cost $100,000 – $150,000, and the additional research and marketing of fertilizers could cost up to $250,000 before the SLS and LFP systems are market ready as stand-alone units designed for turning digester residuals into higher value fertilizer products. However, the SLS system—or a version of the system—will be necessary for regular digester operations. Therefore, that system has reached its investment threshold for this use, and manufacturing on a small scale should begin immediately.

As long as the prototype unit continues to serve the needs of the existing sites, CleanWorld may not build a second system in the immediate future. However, it is very likely that another one will need to be built in the next year to serve the needs of CleanWorld's expanding facility infrastructure. Furthermore, aggressive testing will determine whether the SLS system should be integrated into the fundamental design of CleanWorld's AD systems and how that might occur.

The LFP system will require additional investment if it is solely being utilized for fertilizer production. However, the same system may also help reduce effluent disposal costs, in which case that too could become an integral part of the AD system design. At the Sacramento BioDigester facility, this is the case. Therefore, the prototype system will most likely be used both for effluent treatment prior to disposal as well as for fertilizer production. Some additional field experience is needed before that system will be ready to be implemented at CleanWorld's other AD facilities in the Sacramento area. The investment should be less than $50,000, however, before the base LFP system will be ready to be implemented at CleanWorld's other facilities. A version of the LFP system will most likely also be included in all future AD system designs for new customers as well.

CHAPTER 8: Final Conclusions

The work performed under this grant resulted in the development of new technologies that will help advance anaerobic digestion for the creation of RNG as a transportation fuel. It will also help improve the profitability of anaerobic digestion as a beneficial technology, which will ultimately help expand the use and usefulness of AD and reduce dependence on non-renewable energy and fertilizer. At CleanWorld, large scale systems in excess of 100 tons per day (TPD) (40,000 tons per year (TPY)) are can be financially viable without sales of effluent byproducts, assuming sufficient revenues from tipping fees and sales of bioelectricity or RNG. However, the capital cost of small (25 TPD, or 10,000 TPY) and mid-size (50 TPD, or 20,000 TPY) facilities is substantial enough that a co-product revenue source is required to allow most systems to achieve financial viability. For these systems, even a modest revenue stream generating 10 cents per gallon of liquid digestate will create a meaningful new income stream equal to approximately 20 percent of all project revenues. This is critical because small- and mid-size AD systems make it easier to site projects at the facility owned by an individual waste producer, dramatically lowering the cost of waste transportation and reducing greenhouse gas and other environmental costs while also generating electricity, heat, and RNG for the host site. As discussed in section 5.2, the FPS system is expected to provide up to $3.65 million per year in State revenue if its application were extended to 10 new systems over the next five years. While the exact value of the liquid fertilizer is not yet fully understood and the market potential of liquid fertilizers is not yet known, this estimate provides a reasonable baseline by which to judge the success of liquid fertilizer production from AD systems into the future. The FPS system designed and built for this grant will transform anaerobic digestion from a waste treatment and renewable energy technology to a waste treatment, renewable energy, and fertilizer production technology.

CleanWorld has already proven the ability to use the FPS technology for creation and sale of valuable fertilizers. This has added revenue to CleanWorld's existing digester projects, and it will continue to do so as the markets for these fertilizer products expand. The market research also helped to pinpoint ideal fertilizers and end-users, which in turn will help to further expand the market. The energy savings shown for the FPS system over traditional anhydrous ammonia production was significant and was demonstrated at comparable energy consumption to the compost. Cost savings is also applicable in most cases when employing the FPS system because the effluent must be disposed at some cost; which means that the value of the effluent as an input for fertilizer production is actually a disposal offset, which could be accounted as a kind of revenue for the fertilizer production system. The FPS system is also at an advantage over traditional fertilizer manufacturing because it is a process to refine a byproduct produced at an already profitable BioDigester project. The BioDigester is a net producer of energy and a waste treatment system. Revenue is generated from the sales of energy and tipping fees, making the project profitable before the creation and sales of fertilizer from the effluent. The fertilizers produced from the FPS system also reduce greenhouse gas emissions by reducing the use of chemical fertilizers in the agricultural sector. Additional benefits that were seen in the data collection of the FPS trials include production of sustainable communities, odor reduction, and reduction of waste and wastewater disposal.

In addition to improving anaerobic digestion technology, the work performed under this grant will help CleanWorld to become a better company. The market research helped inform the CleanWorld team and allowed its managers to create more effective business strategies. The laboratory research on fertilizer application helped the company to develop better marketing collateral for its customers, both as end users of the fertilizer products and as third party digester operators who also wish to create high value fertilizers. The creation of novel effluent treatment technologies and the experience with existing technologies greatly improved the effectiveness of the company in addressing customers' needs regarding effluent treatment, processing, and use. This will have impacts on fertilizer creation as well as effluent treatment for reduction in disposal costs. The technologies designed and tested by CleanWorld as well as the knowledge gained in the execution of this grant add value to the company.

CleanWorld looks forward to continuing to expand on the work initiated under this grant. The research and development activities performed here will lead to new research and development activities for the company. CleanWorld has already begun working with UC Davis researchers to expand on the findings from this study through collaborations on other studies funded by the CDFA and the United States Department of Agriculture. These studies will expand the application of the FPS system to other industries such as dairies by continuing to test digestate-based fertilizers at larger scales and in more depth. In addition, research on the microbiological composition of digestate and the effect of these microbes on field crops which was initiated under this grant is also continuing. The results of this research will help in understanding the appropriate application of CleanWorld's products and it will expand the marketability of the products. CleanWorld continues to use the technologies installed under this grant at its operating digester facilities, and through this field experience CleanWorld continues to improve the design and optimize the operation of these technologies.

GLOSSARY

Term	Definition
AC	Alternating Current
AD	Anaerobic Digester
ARP	American River Packaging
BOD	Biological Oxygen Demand
CDFA	California Department of Food and Agriculture
CO_2	Carbon Dioxide
DGE	Diesel Gallon Equivalent
FPS	Fertilizer Production System
GHG	Green House Gas
HP	Horse Power
IBC	Stackable Bulk Container
K	Potassium
KW	Kilowatt
KWh	Kilowatt-hour
LFP	Liquid Fertilizer Production
N	Nitrogen
NPK	Ratio of Nitrogen to Potassium to Phosphorous in soil
OMRI	Organic Materials Review Institute
P	Phosphorous
P&ID	Piping and Instrumentation Diagram
RNG	Renewable Natural Gas
RO	Reverse Osmosis
SLS	Solid-Liquid Separation
SOP	Standard Operating Procedure
TS	Total Solids

TSS	Total Suspended Solids
UAN	Urea Ammonium Nitrate
UC	University of California
UC Davis	University of California, Davis
USDA	United States Department of Agriculture
V	Volts
VFD	Variable-Frequency Drive