California State University, Chico

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PROJECT NO: RU-7

ANNUAL REPORT COMPREHENSIVE
RESEARCH ON RICE January 1, 2017 -
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PROJECT TITLE: RiceBoard Laminated BioComposite Development for Rice Straw based Construction Panels and Anaerobic Digestion of Farm Waste

PROJECT LEADER (include address): Joseph Greene, Ph.D.

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PRINCIPAL UC INVESTIGATORS (include departmental affiliation):

COOPERATORS: None

LEVEL OF 2017 FUNDING: $18,250

OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

The objectives of the research are as follows:

1. Evaluate the commercial viability of the Biobased Structural Insulating Panel (BSIP) for producing riceboard laminated biocomposite.
2. Evaluate current technology and research to anaerobically digest agricultural waste including algae, manure, rice straw, rice, food waste, and crop waste.
3. Develop a laboratory-scale test equipment to measure methane and carbon dioxide gases from biodegrading agricultural waste.
4. Test several farm related materials, including, food waste, fruit waste, manure, algae, and crop waste, for generating methane gas with anaerobic digestion.
5. Develop pre-conditioners and equipment to improve the efficiency of anaerobic digestion.
6. Measure the emission of methane and carbon dioxide from the agricultural materials that have pretreatments to improve the biodegradation.
7. Design prototype anaerobic digestion equipment and pretreatment equipment to convert waste agricultural materials to methane gas and carbon dioxide.
8. Evaluate the technical viability of the process.

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SUMMARY OF 2017 RESEARCH (major accomplishments), BY OBJECTIVE:

Experiments were conducted at the CSU, Chico Plastics Laboratory in Chico, CA.

(Objective 1- Commercial viability of riceboard laminated biocomposite)

The biocomposite (BSIP) was proven last year that it is technically feasible and can be made with current materials and technology. The costs though were higher than commercial products made with particle board and Styrofoam. The BSIP was shown to some professors in the Construction Management Department at Chico State University in order to include it in their blitz build project in Chico. Unfortunately, there was little interest from the professors or construction companies to use the biocomposite material in construction projects. The cost was too high. Further development of the PLA foam material led to difficulty in producing thicker and cheaper foam materials. A sport and gun company showed interest in the material to be used to create a biodegradable sport pigeon to replace the clay pigeon. The project should use the similar biobased plastic and rice straw materials with a new part. The new project for 2018 will be described later.

(Objective 2- Evaluate current technology)

Current technology exists for converting waste animal waste to methane gas and electricity using anaerobic digestion. Several researchers were able to convert wastes from sugar beets, sewer sludge, pulp and paper mill, food, rice straw, manure, potatoe, algae, corn stover, and wine. The researchers were able to convert the waste to methane gas using a two-step process with hydrolysis and methanogenesis. Table 1 depicts the amount of methane generated per gram of waste.

Table 1. Typical methane generation using anaerobic digestion (AD).

Waste type	Methane (L) per kg of waste
Dairy manure	591
Manure, maize, onion, potato	540
Rice straw	330
Rice straw	285
Straw and corn stover	264

Brown algae	200
Aloe peel	195

The results show that dairy manure created the most biogas and that rice straw can generate 330 liters of gas per kg of waste rice straw.

(Objective 3 - Develop a laboratory-scale test)
A laboratory-scale test equipment was developed to convert the farm waste to methane gas using a two-step anaerobic digestion process. Anaerobic digestion is the process in which biodegradable material is broken down by bacteria in the absence of oxygen to produce biogas. The experiment was carried out by placing the waste in separate jars filled with inoculum acquired from a two-stage mesophilic semi continuous anaerobic digester in the North State Rendering - Plant Construction in Oroville California, and storing them in an incubator under mesophilic conditions (37 ℃). The gas production was then measured by the use of inverted tubes held over a tub of water with a low pH concentration. Figure 1 depicts the process used in the experiments.

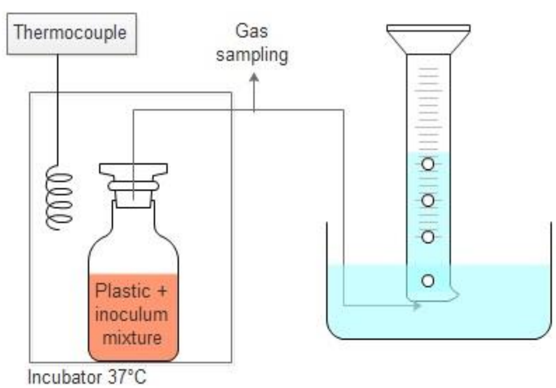

Figure 1. Experimental set-up.

This research experiment analyzed the biodegradation and biogas generation of different food wastes. A recipe of farm materials will be created that will allow the waste to biodegrade with the rice straw. Two experimental trials were conducted. In the first trial an apple and rice straw that had been in an oxygen depleted bag, were put into jars with 1L of inoculum in order to check their biogas production. In addition, a blank jar was also placed in the oven for calculation purposes and a jar with cellulose and 1L of inoculum was used as a positive control. In the second trial different amounts of peach, olives, rice straw exposed to oxygen, and cellulose were put into five different jars with 2L of inoculum.

The inoculum was obtained from a two stage mesophilic semi-continuous anaerobic digester owned by North State Rendering (Oroville, California). The plant was composed of two hydrolysis tanks and one digester. The inoculum used was stored in an oven for a week at a temperature of 37℃ to in order to degas. The inoculum's main feed was whey cheese, food waste, grease trap and pasta.

Materials and Test Method

The fruits and samples used in this experiment were:

- Olives
- Peaches
- Rice straw
- Apples
- Cellulose Avicel PH-101

The test method used to check each material's biodegradation into methane and carbon dioxide gases was based on the Standard Test Method for Determining Anaerobic biodegradation of Plastic Materials Under High-Solids Anaerobic-Digestion Conditions ASTM 5511-02 (ASTM International, 2012). The experimental system kept temperature at 37°C (+/-2°C). In order to keep consistency in our laboratory scale with the North State Rendering Plant's usual feeding rate the plastic concentration was chosen to be between 0.5 g/L to 28 g/L as shown in Table 2**)**. The usual concentration for phase one is 4g/L but various trials of different concentrations were made to observe the effect it has on the biodegradability over all, if any. Table 2 also shows that the olives had the most grams of carbon. Peach samples had the lowest amount of carbon. Rice straw had 1.745 grams of carbon in the test samples. The fruits also has larger amounts of water in them.

Table 2. Grams of carbon in fruit

Material	g C/ g_fruit	g of Carbon	Fruit concentration, g/L
Olives	0.2205	4.446	28
Peach	0.1577	1.621	26
Apple	0.1824	2.782	13
Rice straw1	0.8051	1.731	0.5
Rice straw2	0.8066	1.745	0.5

The laboratory scale batch reactors were connected to an air tight plastic tube designed to move the biogas produced to an airtight PVC pipe where the gas would be collected and measured. The pipes were sealed on one end and inverted in a container filled with low pH water. As the gas is produced, the water in the pipes will be displaced.

In addition, the water is kept at a pH of 2 to avoid the carbon dioxide dissolving into the water. At the beginning of the experiment, atmospheric oxygen was present inside the headspace of the reactor. Taking this information into consideration the experiment was designed so that there would be a small volume of headspace (0.150L). The oxygen in this headspace was rapidly consumed during the initial stages of degradation and afterwards the reactor became anaerobic. Each reactor is a bottle closed with rubber tape and silicon to ensure they are airtight. The gas production will be continuously observed and analyzed until biogas production stops.

Biogas Results

The biogas produced was measured utilizing an SRI Model 310 Gas Chromatograph (GC), calibrated with standard gas before every use, using a 100 µl syringe. The gas chromatograph in Figure 2 had an oven temperature of 91 ℃ and a carrier pressure of 30 psi. Helium served as the carrier gas in this experiment with an inlet pressure of 50 psi. Before every use, the GC was calibrated with the use of standard gas. The graph readings in the Gas Chromatograph were able to be read with the use of Logger Pro.

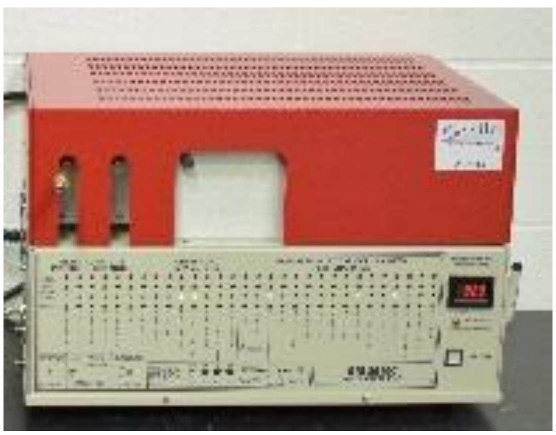

Figure 2. SRI Model 310 Gas Chromatograph (GC)

***(Objective 4 - Test several farm related materials*)**

The fruit samples and rice straw were tested for percentage of moisture and percentage of carbon by heating the samples to 225°F for four hours to measure the moisture content and then at 1100°F for eight hours to measure the percentage of carbon. Table three shows the results of the grams of carbon per sample. All of the fruit had moisture content greater that 60% and the rice straw had moisture content of 10%.

Table 3. Grams of carbon in fruit per gram of fruit and rice straw.

	Carbon [g] /gram of fruit (Average)
Olives	0.220478692
Peaches	0.157654307
Apples	0.182387675
Rice Straw	0.812483209

Figure 3. *Burn-off test results for percentage of carbon*

The volume produced by the plastic samples were recorded with uncertainty due to complications with the SRI Model 310 Gas Chromatograph. The first trial was cut short because the bacteria had died as a result of being exposed to oxygen whilst degassing. It also became apparent through previous trials performed that the bacteria would continue dying if left to degas for a period of 7 days. To prevent the same situation the bacteria used was left to degas for a period of 5 days, however, it also appeared to die after a few days, for unknown reasons. Although the pieces of apple were carefully chosen before being placed in the jar, one must acknowledge that at least half of the apple had begun to rot. Therefore, it may have altered the apple's recorded biodegradation process.

(Objective 5 - Develop pre-conditioners for improved biogas production)

The olives and apples had high biodegradation and generated much biogas. The peaches generated less biogas for some unknown reasons. This will be studied further next year. The rice straw produced less biogas. Some of the rice straw was placed in a plastic bag for four weeks. The rice straw in the plastic bag had more biogas generation than the rice straw left out in the lab. Other preconditioning of rice straw can include acid and alkaline soaking. This will be studied in the next year.

(Objective 6- Measure the emission of biogas from samples)
The biodegradation of food waste was calculated based on the amount of biogas generated and the amount of carbon in the sample. Figures 4 and 5 demonstrate that the olives, apples, and the rice straw that was exposed to oxygen had a biodegradation percentage of 13%, 27%, and 1% respectively. The peach, cellulose, and the rice straw that was not exposed to oxygen were done biodegrading by the second day with a max biodegradation rate of 27%, 5%, and 2% respectively. The rice straw without oxygen was placed and left inside a plastic bag for about a month. It is important to note the same concentration of rice straw was used for both tests.

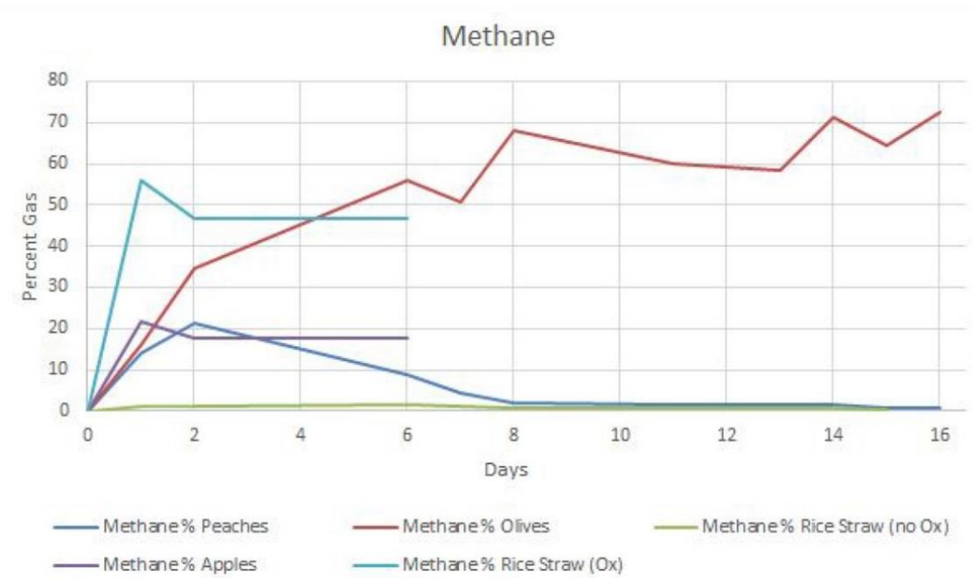

Figure 4. Methane gas yields for digesting fruit.

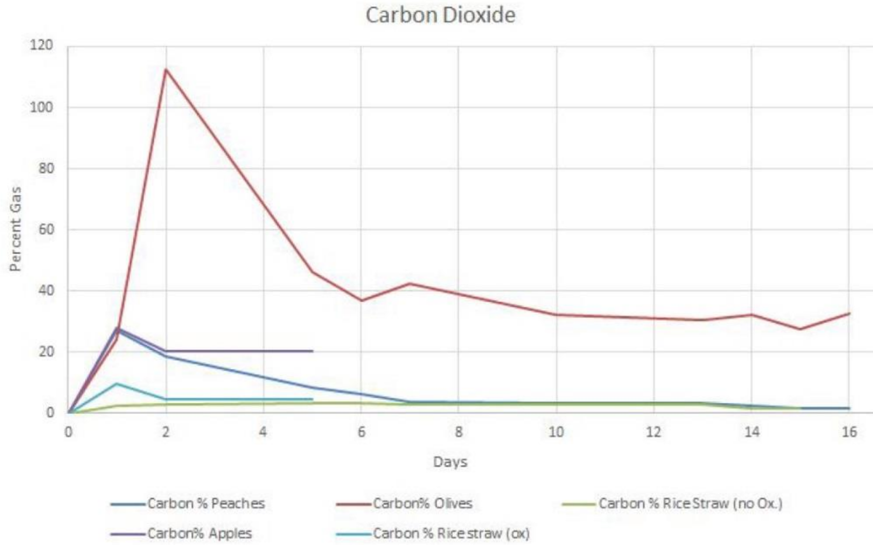

Figure 5. Carbon dioxide gas yields for digesting fruit.

The biodegradation of the gases are based on the generation of biogas from the digesting fruit and rice straw. The volume of gas was measured by the displacement of water in the tubes in Figure 6. Figure 7 shows the bottles in the oven that the fruit and rice straw samples were placed in with the inoculum. Figure 8 details the amount of methane produced in one week of testing.


Figure 6. Equipment to measure volume of biogas generated with inverted columns of water.

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Figure 7. Experimental jars to hold the samples and inoculum.

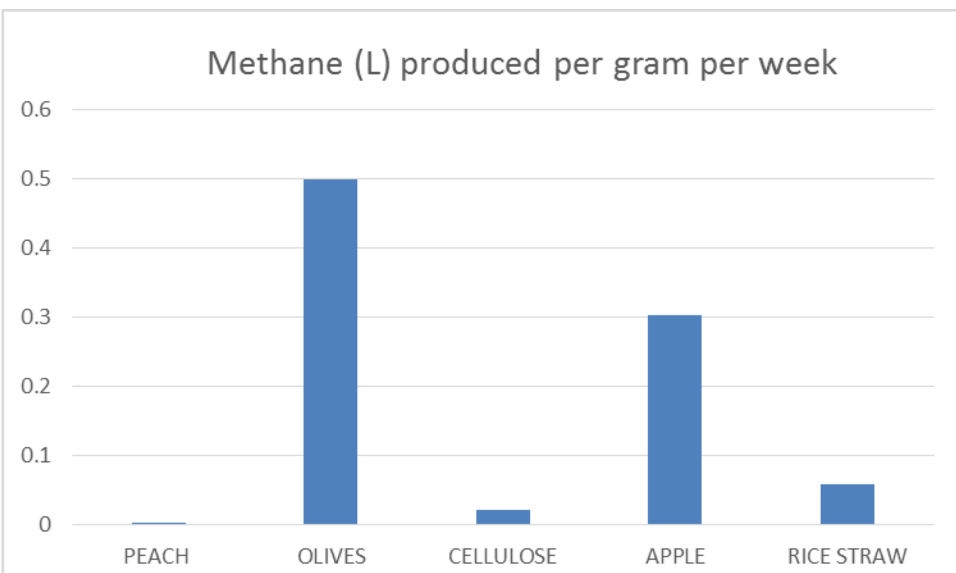

Figure 8. Biogas production as measured inverted tubes and water displacement

Table 4 lists the results for methane gas generation during the one week experiment. The test ran for two weeks but the gas stop generating after seven days. The results show that olives produced the most biogas during the seven days. Apples and rice straw also produced biogas during the experiment. The rice straw that was held in a plastic bag generated more biogas than the rice straw in the open.

The results from this year's experiments can be used to predict the expected methane generation once 100-gallon anaerobic digester is built next year. The amount of gas generation in a week can be extrapolated to our 100-gallon tank by assuming the following:

- Density of methane gas is 0.656 g/cc.
- The density of rice straw is 0.12 g/cc.
- The volume of solids is 10% of the liquid.
- The solids in the liquid will be a combination of rice straw, olives, apples, and peaches.
- The methane gas will be captured.
- The methane gas will be compressed in CNG.

Table 4. Methane generation results for samples after one week.

Material	Methane (L) produced per gram per week	density g/cc	Mass per 10 gallons	Methane (Gal) produced per tank per week
PEACH	0.0035	0.25	9463.60	8.63
OLIVES	0.4993	0.9	34068.97	4493.51
CELLULOSE	0.0214	1.5	56781.62	321.18
APPLE	0.3024	0.24	9085.06	725.83
RICE STRAW	0.0587	0.12	4542.53	70.45

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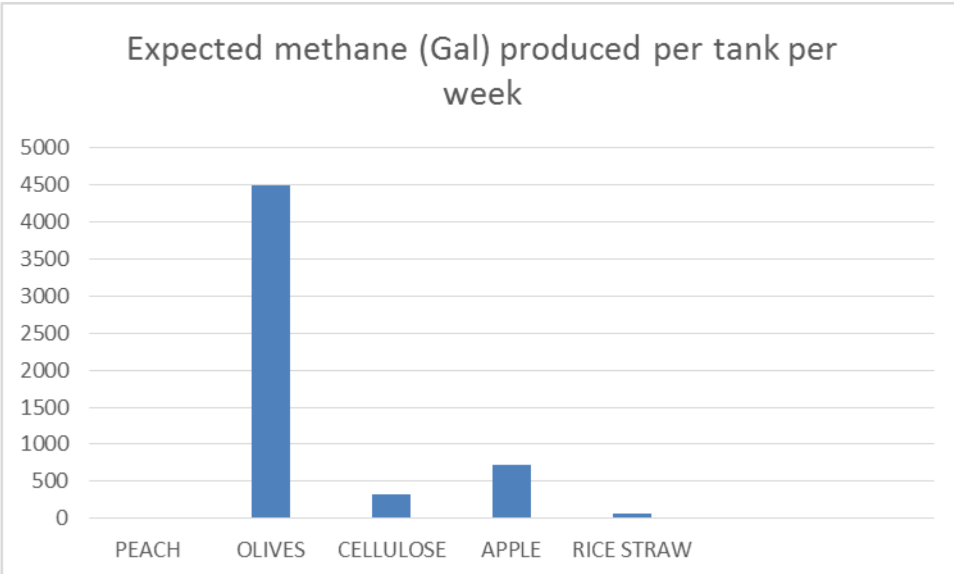

Figure 8. Expected methane generation in gallons in 100–gallon AD reactor

Figure 5 and Table 4 shows that olives can generate 4494 gallons of methane per week in the 100-gallon anaerobic digester reactor. Apples can generate 726 and rice straw can generate 70 gallons of methane per week.

Anaerobic Digester Design

(Objective 7. Design prototype anaerobic digester tank)

The second phase of the research involved designing the 100 gallon anaerobic digester. The project was completed by a team of mechanical engineering students in the MMEM Department as part of their senior project course. The project's scope included the following qualitative and quantitative parameters:

Quantitative parameters

- Measure temperature, pressure, pH, and flow rate in tank.
- Maintain 10% solids in the fluid.
- Measure the volume of methane produced.

Qualitative parameters

- Portable unit.
- Capture the gas
- Use blade agitation method.

The development team designed an anaerobic digester of 100 gallons to convert food waste and farm waste to methane gas. The anaerobic digester has a design with special pumps to transfer high solids (~10%) liquid flows into the hydrolysis tank. The temperature, pressure, and pH are monitored in the two tanks. The design is shown in Figure 9.

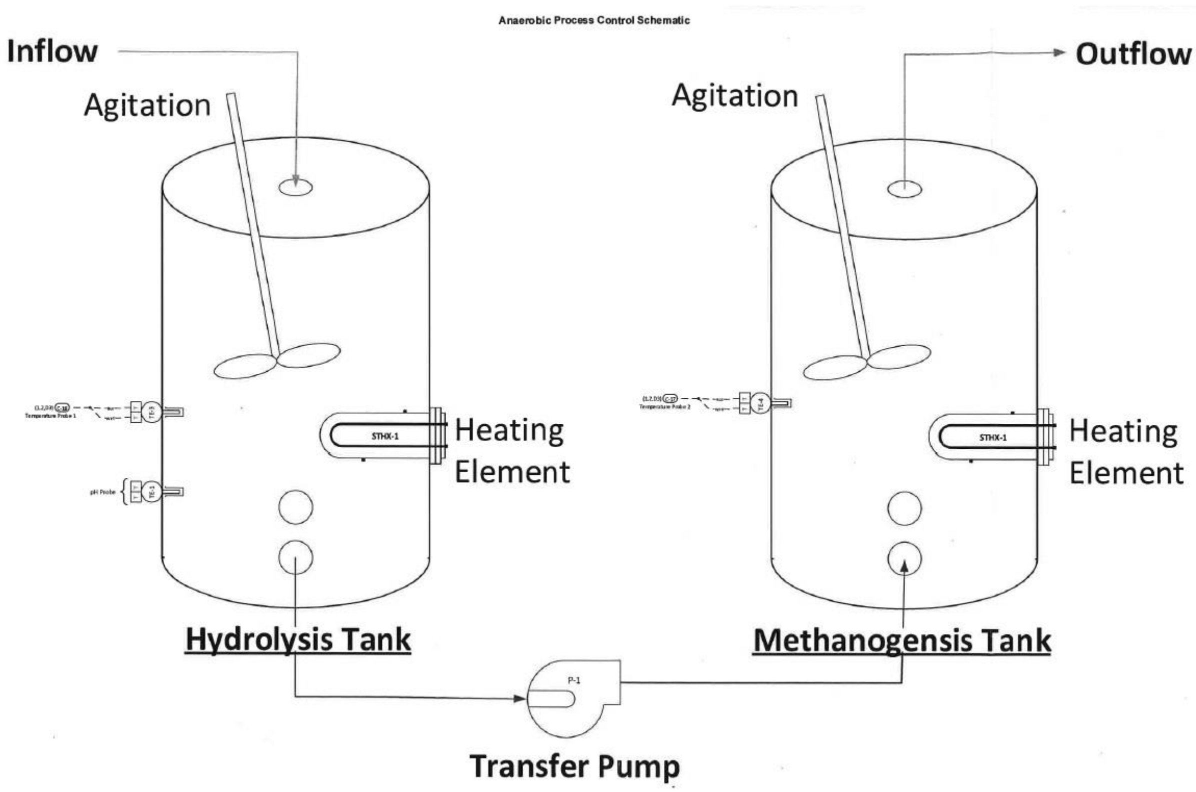

Figure 9. Design of anaerobic digestion tank of a100 gallons.

(Objective 8- Evaluate the technical viability of the process)

The technical viability of the project is very good since the anaerobic digestion technology is used at the Biogas plant just south of Chico. A scientist from the company helped design the anaerobic digester reactor for use at their biogas plant. The design of the anaerobic digester reactor utilizes current technology and has a robust design, as shown in Figure 9. The development team is a strong group of mechanical engineering students who have been educated in engineering that will be utilized in the design and building of the new machine. Dr. Greene will lead the efforts based on his experience with anaerobic digestion.

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PUBLICATIONS OR REPORTS

J.P. Greene, "PHA and PLA Biodegradable Plastics with Rice Straw Filler to Create Biobased Structural Insulating Panels (BSIPs),"Proceedings of the SPE ANTEC Conference, May, 2017

Future publications are expected with the anaerobic digestion research once additional work is accomplished to reduce the inconsistencies in the test results. The research can be published in the future at national conferences on use of farm materials for sustainable farming practices.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

We were able to generate biogas from several fruits and from rice straw. We were able to generate methane gas from peaches, apples, olives, and rice straw using the anaerobic digestion process. We were able to design a 100-gallon anaerobic digester that will be built next year.