



CALIFORNIA  
ENERGY  
COMMISSION

**ENERGY INNOVATIONS SMALL GRANT PROGRAM**  
**Renewable Energy Technologies**

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The Anaerobic Pump Prototype Testing

**FEASIBILITY ANALYSIS**

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# CALIFORNIA ENERGY COMMISSION

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## PREFACE

The 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, managed by the California Energy Commission (Commission), annually awards up to \$62 million of which \$2 million/year is allocated to the Energy Innovation Small Grant (EISG) Program for grants. The EISG Program is administered by the San Diego State University Foundation under contract to the California State University, which is under contract to the Commission.

The EISG Program conducts up to four solicitations a year and awards grants up to \$75,000 for promising proof-of-concept energy research.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

The EISG Program Administrator is required by contract to generate and deliver to the Commission a Feasibility Analysis Report (FAR) on all completed grant projects. The purpose of the FAR is to provide a concise summary and independent assessment of the grant project using the Stages and Gates methodology in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions (as presented in the Independent Assessment section).

The FAR is organized into the following sections:

- Executive Summary
- Stages and Gates Methodology
- Independent Assessment
- Appendices
  - Appendix A: Final Report (under separate cover)
  - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the FAR, please visit the EISG program page on the Commission's Web site at:

<http://www.energy.ca.gov/research/innovations>

or contact the EISG Program Administrator at (619) 594-1049 or email

[eisgp@energy.state.ca.us](mailto:eisgp@energy.state.ca.us).

For more information on the overall PIER Program, please visit the Commission's Web site at

<http://www.energy.ca.gov/research/index.html>.

# Executive Summary

## Introduction

Anaerobic digestion, as it is currently practiced, is limited in application because incomplete biochemical reactions severely limit the extent of the biological production of methane. This limitation is mainly due to the resistance to decomposition of many complex solid organic substances that constitute wet biomass.

In 1980, Dr. Keith A. Schimel invented a new continuous flow, continuous culture anaerobic process which was shown to nearly complete the digestion of wet biomass solids with an ordinary mixed culture of anaerobes. The design concept of this process is based on using the product biogas to plasticize the residual solids. In these early tests, development was focused on solids reduction and doubling the normal digestion speed of raw waste activated sludge. The data showed as much as 90% volatile solids (Organic materials) reduction and 80% chemical oxygen demand reduction could be achieved if the process is operating at optimum.

In the current project the focus was to validate the high solids reduction and improve the process's biogas (primarily methane) production. Methane produced by this process can be used to fuel electricity power plants in California. If deployed the technology could not only play an important role in the reduction of wet biomass solids, it could also provide a significant amount of fuel gas (methane) for power plants.

The project compared the methane production performance of this advanced hydrolysis and biogasification process with a conventional digestion process. Two prototype reactor systems were implemented. The advanced hydrolysis and biogasification process and a conventional, single-stage, "completely mixed by stirring" (CSTR) digester were operated side by side under identical conditions. Both systems were fed the same substrate, a 50:50 mixture of wastewater sludge at the same loading rates. This substrate is commonly used as a test substrate because it is widely available and is difficult to degrade. Both systems were held at the same low incubation temperature (20 °C) so that accurate observations could be made.

## Objectives

The goal of this project was to determine the feasibility of using the advanced hydrolysis and biogasification process for significant production of power plant fuel (biogas) by the reduction of wet biomass solids. The performance of the prototype reactor system implementing the advanced hydrolysis and biogasification process was compared with the performance of the CSTR reactor, the conventional technology used to reduce wet biomass solids. The following project objectives were established:

1. Peak specific gas production rate higher than the CSTR by a factor of 3.
2. Peak Methane production rate higher than the CSTR by a factor of 4.
3. Methane yield in liters per kg volatile solids twice that of the CSTR.
4. Total volatile solids reduction three times higher than the CSTR.
5. Total volatile Chemical Oxygen Demand Reduction three times better than the CSTR.

## Outcomes

This prototype reactor system implementing the advanced process had the following measurable outcomes:

1. The specific gas production rate is 3.3 times higher than that for the CSTR.
2. The peak methane production rate is 3.9 times higher than that for the CSTR.
3. The methane yield in liters per kg volatile solids added is 1.88 higher than the CSTR.

4. The volatile solids reduction is 2.35 times more than for the CSTR.
5. The total Chemical Oxygen Demand Reduction is 3.35 better than for the CSTR.

## **Conclusions**

These results were developed by comparing the results of the tests of the two prototype units of identical volume, operated side by side at 20 degrees Centigrade. The Outcomes show that the prototype reactor system implementing the advanced process produces 1.88 times more methane per unit mass fed than the CSTR. All other figures of merit are also superior to those of the CSTR.

These results verify the feasibility of using the advanced hydrolysis and biogasification process for methane production thereby increasing wet biomass solids reduction. Overall, the advanced hydrolysis and biogasification process can convert organic solids to methane between two (2) and four (4) times faster (depending on loading) than a comparable CSTR unit. Most importantly, the total volatile solids reduction was 2.35 times more complete on the advanced hydrolysis and biogasification process than with CSTR. While this is less than the goal of three times improvement, it is nonetheless a significant improvement, because with the advanced hydrolysis and biogasification process nearly all the biomass feedstock is convertible to biogas (primarily methane), leaving little solid material for disposal.

It is important to note that while this experiment was performed at 20 °C in order to slow the reaction for purposes of comparison between the advanced hydrolysis and biogasification process and CSTR, the optimal operating temperature for the mesophilic range is 35 °C. The standard rule of thumb is that the reaction rates for these digesters would be about 2.5 times faster if operated at 35 °C rather than at 20 °C.

## **Benefits to California**

All large power plants being proposed for California rely on natural gas as the fuel. Most of that fuel is imported into the state. Biogas (predominately methane) can be produced from indigenous biomass material. The major sources of wet biomass waste produced in California are sewage sludge production, fiber production (pulp and paper), food processing, agriculture and animal wastes. These sources could generate over 45 million tons of wet biomass in California. If the advanced hydrolysis and biogasification process were to penetrate 100 % of the Wastewater Treatment industry and 20 % of the agriculture industry, that process would produce an estimated 1.54 billion therms of biogas (methane) gas per year for electrical generation or for process heat. Because of the existing capital investments in waste treatment, benefits would build over a period of 10 to 15 years. It is likely that investors would first build treatment facilities utilizing the advanced hydrolysis and biogasification process to handle concentrated sources of wet biomass waste. Once scrubbed of impurities, the biogas could be directly used in power plants.

In addition, the deployment of this process would reduce the environmental problems and expense associated with the disposal of large volumes of wet biomass solids.

## **Recommendations**

The testing completed on this project has assisted in identifying areas where additional development is needed. Areas for additional effort are:

- Demonstrate a commercial scale (sized 1 to 4 ton/day) agricultural prototype, and select a strategic partner to help with commercialization. Seriously evaluate the benefits of designing this prototype to be highway truck transportable.
- Evaluate methane production from new feed stocks to expand applications for the advanced hydrolysis and biogasification process.

## Stages and Gates Methodology

The California Energy Commission utilizes a stages and gates methodology for assessing a project’s level of development and for making project management decisions. For research and development projects to be successful they need to address several key activities in a coordinated fashion as they progress through the various stages of development. The activities of the stages and gates process are typically tailored to fit a specific industry and in the case of PIER the activities were tailored to be appropriate for a publicly funded energy research and development program. In total there are seven types of activities that are tracked across eight stages of development as represented in the matrix below.

**Development Stage/Activity Matrix**

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Activity 1								
Activity 2								
Activity 3								
Activity 4								
Activity 5								
Activity 6								
Activity 7								

A description the PIER Stages and Gates approach may be found under "Active Award Document Resources" at: <http://www.energy.ca.gov/research/innovations> and are summarized here.

As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing technical feasibility. Shaded cells in the matrix above require no activity, assuming prior stage activity has been completed. The development stages and development activities are identified below.

Development Stages:	Development Activities:
Stage 1: Idea Generation & Work Statement Development	Activity 1: Marketing / Connection to Market
Stage 2: Technical and Market Analysis	Activity 2: Engineering / Technical
Stage 3: Research & Bench Scale Testing	Activity 3: Legal / Contractual
Stage 4: Technology Development and Field Experiments	Activity 4: Environmental, Safety, and Other Risk Assessments / Quality Plans
Stage 5: Product Development and Field Testing	Activity 5: Strategic Planning / PIER Fit - Critical Path Analysis
Stage 6: Demonstration and Full-Scale Testing	Activity 6: Production Readiness / Commercialization
Stage 7: Market Transformation	Activity 7: Public Benefits / Cost
Stage 8: Commercialization	

## Independent Assessment

For the research under evaluation, the Program Administrator assessed the level of development for each activity tracked by the Stages and Gates methodology. This assessment is summarized in the Development Assessment Matrix below. Shaded bars are used to represent the assessed level of development for each activity as related to the development stages. Our assessment is based entirely on the information provided in the course of this project, and the final report. Hence it is only accurate to the extent that all current and past work related to the development activities are reported.

**Development Assessment Matrix**

Stages	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Develop- ment	5 Product Develop- ment	6 Demon- stration	7 Market Transfor- mation	8 Commer- cialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

The Program Administrator’s assessment was based on the following supporting details:

**Marketing/Connection to the Market.** The awardee's marketing and connection to the market results from a long career in the field. Specific market connection will be established by the initial success of commercialization activities. Appendix A lists 6 specific limiting factors in the BioEnergy markets.

**Engineering/Technical.** This project was successful. Engineering and technical feasibility of the advanced hydrolysis and biogasification process was confirmed. Technical problems, which arose during this study, did not present a fatal challenge and were successfully overcome in the process of the research.

**Legal/Contractual.** The advanced hydrolysis and biogasification process is protected by patent. Systems incorporating this process have been named “The Anaerobic Pump” (TAP). A commercializer has not been selected.

**Environmental, Safety, Risk Assessments/ Quality Plans.** The researcher must complete the planning process for commercialization of this product. Initial drafts of the following Quality Plans are needed prior to initiation of Stage 4 development activity: Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, Product Safety and Environmental.

**Strategic.** This product has no known critical dependencies on other projects under development by PIER or elsewhere.

**Production Readiness/Commercialization.** Currently there are no full-scale TAP units in operation in California. Effort has been devoted to finding an industrial partner to help develop and sell this technology.

**Public Benefits.** Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system.
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary public benefit offered by the proposed technology is to increase the reliability of the California electricity system. This will be accomplished by providing an additional, more economical source of fuel for electric power generation. Biogas will tend to stabilize the price of methane fuel for electric generation especially in times of short supply.

The following table was prepared from source data provided in Appendix A and its Appendix 1. It assumes a 15 ton/day TAP reactor system operating at 20 °C. This is the temperature at which this project experiment was conducted; hence the data reported in Appendix A is directly applicable. The table shows that the 15 ton TAP unit would produce over 10 MBTU/hour (101.05 Therms) with a spot market value of \$165,524 per year under the stated assumptions.

20 °C 15 Ton/Day Methane Income Worksheet			
Step Description	TAP	CSTR	Assumption / Ref. To Appendix A / Factors
Volatile Solids (VS) Feed	584	584	Kg/hr, see App. 1, page 28 (TAP) and page 30 (CSTR).
Volatile Solids (VS) Feed	14,016	14,016	Kg/day (kg/hr x 24 hr/day)
Volatile Solids (VS) Feed	15.42	15.42	Short Tons/day (Units Conversion)
Methane Yield factor	0.49	0.26	m <sup>3</sup> CH <sub>4</sub> /kg VS added - See Exec. Summary, Page 5.
Methane Produced - m <sup>3</sup> /day	6,867.84	3,644.16	m <sup>3</sup> Check the ratio = 1.884615, see Table XII, Page 32
Methane Produced - SCF/day	242,508.47	128,677.97	Convert by 35.3107344632768 SCF/m <sup>3</sup>
Methane Produced - SCF/hour	10,104.52	5,361.58	
Heating Value of Methane	1000	1000	BTU/SCF
Energy Produced	10,104,520	5,361,582	BTU/hour
Energy Produced as Methane	101.05	53.62	Therm
Value of the Methane gas/hour	\$ 22.23	\$ 11.80	At \$0.22 per Therm (Current futures Spot Market)
Value of the Methane as gas	\$ 533.52	\$ 283.09	Per Day
Value of the Methane as gas	\$ 165,524	\$ 87,829	Per year at 85% utilization

The preceding analysis assumes that the biogas is sufficiently pure to be marketed as a gas product at the price of equivalently energetic natural gas. This may or may not be the case.

An alternative approach to marketing the product is to convert the biogas to electricity on site. Several different generator systems could be envisioned ranging from a combined cycle power

plant with thermal efficiency over 50% or a methane burning reciprocating engine driven generator with a thermal efficiency of approximately 40%, or as the researcher has proposed in Appendix A, a Solo Micro turbine. The income worksheet for this generator system follows.

20 °C 15 Ton/Day Worksheet - Income from the Sale of Electricity			
Step Description	TAP	CSTR	Assumption / Ref. To Appendix A / Factors
Micro turbine thermal efficiency	27.1%	27.1%	Solo Micro turbine, see App. 1, page 29
Conversion Factor	0.000293	0.000293	Conversion of BTU to KwHr
Power Output, Kw	802.33	425.73	Electricity generated by Micro turbine
Value of the Electricity at \$0.06	\$ 48.14	\$ 25.54	Per hour
Value of the Electricity at \$0.06	\$ 1,155.35	\$ 613.04	Per day
Value of the Electricity at \$0.06	\$ 358,448.59	\$ 190,197.21	Per year at 85% utilization

Using this generator, and with an assumed market value for biogas generated electricity of six cents per KW-HR, the product value is \$358,448 per year. The wholesale electricity market has high volatility. At the time this report was written, electricity was worth about three cents per KW-HR.

The estimated capital investment required to construct the 15 ton/day TAP system including micro turbine is tabulated below. Refer to pages 34 and 35 of Appendix 1 of Appendix A.

20 °C 15 Ton/Day Summary Cost Worksheet		
Cost Item / Activity	Non-recurring	Recurring
Capital Costs	\$ 2,306,670	
Installation Costs	\$ 216,878	
Annual O&M Costs		\$60,217
Misc. Costs	\$ 280,395	
Total Costs	\$ 2,803,943	\$60,217

These tabulated data include the \$510,000 cost (approximately) of one micro turbine generator. The income figure of \$358,448 per year depends on the 6 cent per KW-HR sales price. Subsidies from state and federal governments will have an additional effect on the economics of biogas. With these numbers there is a simple payback in 9.4 years. The additional major income source for this system is tipping fees collected for disposal of the sewage sludge (feedstock of TAP). The EISG Program Administrator estimates tipping fees to be \$20 per ton across all EISG projects, in order to compare fairly one project to another. Note that the collection of tipping fees represents a risk to the operator of TAP that is not controlled by TAP. With that caveat, a 15 tons per day facility operating at 85% plant availability, could collect \$232,687 in tipping fees per year. The simple payback with tipping fee income and a six-cent power price is 5.27 years.

The preceding analysis is for a TAP system operating at 20 °C, because the project experiment was held at that temperature for experimental reasons. That is, to slow the reaction for a manageable experiment as well as for convenience and for economy of construction of the prototype digesters. In the real world of digester operation, the optimum set temperature would be 35 °C. At this temperature, the digestion process would be expected to proceed at a rate of 2.5 times the rate at 20 °C and if operated at 60 °C the reaction speed could be expected to double

one more time. When calculations similar to the preceding are made using a 15 ton/day system designed to operate at 35 °C, the simple payback is about 2.5 years,

### **Program Administrator Assessment**

After taking into consideration: (a) research findings in the grant project, (b) overall development status as determined by stages and gates and (c) relevance of the technology to California and the PIER program, the Program Administrator has determined that the proposed technology should be considered for follow-on funding within the PIER program.

Receiving follow-on funding ultimately depends upon: (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation and (c) successful evaluation of the proposal.

**Appendix A:** Final Report (under separate cover)

**Appendix B:** Awardee Rebuttal to Independent Assessment (none submitted)