CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Renewable Energy Technologies

Biomass Boundary Layer Turbine Power System

FEASIBILITY ANALYSIS

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LEGAL NOTICE

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 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.

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

This project explored the potential for cost effective electricity production from biomass in distributed generation applications. The focus was on the means of energy extraction from the high-energy flue gasses resulting from biomass combustion. Sufficiently energetic flue gasses from biomass combustion contain ash and other particulates that could hinder the operation of most high temperature machinery.

The researcher tested a turbine with a rotor that consists of many parallel disks. He measured its performance while firing biomass fuel. This turbine, called a "boundary layer turbine," relies on the friction of the gases passing through the rotor to impart motion to the shaft. The technology is well known for its resistance to erosion in viscous pumping applications.

The proposed turbine was not completed and made available in accordance with the project's schedule, however, a manufacturer, at no cost, supplied a low-efficiency turbine to the project. A used pressurized combustor was purchased and adapted to a pressurized combustion residence chamber. Over 40 hours of testing at various operating states was accomplished at very low research cost. At the conclusion of this test series, the researcher concluded that no significant barriers exist within the boundary layer turbine to hamper the use of biomass fuels.

Objectives

The goal of this project was to determine the feasibility of operating a boundary layer turbine on flue gasses of a biomass combustor. The following project objectives were established:

1. Demonstrate the performance of a boundary layer turbine operating on combustion flue gas.
2. Optimize turbine performance, achieve 21 % conversion efficiency.
3. Achieve low levels of deposition, corrosion, and erosion of the turbine.
4. Design the next generation boundary layer turbine.

Outcomes

Testing of a turbine proved that it did run on biomass fuel with the following performance.

1. Boundary layer turbine performance for five operational scenarios is tabulated here.

Case	Working fluid/fuel	Firing rate	Temper-ature	Pressure	RPM	Power	Isentropic efficiency
1	Compressed air	N/a	Unk	86 psig	8193	11.6 HP	Unk
2	Compressed air	N/a	69 ^{o}F	33 psig	1100	0.6 HP	16%
3	Natural gas flue gas	173,000 Btu/hr	832 ^{o}F	35psig	6218	4.6 HP	12.25 %
4	Biomass flue gas	192,600 Btu/hr	737 ^{o}F	40 psig	6284	4.3 HP	11 %
*5	Saturated Steam	Unk	N/a	100 psig	6500	12.4 HP	13.7 %

2. Conditions were varied to determine optimum turbine operating conditions. The highest efficiencies were obtained at the highest operating speeds. Under hot operating conditions (800°F) and less than 50 psig, efficiencies of 12% were obtained. The highest rotational speed under these conditions was 6500 rpm. The efficiency and horsepower curve are linear

with speed, suggesting that higher efficiencies could be obtained. Increasing pressure increased power and efficiency. Increased temperatures had the same effect but to a lesser degree. The highest torques (100 in-lbs) were obtained at the lowest rotational speeds. The turbine was equipped with two nozzles. Primarily only one nozzle was used during testing. Experiments with the second nozzle resulted in little improvement in power or efficiency.

3. Qualitative assessment of deposition, erosion, and corrosion are as follows. 150 lbs of biomass was fired in the turbine with an average ash content of 1%. The biomass consisted of wood-derived sawdust and oats, fired separately. Firing of 100% biomass was achieved. Post inspection of the turbine rotor provided no indication of ash deposits, plugging between disks, or excessive build up in the turbine housing.
4. Evaluation of power cycles was completed to arrive at a design for the next generation biomass boundary layer turbine. This preliminary design is specified in the form of a process flow diagram.

Conclusions

1. This project proved that it is feasible to drive a boundary layer turbine with flue gasses from biomass combustion.
2. The efficiency obtained was not as high as projected in the proposal, but the turbine used was not the one planned in the proposal. This was because when the time came to use it, the proposed turbine was not ready. Documentation of more efficient boundary layer turbines is provided. The conclusion is that higher efficiencies might be obtained with proper design of the turbine and the matching combustor.
3. No indication of ash deposits, plugging between disks, or excessive build up in the turbine housing was observed on posttest teardown. This is positive indication that this simple turbine architecture is tolerant of particulate matter in the working fluid. It seems obvious that partially burned pieces of biomass must not be fed into the turbine, but tolerance of fly ash can be a very useful characteristic.
4. Engineering calculations indicate that the achievable system efficiency may be as high as 25% with a boundary layer turbine. This will require an isentropic efficiency of 60% for the turbine. While this efficiency is theoretically achievable, only 49% efficiency has been achieved/reported in practice.

Benefits to California

The benefits to California from this technology are derived from the simplicity of the system, and its potential to be transported to the source of the biomass. The challenge with forest slash and other forest biomass is its location. Transportation of the fuel to the power generator makes the fuel very expensive due to transportation costs. By transporting the power generator to the forest, the biomass fuel can be used to generate electricity. Then the problem is to transport the electricity to the consumer by attaching the generator to the grid. The added cost of grid interconnection equipment was not estimated in this project but could be high relative to the cost of the turbine.

Recommendations

This project was proposed and funded with a targeted 21% isentropic efficiency. The efficiency achieved was 11 to 13%. The turbine efficiency must be approximately 50% or better in order for this technology to compete with established systems.

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 Activity	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 technology is targeted at small co-generation applications using biomass fuels. The size of the California market has been estimated using information from other studies. Pathways to this market have not been identified.

Engineering/Technical

This project achieved the goal of demonstrating the operation of a boundary layer turbine using combustion flue gas from biomass, that is, wood and oats. However, it did not do so at any reasonable turbine efficiency. A significant engineering effort remains to improve turbine efficiency, which may result in modified spacing between the turbine disks. If so, the likelihood exists that the tests performed by this project will need to be performed again.

Legal/Contractual

Cursory patent searches have been completed. The indication is that there is the potential for new patents. The investigator believes that this effort could be completed in a period of twelve months.

Environmental, Safety, Risk Assessments/ Quality Plans

Quality Plans include Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, and Product Safety and Environmental.

Strategic

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

Production Readiness/Commercialization

No commercializing partner has been identified though initial steps are being taken to identify potential partners.

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 benefit to the ratepayer from this research will be to reduce the environmental impact of the California electric system. By using local renewable biomass fuel it mitigates the need to import hydrocarbon fuels into the state, and will tend to stabilize the price of those fuels, which would otherwise be causing additional emissions within the state.

Appendix A: Final Report (under separate cover)

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