CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Environmentally-Preferred Advanced Generation

IMPROVED OPERATIONAL TURNDOWN OF AN ULTRA-LOW EMISSION GAS TURBINE COMBUSTOR

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
    - o Appendix A: Final Report (under separate cover)
    - o 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

Alzeta Corporation is a manufacturer of industrial burners and combustion systems. Alzeta is developing an advanced low-emissions combustor for use in industrial gas turbines and micro-turbines. Alzeta's goal is to develop a low emissions combustor that is effective, relatively low cost and can be designed to fit into most existing gas turbine engines. The final report (see Appendix A) details design and testing of Alzeta's Gas Turbine Surface Burner (GTSB). Testing was accomplished at atmospheric conditions and in Honeywell's 75 kilowatt combustor test rig.

In California's changing electricity market, small gas turbine generators may be playing an increasingly important role. These units hold the promise of bringing cheaper, more reliable electricity to California's ratepayers. To reduce harmful air emissions, these units must be equipped with combustors that reduce the oxides of nitrogen to less than 5 ppm. Alzeta's GTSB is being developed to address emissions reduction to these levels without significantly increasing capital equipment costs.

The low-emissions performance of the GTSB derives from its ability to stabilize combustion at low adiabatic flame temperatures where side reactions responsible for NO_X formation are thermodynamically less favorable than complete combustion of hydrocarbon fuel. To reduce the adiabatic flame temperature, more air than necessary for complete combustion is premixed with gaseous fuel and directed through the combustor. In the gas turbine industry, this approach is called lean-premixed, dry low-NO_X (DLN) combustion. The GTSB differs from existing DLN systems. Its stabilization mechanism removes heat from the combustion reactions by radiant heat transfer resulting in lower NO_X formation than attainable by well-stirred premixed combustion with the same amount of excess air.

A potential barrier to commercialization of the GTSB, as with other DLN systems, is the problem of operational turndown. It is difficult for DLN systems to sustain combustion when the power level is reduced from full power to levels as low as 50% power. Increasing the operational turndown of the GTSB requires precise local control of the air-fuel ratio over selected regions of the burner surface. This level of control can be accomplished by partitioning the GTSB into independent segments. Under low fuel-flow conditions, the air-fuel ratio can be maintained in an individual segment while fuel-free air passes through adjoining ones. The number and size of the segments can be adjusted to provide stable combustion over the load range. At full load, the entire GTSB is fired with fuel divided among its segments such that each is operated at the same air-fuel ratio.

Goal and Objectives

The goal of this project was to determine the feasibility of a segmented GTSB. Alzeta's strategy is to develop a low emissions gas turbine combustor that is effective, relatively low cost, adaptable to existing engines, and has the flexibility to operate over a broad engine turndown ratio. This project's focus is on increasing the operational turndown ratio of the GTSB while maintaining low emissions over the load range. Alzeta partitioned the burner into segments to achieve this result. They planned to add a fuel-air mixture to the segments in a sequential manner as engine load increased. To be successful, the segmented GTSB had to meet emissions targets of sub-5 ppm NO_X (referenced to 15% O_2), sub-10 ppm CO and sub-10 ppm unburned hydrocarbons over the operating range of a micro-turbine engine. The following project objectives were established:

1. Provide three conceptual designs of segmented GTSB. The designs should be differentiated by geometry and number of segments. Create criteria to identify and select the most promising design. Produce design drawings for a GTSB that will fit into the Honeywell 75 kWe combustor test rig.

2. Build and instrument the test combustor. This design objective is important because a segmented GTSB is a new concept and has not been previously designed for testing at gas turbine conditions.

3. Test the segmented GTSB at atmospheric conditions. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NO_X and CO emissions at each operating condition and each segmented fuel flow condition. The objective is to prove the capability of the segmented GTSB to achieve NO_X emissions less than 5 ppm at atmospheric pressure over simulated engine operating conditions. This atmospheric pressure test, while less rigorous than Objective 4, provides relatively low cost data to the designers early in the development cycle so that adjustments can be quickly and easily made.

4. Test the segmented GTSB at pressures typical of the Honeywell 75 kilowatt Parallon engine. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NO_X and CO emissions at each engine condition and each segmented fuel flow condition. The Honeywell engine operates at conditions typical of most micro-turbines. Gas turbine emissions often increase with increasing engine pressures. Testing at simulated engine pressures provides information about the pressure sensitivity of the emissions from a combustor without developing a full engine test.

Outcomes

1. Three GTSB concepts were evaluated. A two-segment GTSB was selected based on ease of fabrication, control system integration and the effect of internal baffles on air-fuel mixing. Alzeta engineers designed the selected GTSB concept to mate with both the Alzeta test facility and Honeywell's test facility for the Parallon 75 micro-turbine.

2. The GTSB was fabricated. The test GTSB was instrumented with thermocouples and gas-sample lines. No unusual problems were encountered.

3. The segmented GTSB was tested at atmospheric conditions at the Alzeta test facility. It was operated stably at six conditions that simulated engine power conditions from idle to full power. The NO_X emissions were less than 5 ppm (adjusted to 15% oxygen) and CO emissions were less than 10 ppm. The fuel flow split between the two segments was adjusted at each operating condition to optimize the emissions.

4. The segmented GTSB for the Parallon 75 was fabricated and installed in the pressurized test facility at Honeywell. Testing of the segmented GTSB was accomplished at five of the six planned engines conditions. The selected set points were established in terms of air flow through the GTSB. These points were: 13.6 pounds per hour (pph), 18.5 pph, 24.7 pph, 30.8 pph, 37 pph, and 41.6 pph (full power). The test was halted during the transition to full power test conditions due to a mechanical failure of the GTSB. Alzeta engineers believed that the failure was caused by flashback (the flame-front moved backwards toward the GTSB surface and rapidly burned the air-fuel mixture inside of the fuel injector). All tests performed up to the full engine operating condition demonstrated NO_X below 5 ppm (adjusted to 15% oxygen) and CO less than 10 ppm. Unburned hydrocarbon emissions were undetectable under most conditions. All tests were accomplished using only one segment of the two-segment GTSB. The tests using various fuel splits between segments could not be accomplished after the failure of the test GTSB. Since only one day of testing was available at the Honeywell test facility, retesting could not be accomplished.

Conclusions

Alzeta's segmented GTSB operated as planned at atmospheric pressure conditions. Alzeta's GTSB is capable of producing sub-5 ppm NO_X , sub-10 ppm CO, and near zero unburned hydrocarbons at partial load operating conditions of the Honeywell Parallon 75 micro-turbine. Collected temperature data demonstrate that GTSB combustion performance is consistent with Honeywell's combustor design and can be adapted without changing the materials of construction. Demonstration of the segmented GTSB at full engine load conditions was not accomplished due to component failure.

Subsequent to the completion of this project, Honeywell decided to exit the micro-turbine business. This does not diminish the value of the research conducted during this project. Even though the important technical objective of testing a segmented GTSB at engine pressures is yet to be achieved, this EISG funded project has advanced segmented GTSB technology.

Recommendations

Successful demonstration of the segmented GTSB at points traversing the startup fuel schedule and over the entire load range at atmospheric conditions could lead to an engine ready design and testing in a micro-turbine or full size turbine. Once the GTSB is installed in an engine, the engine start schedule and control logic will have to be developed to provide low emissions over the load range. Extended demonstration in a test or field engine will provide critical operating data for the commercial GTSB micro-turbine product. Finally, GTSB durability and flashback prevention should be objectives of subsequent research and development. The California Energy Commission awarded Alzeta another development program for this burner concept in March of 2001 and has recently announced its intention to expand this line of research under the Environmentally Preferred Advanced Generation subject area of the PIER program. The Program Administration endorses these actions.

Benefits to California

Once commercialized, the GTSB may allow low emissions turbine generators to be sited in California at a reasonable cost. Actual engine emissions with the GTSB must meet emission control standards in effect at the time of commercialization. The segmented GTSB appears to provide low emissions over a broader load range than currently available technology. This increases design and operational flexibility for turbine engine manufacturers. Distributed power generation has the potential to reduce peak demand on California's power grid and provide reliable backup power in the face of potential power shortages.

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. Demonstration of the GTSB at Honeywell's test facility helped to define the GTSB's role in the micro-turbine market. The capability of the GTSB to provide low emissions under partial load operation distinguishes it from existing technologies that rely on a diffusion pilot for stability during partial load. While Honeywell has exited the micro-turbine business, Alzeta has been building relationships with other potential users of this technology such as Solar Turbines, Inc.

Testing also reinforced the importance of a segmented burner design. A properly designed segmented burner may be less likely to fail during load transients and more able to follow the startup fuel schedule. Future research and demonstration of the segmented burner will resolve these issues that are important to market acceptance.

Engineering/Technical. Two of three technical goals were realized during the project: the GTSB was successfully demonstrated in Honeywell's test facility in micro-turbine hardware and a segmented GTSB was designed and fabricated.

Results from this project were sufficiently encouraging that Alzeta intends to continue developing the GTSB. Demonstration of the segmented GTSB in an operating engine is the next logical step in proving technical feasibility.

Legal/Contractual. No new patent issues arose during this project.

Environmental, Safety, Risk Assessments/ Quality Plans. No work related to this activity was performed.

Strategic. Development of the GTSB continues to be supported by funding agencies. The U.S. DOE awarded a contract for the GTSB in September 2000, shortly after Alzeta completed its Small Grant project. The PIER Environmentally Preferred Advanced Generation (EPAG) subject area awarded Alzeta Contract number 500-00-004 on February 14, 2001 to continue GTSB development for both industrial and micro-turbines. In September of 2001 the CEC released a Notice of Proposed Awards for the EPAG subject area. The Commission approved that award on October 31, 2001.

Production Readiness/Commercialization. Alzeta has developed a production readiness plan.

Public Benefits. PIER research public benefits are defined as follows:

- 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 make electrical energy more affordable in California by reducing the cost of emission reduction systems and extending the operational range of low emission gas turbine engines used in power generation and combined heat and power applications.

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. The CEC has taken action to provide funding for the next development steps.

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)