CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Environmentally Preferred Advanced Generation

Catalytic Stabilizer for Industrial Gas Turbines

FEASIBILITY ANALYSIS

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Prepared By:
Hal Clark
Grant Program Administrator
San Diego State University Foundation

Prepared For:
California Energy Commission
Energy Innovations Small Grant Program

Researcher:
Dr. Shahrokh Etemad
Precision Combustion Inc.

Grant Number:
99-26

Philip Misemer
Grant Program Manager

Marwan Masri
Deputy Director
Technology Systems Division

Robert Therkelsen
Executive Director

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.

Catalytic Stabilizer for Industrial Gas Turbines

EISG Grant # 99-26

Awardee: Precision Combustion, Inc.
Principal Investigator: Shah Etemad
PI Contact Info: Phone: (203) 287-3700;
Email; setemad@precision-combustion.com

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Grant Term: April 2000 – May 2001

Introduction

Air emissions from combustion turbines used in mechanical and power generating applications are a major issue when seeking approval for installation. Oxides of nitrogen, NO_X, are major constituents of those emissions. Gas turbine manufacturers have developed dry, low NO_X (DLN) technology to reduce NO_X emissions from over 200 parts per million to a range of 9 to 25 parts per million (ppm). These levels of emissions are achieved without the use of water or steam injection, or the use of selective catalytic reduction (SCR) devices in the exhaust. When SCR technology is combined with DLN technology the NO_X emissions are reduced to the range of 2.5 to 5 ppm. This is the most common technology suite for large (>50MW) combustion turbines. Unfortunately SCR technology is very expensive making its use on the smaller combustion turbines uncommon. Smaller combustion turbines serve an important purpose in California's overall energy strategy when they are used in combined heat and power applications. In these installations over 70% of the energy of the fuel is put to productive use.

Researchers have determined the major reasons that DLN technology is limited to 9 ppm NO_X. The primary reason is the use of a pilot burner to stabilize combustion over all operating conditions (i.e. startup, part load, full-load, and transients.) Without the pilot burner the engine could cease operation during various engine exercises. The pilot burner also reduces combustor "rumble", a vibration that can destroy an engine in a relatively short period of time. Although DLN pilots commonly burn only 2-5% of the fuel at full load, they are still the source of about 50% of the NO_X emissions in a DLN burner. If the pilot burner emissions could be eliminated or reduced, a DLN burner could achieve NO_X levels of less than 5 ppm.

This project tested the feasibility of using a catalytic stabilizer to replace the pilot burner in a regular DLN burner. The concept is to install the catalytic stabilizer in the fuel injectors (there may be 8 to 18 injectors in one DLN burner assembly). While catalytic combustion techniques have been under test for decades, those concepts replaced the entire DLN system with a catalytic system. The novelty of this concept is the use of catalytic technology only for the pilot burner, a small part of the overall combustion assembly. Full catalytic systems are large, often requiring extensive redesign of the engine casings. The catalytic stabilizer used in this project was built into an existing fuel injector without having to redesign major engine components. If this technology proves to be acceptable to the turbine manufacturers it could be readily retrofitted into combustion turbines already in the field. The use of the catalytic stabilizer could reduce DLN emissions to less than 5ppm NO_X.

The catalytic reactor used in this study can begin and sustain operation at the relatively low outlet temperatures typical of today's combustion turbine compressors. That is the temperature of the air that after being compressed enters the combustion assembly. Operation of catalytic devices at such low temperatures (as low as 671° F) is unusual and a key feature that makes this concept work.

Objectives

The goal of this project was to determine the feasibility of building a catalytic stabilizer in place of the pilot burner in a standard engine fuel injector. The following project objectives were established:

1. Design the catalytic stabilizer to fit into an existing fuel injector for a Taurus 70 engine (Solar Turbines Inc.).
2. Determine if the catalytic stabilizer can begin and sustain fuel injector operations at the relatively low temperatures of the engine compressor outlet air. (Is a pre-burner required for the catalytic system?)
3. Achieve NO_X emissions of less than 5 ppm for the Taurus fuel injector with the catalytic stabilizer replacing the standard pilot burner.
4. Determine if the catalytic stabilizer will allow leaner operation of the fuel injector.
5. Evaluate the operation of the catalytic stabilizer at a number of standard engine operating conditions.

Outcomes

1. The catalytic stabilizer fits into the existing Taurus 70 engine without major modification to the injector.
2. No pre-burner is required for the operation of the catalytic stabilizer. The catalytic stabilizer lit off at temperature around 355°C (671° F) during high pressure testing of the catalytic stabilizer – which is lower than the 435°C combustor inlet temperature.
3. The integrated catalytic stabilizer and the Taurus 70-injector assembly delivered NO_X and CO emissions below 5 ppm.
4. The catalytic stabilizer allowed leaner operation of the injector.
5. The catalytic stabilizer demonstrated variable-load operability. In addition, low emissions were obtained at both 100% and 50% load conditions.

Conclusions

The catalytic stabilizer was built into two Taurus 70 production fuel injectors. The modified injectors were operated at both ambient conditions and simulated engine pressures. Data supported the key objectives of the program. The catalytic stabilizer could be designed to fit into the space envelope allowed by the Taurus 70 fuel injector. It did begin and sustain operation without the use of a pre-burner. And low emissions were achieved.

1. There are potential cost advantages to this technology since major modifications to the injector were not necessary.
2. The modified fuel injector could begin and sustain operation without a pre-burner. The tests showed that no pre-burner is required for the operation of the catalytic stabilizer from half load to base load conditions for the Taurus 70 fuel injector. It also operated free from auto-ignition and flashback over a wide range of stabilizer fuel-air ratios and airflows. Auto-ignition and flashback can be major operational problems with fuel injectors resulting in severe engine damage.
3. The project successfully demonstrated NO_X and CO emissions of less than 5 ppm at Taurus 70 baseload (high pressure) conditions for a single injector.

4. The project demonstrated that leaner operation in the upstream end of the combustor can be achieved by the catalytic stabilizer. Additionally, the results show that the catalytic stabilized fuel injector can achieve low emissions at lower inlet temperatures than those required for a "conventional" catalytic combustor.

The project demonstrated that sufficient catalytic activity can be achieved by both baseload and half load conditions to achieve stable combustion.

After this project was completed the California Air Resources Board (CARB) lowered the limits on regulated emissions, including NO_X. This project achieved the targets that were based on regulations existing at the time of the proposal, as well as satisfied the new regulations with the effective date of 2003. However, the PA is concerned that the approach of this project will not provide an adequate operational safety margin in the emissions levels to satisfy the newly imposed regulations with the effective date of 2007. While this approach may find a broad world market with huge reductions in emissions world wide, it does not appear to be applicable in California in its current configuration.

Benefits to California

This project has contributed to the Public Interest Energy Research (PIER) program objectives for "Environmentally Preferred Advanced Generation" by advancing technology that will reduce emissions from combustion turbines typically deployed in mechanical and distributed power generation applications. Specific benefits are:

1. Improved air quality with cost savings. The catalytic stabilized fuel injector provides relatively low NO_X levels at a low cost. Customers will ask the manufacturer of the gas turbine to guarantee air emissions. At this time the manufacturers have not indicated where they will guarantee an engine with catalytic stabilizers. If the guarantee level is below the level set by the California Air Resources Board for distributed generation, the catalytic stabilizer could be used throughout California to meet those regulations at reasonable costs.
2. Elimination of the use of ammonia to achieve low emissions. Ammonia is not used with the catalytic stabilizer. If gas turbine operators must install an SCR to meet low emission requirements, a measurable amount of ammonia would "slip" into the atmosphere.
3. Enhanced distributed generation. Californians will select gas turbine distributed generation more readily if the manufacturer can guarantee emission levels meeting the 2007 regulations. This will enhance the deployment of distributed generation and cogeneration within the state.
4. Improved air quality from retrofit. Manufacturers can apply the catalytic stabilizer technology to selected existing engines during an engine overhaul and upgrade without major modifications to the engine. These retrofits will further enhance the air quality of California.

Recommendations

This grant proved the feasibility of replacing a pilot burner in a DLN combustor with a catalytic stabilizer. All tests were done with single injectors in test rigs. In subsequent research the development team should reconfigure the technology to satisfy the 2007 CARB emission regulations, install it into an actual engine and develop the control algorithms for engine operation. Engineers should measure emissions levels and compare them with the 2007 CARB regulations for distributed generation. Engineers should also determine reliability and lifetime of the catalytic stabilized device. The provider of the catalytic stabilized device and turbine manufacturer must determine the costs to manufacture and install these devices and compare those costs to the costs of competing technologies.

The PA determined that the data generated during the initial grant was sufficiently complete and successful to recommend taking this technology to the next step of development. To meet the 2007 CARB regulations the catalytic stabilizer would have to be reconfigured. Though significant, reconfiguration should not be a show stopper. Continued cooperation with a major gas turbine manufacturer will accelerate the transfer of the technology into the marketplace. This technology will be of the greatest benefit to engines of less than 50 MW.

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 project has submitted a Preliminary Business Plan detailing the product development to market.

Engineering/Technical. This project successfully demonstrated NOx and CO emissions of less than 5 ppm at 50 and 100% power level conditions for a Taurus 70 gas turbine. The researcher used a simulator when testing the single injector. The tests proved the technical feasibility of the innovation.

Legal/Contractual. Intellectual property related to the core technology is protected by patent.

Environmental, Safety, Risk Assessments/ Quality Plans. 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, and Product Safety.

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

Production Readiness/Commercialization. Prior to commercialization of this technology, actual full-up engine testing must be preformed. Full engine testing is required to determine emission level compliance and to prove reliability of the complete engine with the catalytic stabilizers. The researcher has indicated that this type of testing is planned at a Solar Turbine test facility in the year 2002. Engineers must develop control algorithms and determine engine emissions levels at that time.

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 more affordable electrical energy in California. This will be accomplished by reducing the cost of emission regulation compliance of power generated by more economically attractive distributed generation technologies.

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)