ClearSign

March 20, 2014

State of North Dakota
The Industrial Commission
State Capitol
Bismarck, North Dakota, 58505
ATTN: Lignite Research Program

Re: ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies".

To Whom It May Concern:

Attached please find ClearSign Combustion Corporation's proposal as referred above for your consideration.

We request consideration be given our application for a grant of $50,000 from the North Dakota Industrial Commission, Lignite Energy Resource Council to study the testing and validation of Electrodynamic Combustion Control™ (ECC™) technology for controlling emissions, specifically NOx and PM2.5 with North Dakota lignite coal.

The enclosed proposal encompasses phases I and II of a multi-phase project that seeks to validate ECC technology at pilot scale in order to 1- Prove the benefits of ECC technology to remove criteria pollutants while improving furnace thermal performance and 2- Prepare to scale to larger firing rate systems including utility scale installations in subsequent tests. Our grant request only covers phase I.

We have successfully obtained financial commitments from other entities such as Great River Energy, SaskPower and the National Cooperative Research Association, among others, to fund the phase I research activities. Letters of support from these organizations are attached.

We are fully committed to delivering a successful project to the best of our ability and will devote the needed resources and expertise as noted in our proposal.

On behalf of our company, it is my pleasure to present the grant proposal to the Commission in the form required. We stand ready to answer any further questions the Commission may have.

Sincerely,

Andrew Lee
SVP Business Development

ClearSign Combustion Corporation
12870 Interurban Avenue South,
Seattle, WA 98168
Phone: (206) 673-4848 | Fax: (206) 299-3553 | info@ClearSignCombustion.com

Proposal to:	**North Dakota Industrial Commission**
Project Title:	**Combustion Enhancement of Solid Fuels Using ClearSign's Technologies**
Applicant:	**ClearSign Combustion Corporation 12870 Interurban Ave. S. Seattle, WA 98168**
Contact:	**Andrew U. Lee Sr. VP, Business Development (206) 673-4849**
Principal Investigator:	**Joe Colannino (Chief Technology Officer)**
Date of Application:	**March 20, 2014**
Amount of Request:	**$50,000 USD**

ClearSign

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Abstract

ClearSign Combustion Corporation (ClearSign) has developed a novel combustion technology: Electrodynamic Combustion Control™ (ECC™) that allows for the manipulation of flame structures with the use of high-voltage electric fields to enhance combustion efficiency, heat transfer rates, and control of pollutant emissions. ECC offers the potential for a high-efficiency, cost-competitive emissions control approach that provides an alternative to traditional pollutant mitigation strategies in solid fuel combustion systems. While this technology has shown promising results in tests carried out by ClearSign at the bench scale, it has not yet been evaluated in industrial-scale burner applications. ClearSign proposes to pursue the development of ECC for solid-fuel applications, with primary emphasis on combustion of North Dakota lignite supplied by the Energy and Environmental Research Center (EERC) (or similar), in a two-phase project:

- Phase I - Laboratory evaluation at ClearSign's Seattle, WA facility to be completed over a 15-week period, and,
- Phase II – Field-testing at a solid-fuel-fired site (targeting EERC's research furnace in Grand Forks, ND), to be completed tentatively over a 15-week period.

North Dakota lignite is an excellent candidate fuel for the application of ECC as ECC benefits rely on enhancing the density of positively-charged ions (cations) in the flame. Trace concentrations of sodium, salts and metals present in lignite should help improve cation concentrations above those experienced with other fuels.

Project objectives include the following:
Evaluate the impact of ECC technology on the following key performance parameters:

1. Environmental emissions (NOx, CO and PM). Reduction targets to be agreed upon by Consortium and ClearSign prior to the initiation of the development activities.
2. Flame control. Manipulate flame geometry, provide better flame geometry control.
3. Air distribution. Improved control in a grated combustion system with heterogeneous fuel composition and uneven grate distribution
4. Assess the potential of ECC technology to reduce fouling.

ClearSign's estimated costs to complete the described phases above are as follows:

Total Phase I	$ 400,000
Total Phase II*	$ 750,000
Total Project	$ 1,150,000

* Preliminary

ClearSign has established a consortium encompassing several parties interested in pursuing the technology for solid fuels. Consortium confirmed and prospective participants include: Great River Energy, SaskPower, National Rural Electric Cooperative Association (NRECA), American Sugar Refining, Covanta Holdings, Plum Creek Lumber and Frank's Lumber. These firms are interested in validating our technology for the remediation of NOx and PM 10/PM 2.5. For Phase I, we have confirmed sponsorship of $100,000 with high confidence in another $175,000 for a total of $275,000 against a budget of $400,000. It is ClearSign's intention to cost-share the effort as well.

Additional funding to cover Phase II development activities for lignite will be sought upon the successful completion of Phase I.

Project Summary

ClearSign has developed an innovative, unconventional combustion control technology that applies high-voltage electric fields to flames (ECC) and promises to revolutionize combustion performance for a variety of fuels while controlling harmful emissions.

The electric nature of flames has been known for more than 400 years. As hydrocarbon-based fuel molecules become intermediate radicals during the oxidation process, negative and positive ions are formed. During this process, the flame as a whole is neutral but electric charge exists at the localized level. The application of electric fields in combustion systems was first investigated in an academic environment during the 1950s and 1960s. Seminal work was done by Lawton and Weinberg of London's Imperial College and documented in their book "Electrical Aspects of Combustion," published in 1969. This academic research did not emphasize emission control as it was performed before laws to protect the environment were promulgated. In addition, computers at that time were not affordable and their use was not widespread. Moreover, high voltage supplies were either non-existent or cost prohibitive. Therefore, although this academic research documented the ability of electric fields to manipulate combustion performance, the electrical aspects of combustion remained primarily an academic exercise; surprisingly, the field of study was not pursued by any commercial enterprise until ClearSign in 2008.

ClearSign's ECC technology incorporates a computer-generated waveform (Figure 1). The computer controller is able to generate a variety of wave shapes including symmetric or asymmetric waveforms at high frequencies (60-800 Hz). The signal generator delivers a ± 10 Volt signal to a power amplifier. The power amplifier raises the voltage to about ± 40,000 Volts. When this voltage is delivered to an electrode, the corresponding electric field both enhances and influences cations (+ ions) in the flame. It is the presence of these cations that allows manipulation of flame characteristics.

ClearSign has built and tested several prototype ECC systems including small bench-scale configurations (5,000-300,000 Btu/h), and research furnaces with firing capacities up to 1,000,000 Btu/h. Internal studies performed by ClearSign have used a variety of analytical and measurement tools to record data relating to heat transfer, heat distribution, pollutant formation, flame shape, and other parameters. These prototypes provide a pathway for rapid commercialization and a robust product pipeline. ClearSign's ability to control and improve flame chemistry, mixing and heat transfer in commercially relevant configurations for multiple fuels promises a wide range of potential applications. The effects have been observed in the laboratory in a variety of conditions that simulate a wide range of furnace and boiler conditions in current industrial practice (i.e., temperatures up to 1800°F and excess oxygen levels from 2% to 21%)

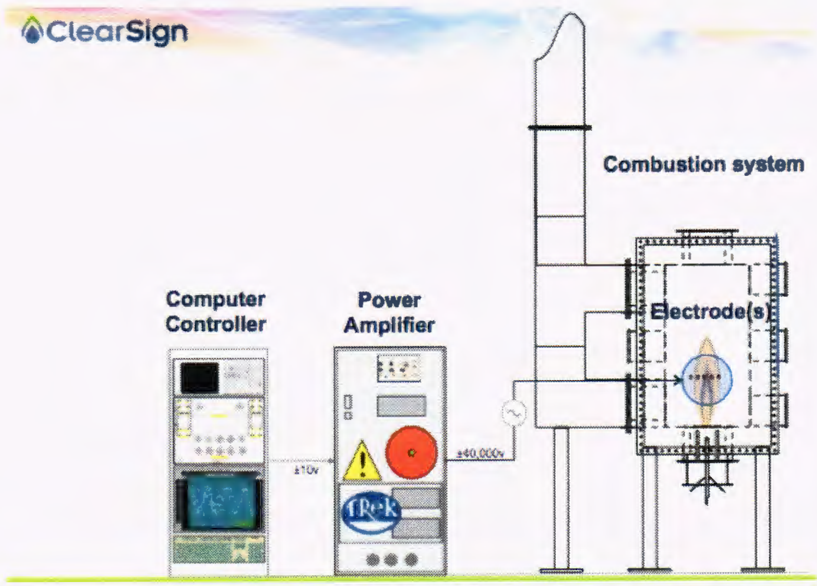

Figure 1. ECC Configuration

ClearSign has also demonstrated the ability to selectively and precisely control flame shape, heat transfer and heat distribution resulting in increased heat transfer to a surface. This has powerful implications for increasing energy efficiency and for simplifying and improving designs in combustion systems ranging from boilers, kilns, and furnaces. Improved mixing and heat distribution also simplifies the design and operation of post combustion controls such as SCR and SNCR whose efficiency can be temperature dependent. Experiments and designs by the company also have shown improvements in flame stability with potential application to Low and Ultra-Low NOx burners.

Repeated tests by ClearSign with multiple fuel types including buoyancy-dominated flames with coal, tire-derived-fuel, and wood, have shown enhanced mixing with reductions in visible Particulate Matter (PM) of over 90% (Figure 2), and significant simultaneous reductions in CO emissions and exit gas temperature (indicative of superior heat transfer to the process). Corresponding reductions in unburned carbon, CO, and particulates, without increased NOx emissions were achieved. These effects are particularly valuable in solid fuel systems where mixing of the oxidant and the fuel becomes challenging, such as those used in industry to burn coal, lignite, municipal solid waste, wood or other opportunity fuels.

Based on the benefits of ECC demonstrated to date, ClearSign proposes to evaluate the technology for several solid fuels (including lignite, coal and biomass) in a laboratory grated furnace at ClearSign's R&D labs (Phase I) and a forced-draft, diffusion flame (Phase II) with the objective of quantifying the impact of ECC in terms of reduction of pollutant emissions (NOx, CO and PM), as well as its ability to control flame geometry, air distribution and potential to reduce fouling.

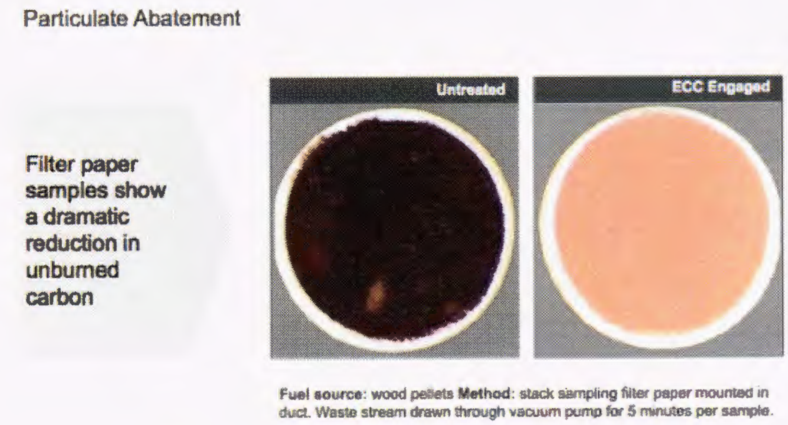

Figure 2. Particulate Matter Control

Project Description

ClearSign proposes to evaluate the ECC technology encompassing the following phases:

- Phase I - Laboratory evaluation at ClearSign's Seattle, WA facility and,
- Phase II – Testing at Energy and Environmental Research Center's research furnace in Grand Forks, ND.

Impacts of ECC technology on the following key performance parameters will be evaluated:

- Environmental emissions (Phases I and II). Reduction targets to be agreed upon by Consortium and ClearSign prior to the initiation of the development activities:
  a. NOx
  b. CO
  c. PM
- Flame control (Phases I and II). Manipulate flame geometry to provide better flame geometry control.
- Air distribution (Phases I and II). Improved control in a grated combustion system with heterogeneous fuel composition and uneven grate distribution
- Assess the potential of ECC technology to reduce fouling (Phase II only).

Scope of Work

The proposed two-phase, multi-task project has been structured to be completed over a 30-week period. A description of the proposed tasks and schedule is as follows:

Phase I – ClearSign Facility Laboratory-scale Testing

Task 1. Kick-off Meeting

A one-day meeting with ClearSign and sponsors' business and technical staff will be scheduled at ClearSign's facility in Seattle, WA as the official kick-off of activities to review the test plan, approach, objectives, budget and schedule.

Task 2. Furnace Preparation

ClearSign's solid fuels grated furnace (Figure 3) will be modified to accommodate a feeding mechanism that provides flexibility to handle the selected solid fuels. A heavy-duty, high-temperature camera will be installed for proper viewing during closed-door experiments. Based on ClearSign's experience, electrode designs

Figure 3 – ClearSign's Solid Fuel Furnace

expected to provide best performance will be selected and manufactured. Furnace access will be identified to minimize intrusiveness in the combustion process.

Access will be provided taking into consideration proper electrical isolation. Grate design will be carried out to ensure readily accessible charge and close simulation of fuel conditions and air distribution. A power supply that provides the required characteristics will be selected and connected to the furnace according to specifications.

Upon completion of all modifications and installation of equipment, shake down experiments will be conducted to ensure the furnace and all of its components and diagnostics work properly prior to initiation of testing activities.

Task 3. Furnace Testing

Closed-door furnace testing will be conducted with and without ECC to assess flame shape characteristics and improvements in emissions of NOx, CO, particulates and opacity.

Various ECC parameters (electrode design, electrode position, AC vs. DC, potential, frequency, wave form, etc.) will be investigated in both furnaces to document improvements in flame shape control, and reduction in emissions of criteria pollutants.

Industrial partners will be invited to witness these tests as schedules allow.

Task 4. Reporting

Monthly reports will be issued documenting technical progress, and comparing actual vs. estimate for the budget and the schedule at each period. A detailed final report will also be issued at the completion Phase I.

Phase II – Energy and Environmental Research Center (Grand Forks, ND) Testing (Preliminary)

Task 5. Design/Manufacture Equipment

The required modifications and instrumentation needs to accommodate the test will be identified and the necessary equipment will be designed, manufactured and shipped to the site.

Task 6. Installation

Equipment and diagnostics installation will be conducted by EERC staff. ClearSign's technical staff will travel to the site and be present during the installation activities to monitor the work.

Task 7. Test

Baseline data will be collected under a variety of process conditions with and without ECC to document performance improvements in flame shape characteristics, temperature distribution, and pollutant emissions (NOx, CO and PM).

Task 8. Document Results
A detailed final report will also be issued at the completion Phase II.

Standards of Success

It is anticipated the standards for success will differ depending on the type of fuel tested. The standards for lignite will be established by the relevant consortium participants taking into consideration the current state-of-the-art pollution control technology and the expectations for pending regulations, with special emphasis on NOx and PM. Preliminary discussions with operators of combustion equipment burning lignite has indicated a NOx emissions reduction in the range of 20-50% is significant. Based on this, our criteria for success will be measured against these targets.

The standard for flame control will be established based on qualitative data obtained through filming and image processing techniques. Air distribution will be assessed by establishing the minimum oxygen concentration in the stack with negligible carbon monoxide emissions.

Background

ClearSign has been developing new technologies to improve the performance of combustion systems. Considerable research has been conducted to assess ECC for gaseous and solid fuels. A white paper describing ECC is included in this proposal as an attachment.

Internal studies performed by ClearSign have used a variety of analytical and measurement tools to record data relating to heat transfer, heat distribution, pollutant formation, flame shape, and other parameters. These prototypes provide a pathway for rapid commercialization and a robust product pipeline. ClearSign's ability to control and improve both flame chemistry and heat transfer in commercially relevant configurations for multiple fuels promises a wide range of potential applications. The observed effects have been viewed in ambient to 1600°F and excess oxygen levels from 2% to 21% air. This simulates a wide range of furnace and boiler conditions in current industrial practice.

ClearSign has also demonstrated the ability to selectively and precisely control flame shape, heat transfer and heat distribution resulting in increased heat transfer to a surface. This has powerful implications for increasing energy efficiency and for simplifying and improving designs in combustion systems ranging from boilers, kilns, and furnaces. Improved heat distribution also simplifies the design and operation of post combustion controls such as SCR and SNCR whose efficiency can be temperature dependent. Experiments and designs by the company also have shown improvements in flame stability with potential application to Low and Ultra-Low NOx burners.

Repeated tests by ClearSign with multiple fuel types including coal, tire-derived-fuel, and wood, have shown reductions in visible Particulate Matter (PM) of over 90%, with significant simultaneous reductions in CO emissions and exit gas temperature (indicative of superior heat transfer to the process). Corresponding reductions in unburned carbon, CO, and particulates, without increased NOx emissions were achieved. These effects are particularly valuable in co-firing applications where natural gas is used to supplement solid fuel systems such as those used in industry to burn wood waste, coal, or other opportunity fuels.

Figure 4 highlights improved mixing with ECC™ technology. A bird's-eye view of a bench scale apparatus shows a diffusion propane flame surrounded by a circular air opening and (at a greater radius) a metal cylinder. In Case (a) the system is off and the propane burns normally. When the system is engaged as in Case (b), the flame is charged with a proprietary electrical waveform. The flame volume increases immediately with no change in firing rate as the positive ions move toward the grounded cylinder and impart momentum to the bulk fluid. Sharp-edged flame structures are formed as the wave is inverted and re-inverted many times per second causing flow reversals along the electrical field lines. The mixing and violence of the flame are greatly enhanced with no additional excess air. When the system is deactivated, the flame immediately reverts to its normal state shown in Figure 4a.

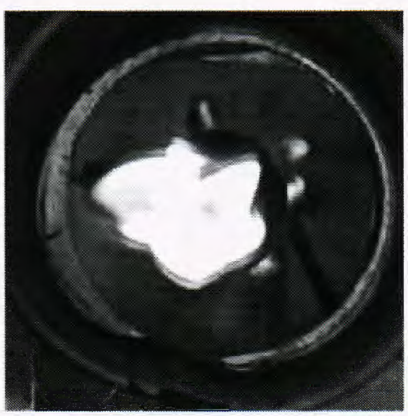

Figure 4a. System Off

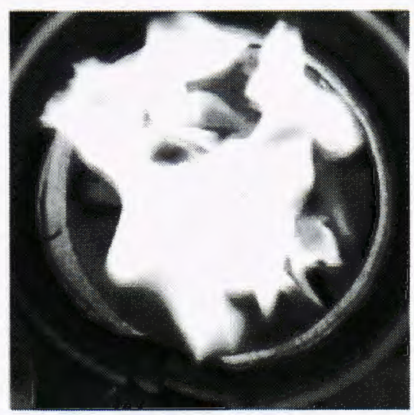

Figure 4b. System Engaged

Figure 5 highlights directed heat transfer via ECC™ technology. The image at left (5a) shows a Schlieren image (elevation view through a circular window) of a propane diffusion flame without the influence of ECC™ technology; a normal vertically rising plume is apparent. The center image (5b) shows the system engaged but with the surroundings left "floating," i.e., ungrounded; here the plume responds in a chaotic fashion, looking for a ground but unable to find one. In the image at right (5c), a surface is grounded (right side of photograph) and the thermal plume is drawn toward it. By one way of reckoning, this should not be possible as ions such as HCO+ should be consumed before entering the flue gas stream and the plume temperature should be too low for the thermal formation of ions. A possibility is that some charge transfer has occurred via random collision (such as some H_2O to H_3O+) and the charged species persist in the flue gas to be driven toward the ground plane.

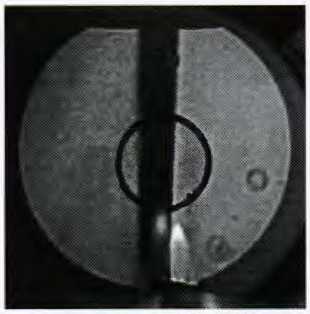
Fig. 5a. System Off


Fig. 5b. Engaged/no ground

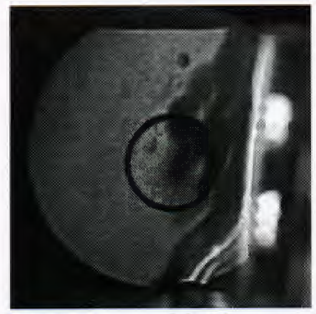
Fig. 5c. Engaged/with ground

Figure 6 highlights enhanced thermal efficiency with ECC™ technology. Images from an infrared camera show an elevation view of a hot spot near the exit of the cylindrical volume from the plume of an internal propane flame. Within two minutes of system activation Case (6b) the temperature is more uniform to the cylindrical enclosure. The exit gas temperature is also reduced and the temperature profile within the enclosure less variant with elevation, suggesting improved, and increased heat transfer to the cylinder. When the system is switched off, the effect is reversed.

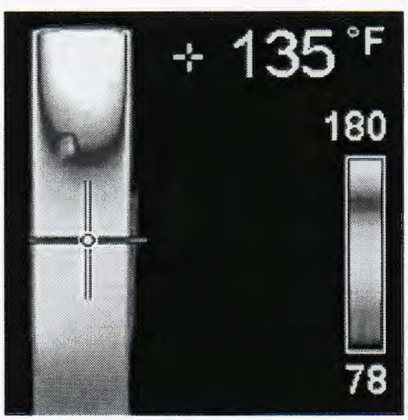

Figure 6a. System Off

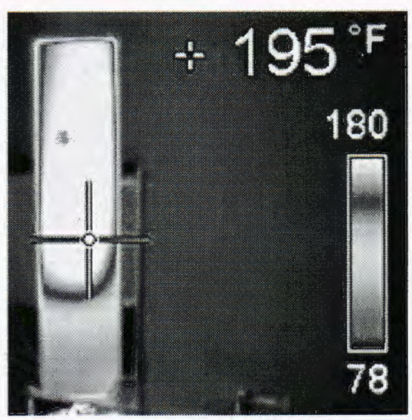

Figure 6b. System On

Additional proprietary background information on the performance of ECC with biomass is included as an appendix.

Qualifications

Our principal investigator (PI), Joseph Colannino, is Chief Technical Officer for ClearSign Combustion Corporation. Prior to joining ClearSign, Joe led global research and development at John Zink Company, reporting to the CEO. As head of global R&D, Joe's responsibilities included management of intellectual property, oversight of John Zink's world class testing facility, comprising more than a dozen large-scale industrial test furnaces, and learning: the John Zink Institute trains more than 1,000 students per year in various aspects of combustion. Mr. Colannino worked at John Zink for 13 years with previous roles including Knowledge Manager and Director of Engineering.

With more than twenty-five years in the industry, Joe is well known, has written scores of articles, and contributed to several books including Industrial Combustion Testing, The Air Pollution Control Guide, and The John Zink Combustion Handbook – CRC Press' largest selling combustion book. Taylor and Francis recently published his latest book: Modeling of Combustion Systems – A Practical Approach.
Mr. Colannino is a graduate of the California Polytechnic University at Pomona with minors in Materials and Chemistry, and a Master's degree in Knowledge Management from the University of Oklahoma. He is a registered professional engineer and has written and reviewed problems appearing on the NCEES professional engineering exam, given in all 50 states for professional engineering licensure.

Mr. Colannino's areas of expertise include R&D management, combustion, pollutant formation and control, and statistical experimental design. Past and present memberships include the American Institute of Chemical Engineers, the American Chemical Society, the Air and Waste Management Association, the American Statistical Association and the National Association of Professional Engineers, among others. He has supervised intellectual property portfolios, the preparation of many patents, and also appears in several Who's Who compilations.

Our project manager and senior advisor on the project will be Dr. Roberto Ruiz. Dr. Ruiz earned a Ph.D in mechanical engineering from the University of Minnesota. Prior to joining ClearSign, Dr. Ruiz served as the President and Chief Operating Officer of OnQuest, Inc., a division of Primoris Services Corporation, a provider of engineering, procurement and construction services for fired heaters (primarily in refinery applications), waste heat recovery units and LNG, hydrogen, ammonia and bio-fuels plants. Previously, he served as Vice President of the Process Burners Group at John Zink Company LLC where he had full operating and P&L responsibility for the company's product lines. His customers included most major domestic and international oil companies and OEMs. As an executive manager, Dr. Ruiz formed and led highly successful teams of engineers, process engineers, project managers, and aftermarket sales and field service professionals. He had previously been VP Technology and Commercial Development at Zink where he was responsible for all R&D as well as the management of the company's intellectual property portfolio. Prior to joining John Zink Company in 1997, Dr. Ruiz worked with the Gas Research Institute and later with Air Liquide, where he was commercial and marketing manager in the Glass Group.

Dr. Ruiz serves as ClearSign's Senior Vice President of Product development.

Assisting Mr. Colannino and Dr. Ruiz will be a team of combustion engineers, technicians and EPA certified emission testers.

Value to North Dakota

Both public and private sector segments are beneficiaries of a successful test. For if the tests indicate positive results in either plant efficiency or lowered air pollution or both, the results will benefit both public and commercial constituencies.

For the public reductions in criteria pollutants have significant health and environmental benefits. For producers of lignite fueled electrical power, increased efficiency with reduced pollution will mean achieving lower emissions at a lower cost than currently available with "best available control technology". In other words, utilities will be able to deliver power more efficiently with lower emissions than previously.

Lignite's high sodium content theoretically makes it an ideal choice for ECC technology since the greater the ion density the greater the control of the flame front. If our theory is correct, unlike competing technologies like Selective Catalytic Reduction, ECC can positively impact the value of lignite coal by increasing its efficiency while reducing its emissions. For lignite producing regions such as North Dakota, addressing these two areas address two key demand drivers for lignite coal. If the tests prove successful the value of lignite will go up as demand increases, jobs will grow with the demand, new jobs will be created, while environmental issues such as EPA regional haze regulations, will be successfully addressed.

Management

ClearSign abides by a disciplined project management approach consistent with gated R&D project management practiced by high quality industrial organizations. An experienced project manager (PM) is assigned to each project. The project manager works closely with the principal investigator (PI) to ensure the project objectives are met within the specified budget and schedule. Daily meetings are held between the PM and the PI to plan activities and review progress, budget and schedule. Likewise, weekly meetings are held with the project team to review the same. Go/No-Go milestones are established at critical points in the project schedule and reviewed accordingly.

Time Table

Phases I and II will be carried out in series over a 30-week period. A project schedule is presented below.

Phase	Task		Title	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I			**Laboratory-scale Testing**																
	1.0		Kick-off Meeting		■														
	2.0		Furnace Preparation																
		2.1	Install Runtime Camera			■	■	■											
		2.2	Electrode Design and Placement			■	■	■	■										
		2.3	Electrical Isolation				■	■	■										
		2.4	Grate Design			■	■	■	■										
		2.5	Power Supply				■	■	■										
		2.6	Shake Down							■									
	3.0		Furnace Testing																
		3.1	Baseline data: flame shape, opacity, particulates,NOx, CO							■	■								
		3.2	Validate/improve flame shape									■	■	■	■				
		3.3	Validate/Improve NOx, CO											■	■	■	■		
		3.4	Improve opacity/particulate emissions														■	■	■
	4.0		Reporting																
		4.1	Monthly Reports						■					■					
		4.2	Final Report																■

Phase I

Phase	Task		Title	Week	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
II			**Field Test**																
	5.0		Design/Manufacture Equipment		■	■	■	■	■	■	■								
	6.0		Installation									■	■						
	7.0		Test											■	■	■	■	■	
	8.0		Document Results															■	■

Phase II

Phase III – Field Test

Upon successful completion of the testing at EERC, potential lignite-powered utility boiler sites will be identified for evaluation of the technology. It is anticipated that either one burner or preferentially a row of burners will be retrofitted to assess the impact of ECC.

A budget and schedule for this phase will be prepared once more details can be gathered.

Budget

ClearSign's estimated costs to complete the described phases above are as follows:

Total Phase I	$ 400,000
Total Phase II*	$ 750,000
Total Project	$ 1,150,000

* Preliminary

ClearSign requests a $50,000 contribution from the North Dakota Industrial Commission to partially cover Phase I costs.

- Phase II budget shown is preliminary. Phase II budget to be finalized upon the successful completion of Phase I.
- Budget for Phase I is shared by ClearSign and several companies with individual contributions ranging from $25,000 to $100,000.

Matching Funds

We are proposing the project as a cost share among the company as well as other interested parties. We have commitments of $25,000 from SaskPower $25,000 from Great River Energy, and $50,000 from National Rural Electrical Cooperative Association (NRECA). Prospective sources that have expressed interest include: American Sugar Refining for $100,000, Mineral Management, $25,000, GrandEg LV in kind, Plum Creek Timber, in kind, Covanta Holdings, in kind, and Frank's Lumber, in kind. Thus, as of this writing, we have confirmed $100,000 of sponsorship with high confidence in another $175,000 or a total of $275,000 against a budget of $400,000. It is ClearSign's intention to cost-share to the effort as well.

Tax Liability

Affidavit as per letter by ClearSign's Chief Financial Officer presented in Appendix 3.

Appendices

Appendix 1 – ECC White Paper (non-proprietary). Under separate attachment.

A ClearSign White Paper

ClearSign

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Electrodynamic Combustion Control™ Technology

By Joseph Colannino
Chief Technology Officer

2012-06-18

Contents

Introduction

ClearSign's Electrodynamic Combustion Control™ (ECC™) technology makes use of computer-controlled high-voltage electric fields to manipulate the movement of electrically charged molecules (ions) that are a natural product of the combustion process. The pulsed field creates very powerful electrostatic forces (Coulombic body forces) within the gas cloud that can be manipulated to precisely control flame shape and the transfer of heat to, through, or away from a surface, as desired. At the same time, the technology provides an unprecedented level of precision for optimizing combustion chemistry to suppress formation of pollutants at the flame source.

How it Works

During the course of combustion, ions are produced within the flame region, as is well known. Such ions comprise HCO+, C_3H_3+, etc. along with their corresponding but dissociated electrons. The ECC technique first introduces a positive charge at high voltage but low amperage into the flame to remove electrons and enhance the concentration of cations. This is most conveniently introduced via a conductive solid or fluid carrier into the flame or even through the burner nozzle itself. Since electrons are roughly 50,000 times less massive than the positive ions they leave behind, their exit from the flame is rapid. The abandoned concentration of positive charge in the flame immediately begins to disperse inasmuch as like charges mutually repel. Technically, the charge imbalance affects only the ionic species, however, collision with neutral species is inevitable and results in a net dispersive bulk flow away from the former flame volume and toward a region of lower electrical potential. In typical furnaces, reactors, and boilers, this means flow toward the reactor tubes along the electrical field lines now established, because such large metal structures are unavoidably grounded. Indeed, other ground planes or even electrically negative surfaces can be introduced in specific regions for particular effects, if desired.

If the charged species were to reach any grounded or oppositely charged structure, they would capture electrons (i.e., *ground out*). So, prior to this event, we cause the electrode or burner nozzle to lower its potential or to reverse polarity. We repeat this effect ad infinitum. The result is a periodic reversal of flow that results in high entrainment and mixing within the flame volume. Since new reactants are continually flowing into the flame volume and new products are continually flowing out of it, power must be continually added to the reaction zone. Experiments at the bench scale have shown that the required power is less than 0.1% of the total thermal power released by the flame. This is much lower than required for plasmas, as the goal is not to create a massive dissociation of electrons from the bulk fluid, but merely to enhance and direct the resulting positive ions that naturally occur within the combustion process. The reversals of direction provide for intimate and increased mixing with the neutral species yet without the need for additional excess air. This brings the following benefits:

- Excess air requirements are reduced because the bulk momentum of the air used for mixing is assisted by the increased turbulence of the flame due to the increased collision and momentum transfer affected by high velocity ions (Figure 1).
- NOx is reduced owing to the increased homogenization of the flame. Such homogenization tends to reduce peak flame temperatures and dramatically reduce NOx. (Flame homogenization is a well-known technique for dramatically reducing NOx.) NOx formation is a complicated mechanism involving many kinetic steps. However, its gross features may be represented by a two-step Zeldovich mechanism.

$$N + O_2 = NO + O \quad (1)$$
$$O + N_2 = NO + N \quad (2)$$
$$N_2 + O_2 \rightarrow 2NO \quad (3)$$

Reaction (2) is the rate limiting step, involving as it does the rupture of the nitrogen-nitrogen triple bond. The reaction rate exponentially increases with temperature; therefore, much of the NOx is formed by hot spots in the flame. Presuming partial equilibrium between molecular and atomic species per Reaction (4), the rate limit equation may be written as Equation (5), where the bracketed species refer to their volume concentrations.

$$\tfrac{1}{2} O_2 = O \quad (4)$$

$$\frac{d[NO]}{dt} = Ae^{-\frac{b}{T}}[N_2]\sqrt{[O_2]} \quad (5)$$

Homogenization of the flame reduces peak flame temperature differences in diffusion flames, thereby reducing the rate of NOx formation.

Effects

1. CO is reduced, owing to the increased homogenization of the flame and increased mixing with the air stream as well as the increased mobility and collisions of HCO+ with oxidants and neutral free radical species such as OH, known to catalyze CO oxidation. For example, CO oxidation occurs primarily by

$$CO + OH = CO_2 + H \quad (6)$$

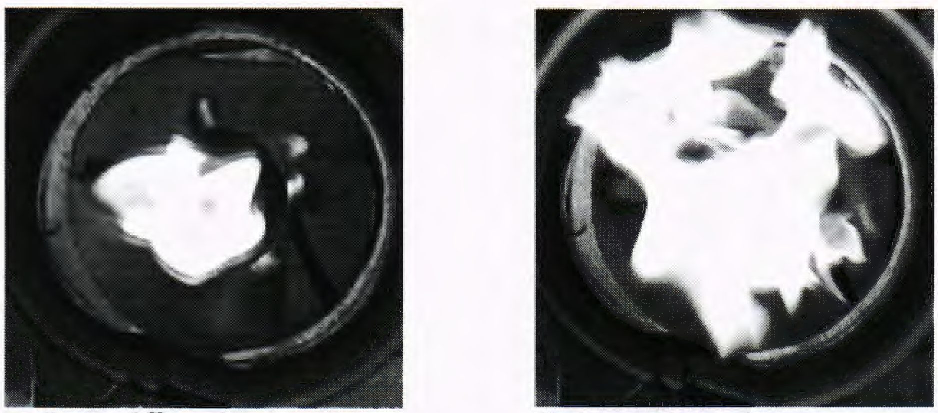
Note that the high temperature dissociation of H_2O and partial oxidation of hydrogen radicals populate the OH radical pool.

$$H_2O = H + OH \quad (7)$$
$$H + O_2 = OH + H \quad (8)$$

2. Particulate is dramatically reduced (see Figures 2 and 3). One mechanism for particulate reduction is the increased mixing of air with fuel and partially combusted products. However, other mechanisms may also be operative. For example, an ionic mechanism of soot has been proposed. Although the main soot formation pathway now appears to be via free radical intermediates, ionic mechanisms may still play a role. The increased collision of charge carrying carbocations with oxidants and other destructive species may account for additional reduction. Whatever particulate is formed (Figure 4) tends to be light, spongy, and large (on the order of millimeters or greater). Such large particulates are easily collected in inexpensive cyclone separators as opposed to requiring more expensive technologies such as electrostatic precipitators or baghouses.

3. Heat transfer is enhanced (Figure 5). Since the thermal flow can be directed toward (or away from) various surfaces, one may use ECC technology to enhance heat transfer (Figure 6) to boiler or process tubes or insulate surfaces such as gas turbine blades and critical engine parts from hot flue gases.

4. Flame shape is dramatically affected (Figure 7). Tailoring flame shape is critical as unwieldy flames are a major source of concern in many units; e.g., process heaters in refining and petrochemicals and boilers. In one interview, a heater expert for a major refiner reported that unruly flames could force as much as a 30% derate in process output for some heaters; i.e., flame shape is critical in most combustion applications. Until now, combustion engineers have had only buoyancy and momentum forces in their tool kit for shaping wayward flames. ECC technology provides a third force of at least an order of magnitude greater than either buoyancy or momentum to shape flames.

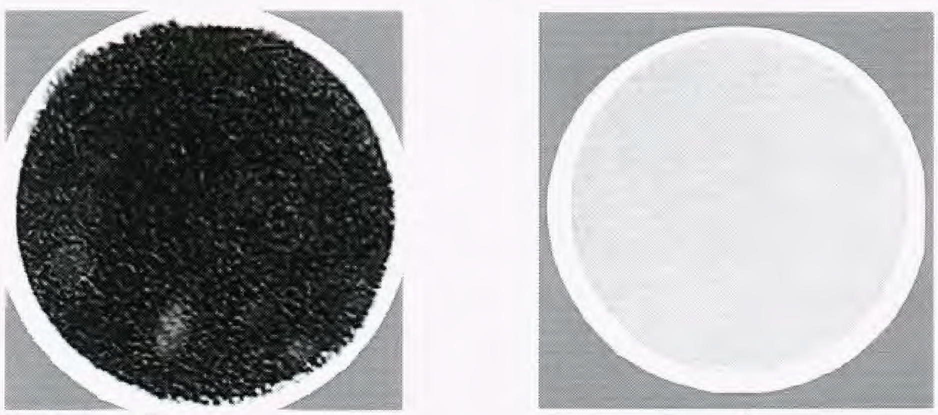


1a. System Off 1b. System Engaged

Figure 1. Improved mixing with ECC technology. A bird's-eye view of a bench scale apparatus shows a diffusion propane flame surrounded by a circular air opening and (at a greater radius) a metal cylinder. In Case (a) the system is off and the propane burns normally. When the system is engaged (b), the flame is charged with a proprietary electrical waveform. The flame volume increases immediately with no change in firing rate as the positive ions move toward the grounded cylinder and impart momentum to the bulk fluid. Sharp-edged flame structures are formed as the wave is inverted and re-inverted many times per second causing flow reversals along the electrical field lines. The mixing and violence of the flame are greatly enhanced with no additional excess air. When the system is deactivated, the flame immediately reverts to its normal state shown in Figure 1a.

2a. System Off   2b. System Engaged

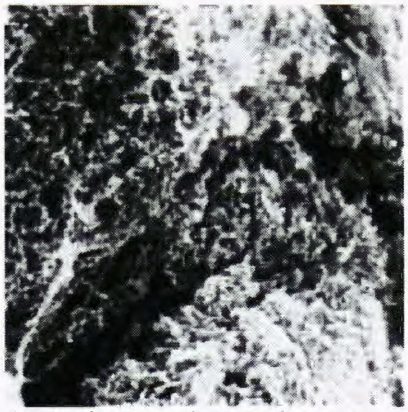
Figure 2. Particulate reduction via ECC technology. Biomass is suspended in a small crucible held over a propane diffusion flame (not visible), generating copious quantities of soot (a). The electric field is switched on and the particulate is eliminated immediately (b). The improvement in opacity is greater than 90%. When the field is switched off, the soot formation resumes as per (a).



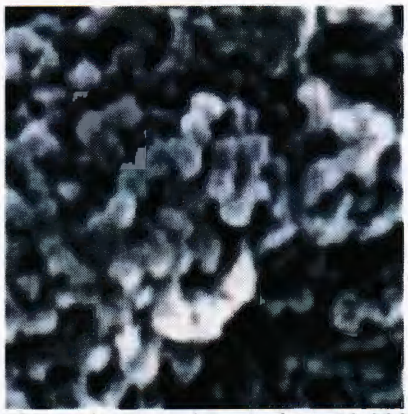
3a. System off   3b. System Engaged

Figure 3. Particulate filter samples with and without ECC technology. In each case, a stack sample is drawn through a vacuum pump for a period of 5 minutes. The filter sample without ECC technology engaged is shown at left (a). This is compared to filter sample drawn under identical conditions with ECC technology engaged (b). Case (b) comprises a pink ash with no visible unburned carbon.

ClearSign

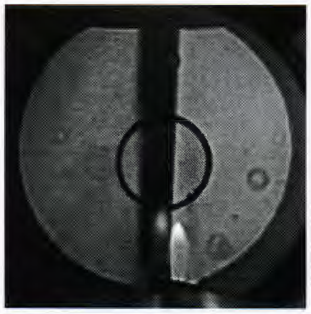


4a. Agglomerated particulate, 500x.

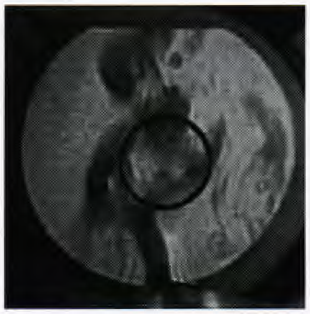


4b. Agglomerated Particulate, 50,000x.

Figure 4. Particulate generated in a fuel rich flame using ECC technology. Using wood as a fuel source, electron micrographs at both 500x and 50,000x magnification showed ultrafine particulates that would otherwise have escaped into the exhaust stream were agglomerated into large macroscopic structures. Such structures are easily removed from a waste stream using low-cost cyclonic separators as opposed to more expensive electrostatic precipitators and baghouses.



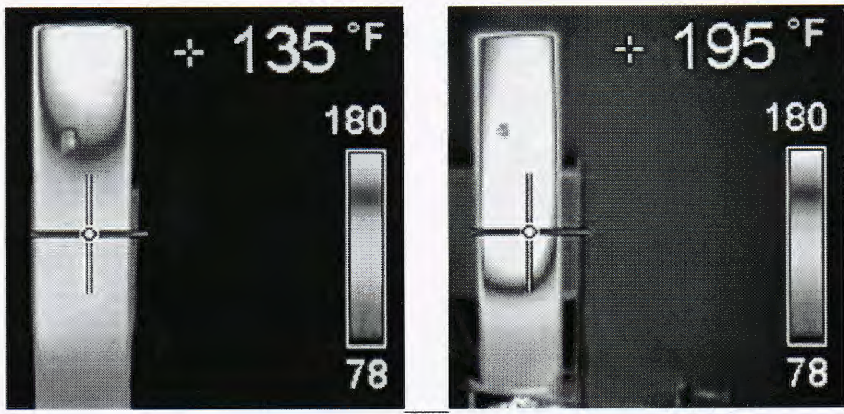
5a. System Off



5b. Sys. Engaged (no ground)

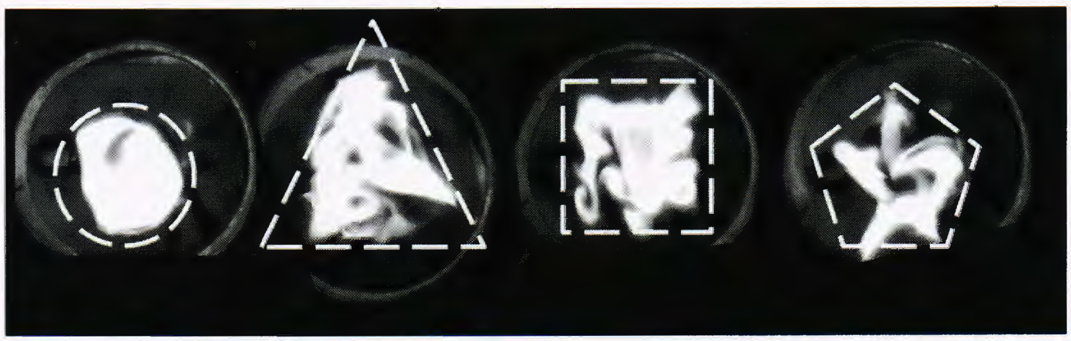
5c. Sys. Engaged with Ground

Figure 5. Directed Heat Transfer via ECC technology. The photograph at left (4a.) shows a Schlieren image (elevation view through a circular window) of a propane diffusion flame without the influence of ECC technology (a); a normal vertically rising plume is apparent. The center figure (b) shows the system engaged but with the surroundings left "floating," i.e., ungrounded; here the plume responds in a chaotic fashion, looking for a ground but unable to find one. In the rightmost photograph (c), a surface is grounded (right side of photograph) and the thermal plume is drawn toward it. By one way of reckoning, this should not be possible as ions such as HCO+ should be consumed before entering the flue gas stream and the plume temperature should be too low for the thermal formation of ions. A possibility is that some charge transfer has occurred via random collision (such as some H_2O to H_3O+) and the charged species persist in the flue gas to be driven toward the ground plane.



6a. System Off 6b. System On

Figure 6. Enhanced Thermal Efficiency with ECC Technology. Photographs from an infrared camera show an elevation view of a hot spot near the exit of the cylindrical volume from the plume of an internal propane flame. Within two minutes of system activation (b) the temperature is more uniform to the cylindrical enclosure. The exit gas temperature is also reduced and the temperature profile within the enclosure less variant with elevation, suggesting improved and increased heat transfer to the cylinder. When the system is switched off, the effect is reversed.



7a. System Off 7b. System Engaged 7c. System Engaged 7d. System Engaged

Figure 7. Flame Shape via ECC technology. The figure shows individual frames (top view) of a video from an operating bench-scale apparatus comprising a propane flame over which regular figures have been superimposed (dotted line segments). In Case (a) the system is off, whereas in Cases (b) through (d) the system is engaged with the cylinder grounded. Owing to normal perturbations within the volume, the flame is drawn in various equiangular shapes. The effect could be made permanent by selectively grounding stationary poles rather than employing a uniform cylindrical ground. Notwithstanding and in view of Figures 1, 5, and 7, it is clear that ECC technology offers a novel and unparalleled tool for shaping flames in extraordinary ways.

Benefits

ClearSign Technology improves key performance characteristics of new and existing combustion systems. Such characteristics include energy efficiency, emissions control, fuel flexibility and overall cost effectiveness. While, in principle, ECC technology can be applied at any scale, the potential cost savings and economic benefits are larger for large-scale combustion systems. Such systems include industrial heat for processes such as refining and petrochemicals production, and steam raising to generate electric power or process steam. The technology is low cost and applicable to new or retrofit installations and promises to substantially reduce the cost of compliance with air quality regulations for criteria pollutants such as NOx and CO. Additionally, a possibility exists for preferential collection of metals ions such as Hg, Cd, or Pb, and the like, though this has not yet been experimentally tested.

In the typical case, current emissions control technologies impose increased capital and operating costs. They often require substantial energy to operate (parasitic load), reducing overall energy efficiency. Often, there is little or no economic return on the investment in such systems. The only and important benefit is compliance with air quality regulations. In contrast, ECC technology promises not only improved emissions control performance but a significant increase in energy efficiency through more efficient heat transfer to surfaces.

Industrial Applications

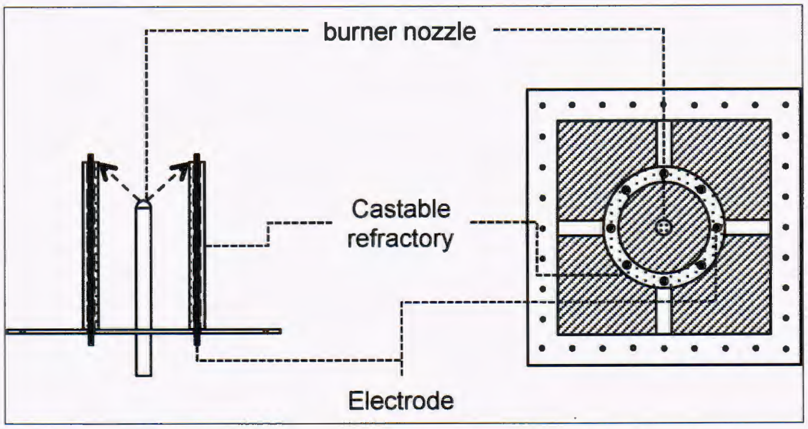
Industrial combustion systems are among the largest consumers of energy in the United States. The ClearSign Electrodynamic Combustion Control (ECC) technology platform represents a revolutionary approach to fundamentally improving their operating characteristics. This novel approach has the potential to radically improve production throughput, energy efficiency and environmental performance *simultaneously.*

In the longer term, ClearSign's technology may provide the basis for fundamental improvements to the design of combustion systems: a combustion system designed around ECC technology could not only set new standards for performance and flexibility, but could also feature a reduction in physical footprint and significantly reduced construction and operating costs. In the largest systems, savings in construction and land use costs alone could range to hundreds of millions of dollars. Selectively improving heat transfer alone would significantly improve the process output (throughput) of existing boilers, furnaces, and reactors.

Technical Management Plan

Prototypes and Experimental Data. The company has built and tested several prototype systems including a small bench-top configuration of 5,000 Btu/h, a larger bench-scale system of 25,000 Btu/h with optical access to give direct visual and infra-red observation of flame shape, and a furnace designed for heat releases to 0.25 MMBtuh. Heat releases for individual burners for process industries range in size from 0.25 MMBtuh (sidewall-fired ethylene cracking units and steam-methane reformers) to 6 – 10 MMBtuh (most process heaters in the petroleum and petrochemical space) to 30 - 100 MMBtuh or greater for packaged and field erected boilers. In order to gain commercial credibility, ClearSign proposes further investigation of momentum-dominated diffusion flames at 0.25 MMBtuh. Figure 10 shows the proposed test burner. The burner is very similar to burners used in the refining and petrochemicals industries with similar fuel discharge velocities and mixing dynamics.

ClearSign



10a. Cross-section, elevation view 10b. Top view

Figure 10. Proposed Test Burner. The burner has capability to fire to 250,000 Btu/h (0.25 MMBtuh). Fuel flows through four orifices in the burner nozzle, entraining air [air openings shown cross hatched in (b)] and stabilizing on the cylindrical refractory ledge. High temperature electrodes charge the flame. Metal surfaces placed inside the furnace to simulate tubes or walls (not shown) provide a source of ground or opposite polarity. The multiple electrodes may be charged in tandem, in sequence, or individually to push and pull the flame into the desired shape.

The observed effects have been viewed in ambient to 1600 °F and excess oxygen fractions from 2% to 21%. This simulates a wide range of furnace and boiler conditions in current industrial practice. Figure 11 shows a burner inserted into the ClearSign furnace and augmented with a damper assembly for the control of air flow, while Figure 12 shows the furnace and stack arrangement with damper for draft control.

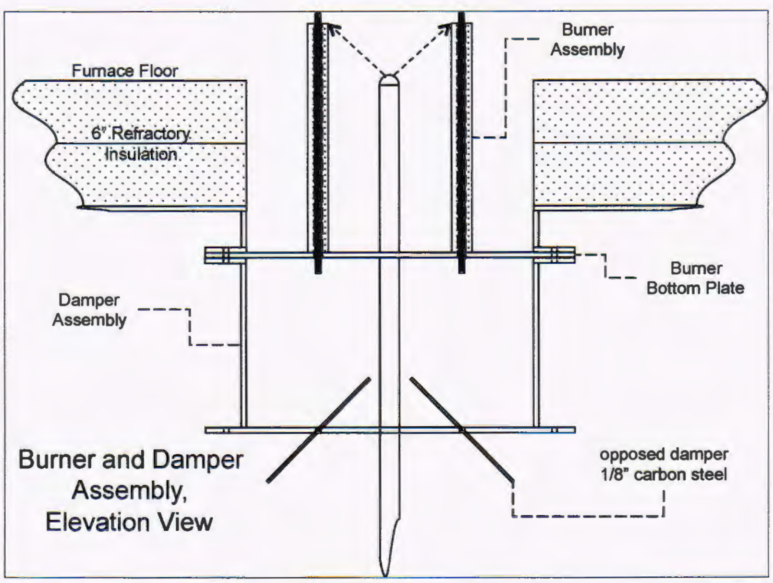


Figure 11. Proposed installation. Here, the burner is shown installed with an inlet damper for excess air control into the bottom of a furnace.

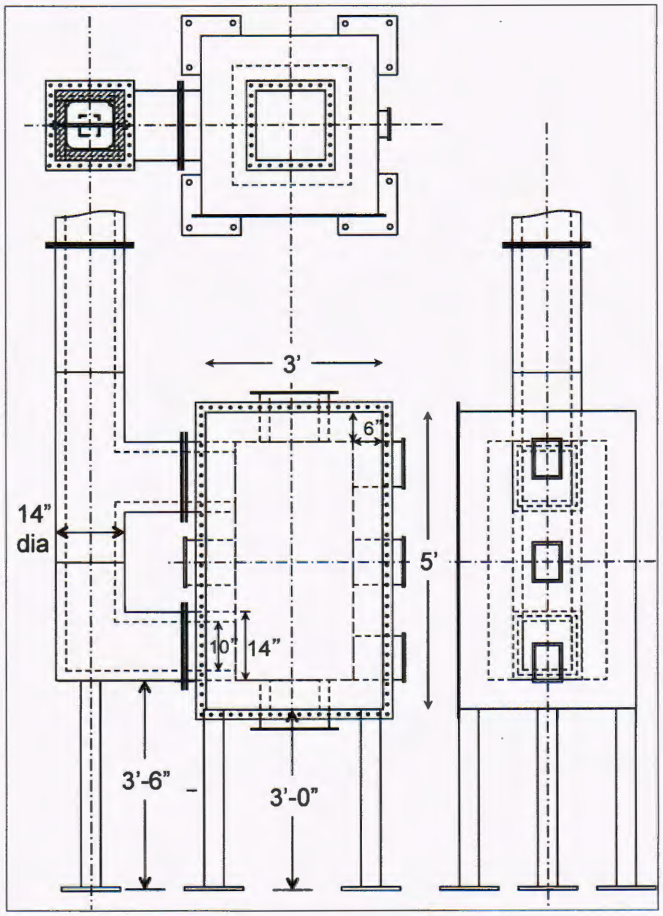


Figure 12. Existing furnace. Here, a general arrangement of the furnace is shown sans burner. The outside dimensions are 3'x3'x5' and the inside dimensions (insulated volume) are 2'x2'x4'. The furnace is capable of 2300 °F continuous operation and has four sight ports (3 East, 1 West) as well as top and bottom burner inlets to allow for up- or down-firing. In normal operation one of the stack outlets is blinded. Draft is controlled by means of an outlet damper.

The pilot-scale system of 250,000 Btu/h will be used to demonstrate the technology at commercially relevant scales for both pre-mixed and diffusion flames. The reactor can accommodate a variety of fuel types and can be up-, down-, or side-fired.

ClearSign Combustion Corporation has state-of-the-art continuous emissions monitors for NOx, SOx, CO, CO_2, O_2, and total hydrocarbons. In addition, we have state-of-the-art waveform generators and power amplifiers.

We have conducted numerous experiments using a variety of analytical and measurement tools to record data relating to heat transfer, heat distribution, pollutant formation, flame shape and other parameters. These prototypes provide a pathway for rapid commercialization and a robust product pipeline. ClearSign's ability to control and improve both flame chemistry and heat transfer in commercially relevant configurations for multiple fuels promises a wide range of potential applications.

Repeated tests by the company with multiple fuel types including coal, tire-derived-fuel, and wood, have shown reductions in visible particulate matter (PM) of over 90%, with significant simultaneous reductions in carbon monoxide (CO) and exit gas temperature (indicative of superior heat transfer to the process). We achieved such reductions in unburned carbon, CO, and particulates, without increased NOx emissions. These effects are particularly valuable in solid fuel systems such as those used in industry to burn wood waste or other opportunity fuels, as well as larger scale coal-fired systems for generating electric power. We have also demonstrated the ability to selectively and precisely control flame shape, heat transfer and heat distribution. We have shown increased heat transfer to a surface, and have also demonstrated steering of the gas cloud away from a surface to cool it. This has powerful implications for increases in energy efficiency and for simplifying and improving designs in combustion systems ranging from boilers and kilns to gas turbines. Improved heat distribution also simplifies the design and operation of post combustion controls such as electrostatic precipitators (ESPs) whose efficiency can be temperature-dependent.

In addition to enhancing control of heat transfer and potentially reducing or eliminating emissions of particulate and ultra-fine particulate (PM2.5), our technology may prove highly effective in suppressing emissions of multiple additional pollutants including NOx and Mercury. Precise control of ion drift velocities and heat distribution selectively controls residence time – i.e., the amount of time that a given molecule is exposed to a high temperature region. This promotes or suppresses particular chemical reactions such as those intermediates that lead to the formation of NOx and CO. This novel and powerful approach to integrated emissions control technology could result in major cost savings implications for solid fuel systems, and would prove transformative for the economics of coal-fired power generation.

Experiments and designs by the company also have shown improvements in flame stability with potential application to Low and Ultra-Low NOx burners.

We have presented detailed data to multiple subject matter experts and selected prospective customers and/or distribution partners. Through these interactions, we have gained considerable insight into how our customers would apply the various features of our technology to deliver meaningful cost savings, production efficiencies and other economic benefits.

ClearSign's technology has been demonstrated at the bench- and pilot-scale for a variety of effects, and the following industries have been selected for detailed consideration.

- Natural-gas fired boilers for industrial and utility steam generation
- Petroleum refining
- Coal- and biomass-fed stoker systems
- Petrochemicals such as ethylene and hydrogen production

ClearSign

Appendix 3

March 20, 2014

State of North Dakota
The Industrial Commission
State Capitol
Bismarck, North Dakota, 58505
ATTN: Lignite Research Program

Re: ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies".
Subject: Affidavit of Tax Liability

To Whom It May Concern:

Please be advised that ClearSign Combustion Corporation does not have an outstanding tax liability owed to the State of North Dakota or any of its political subdivisions.

Sincerely,

James N. Harmon
Chief Financial Officer and Corporate Secretary
ClearSign Combustion Corporation

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ND OIL & GAS
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GREAT RIVER
ENERGY®

Coal Creek Station • 2875 Third Street SW • Underwood, North Dakota 58576-9659 • 701-442-3211 • Fax 701-442-3726

March 26, 2014

State of North Dakota
The Industrial Commission
State Capitol
Bismarck, North Dakota, 58505
ATTN: Lignite Research Program

Re: ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies".
Subject: Letter of Support

To Whom It May Concern:

This letter shall serve to express the support of Great River Energy for the application of the above referenced proposal submitted by ClearSign Combustion Corporation to the North Dakota Industrial Commission, Lignite Research Program.

ClearSign's Electrodynamic Combustion Control technology is a candidate for test and validation to enhance the combustion outcomes of lignite coal and as such we support their application for a Lignite Research Grant. Great River Energy is very interested in exploring the viability of ClearSign technology as a solution to address NOx and PM2.5 remediation in our lignite fueled power plants.

Great River Energy will invest $25,000 US in the effort as well as sending personnel to witness the lignite testing firsthand.

We strongly urge approval of the applicants grant to further improve the combustion outcomes of lignite coal.

Sincerely,

John Weeda
Director of North Dakota Generation
Great River Energy

EERC
Energy & Environmental Research Center
UNIVERSITY OF NORTH DAKOTA
15 North 23rd Street — Stop 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181
Web Site: www.undeerc.org

March 26, 2014

Lignite Research Program
State of North Dakota
The Industrial Commission
State Capitol
Bismarck, ND 58505

To Whom It May Concern:

Subject: Letter of Support for ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies"

This letter expresses the support of the Energy & Environmental Research Center (EERC) for the application of the above-referenced proposal submitted by ClearSign Combustion Corporation to the North Dakota Industrial Commission (NDIC) Lignite Research Program.

We understand that ClearSign's Electrodynamic Combustion Control™ technology is a candidate for testing and validation to enhance the combustion outcomes of lignite coal. We are generally supportive of their application for a Lignite Research Grant, and the EERC is very interested in exploring the viability of ClearSign's technology and any other emerging technology to provide solutions to address NO_x and $PM_{2.5}$ emissions in lignite-fueled power plants. The EERC is interested in testing the technology at the pilot scale should the NDIC determine it merits further evaluation, as the EERC would with any technology.

If you have any questions, please feel free to contact me by phone at (701) 777-5276 or by e-mail at mholmes@undeerc.org.

Sincerely,

Michael J. Holmes
Deputy Associate Director for Research

MJH/mro

Printed on Recycled Paper

March 20, 2014

State of North Dakota
The Industrial Commission
State Capitol
Bismarck, North Dakota, 58505
ATTN: Lignite Research Program

Re: ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies".
Subject: Letter of Support

To Whom It May Concern:

This letter shall serve to express the support of National Rural Electrical Cooperative Association (NRECA) for the application of the above referenced proposal submitted by ClearSign Combustion Corporation to the North Dakota Industrial Commission, Lignite Research Program.

ClearSign's Electrodynamic Combustion Control technology is a candidate for test and validation to enhance the combustion outcomes of lignite coal and as such we support their application for a Lignite Research Grant. NRECA is very interested in exploring the viability of ClearSign technology as a solution to address NOx and PM2.5 remediation in our member's lignite fueled power plants.

NRECA will invest $50,000 US in the effort as well as sending personnel to witness the lignite testing firsthand.

We strongly urge approval of the applicants grant to further improve the combustion outcomes of lignite coal.

Sincerely,

Dale T. Bradshaw

Dale T. Bradshaw

Consultant to NRECA CRN

SaskPower
Powering the future

Asset Management, Generation
2901 Powerhouse Drive
Regina, SK S4N 0A1
Phone: (306) 566-2290
Fax: (306) 566-3348

2014 March 21

State of North Dakota
The Industrial Commission
State Capitol
Bismarck, North Dakota, 58505
ATTN: Lignite Research Program

Re: Support of ClearSign Proposal Entitled "Combustion Enhancement of Solid Fuels Using ClearSign's Technologies".

To Whom It May Concern:

SaskPower is pleased to support the proposal from ClearSign Combustion Corporation to the North Dakota Industrial Commission, Lignite Research Program for Combustion Enhancement of Solid Fuels Using ClearSign's Technologies.

The coal-fired electric generation sector is currently facing a variety of serious challenges. Of particular concern to utilities burning Fort Union lignite is the lack of a suitable technology to meet upcoming regulatory limits for nitrogen oxide (NO_X) emission due to the current incompatibility of selective catalytic reduction (SCR) with combustion of our lignite. ClearSign's Electrodynamic Combustion Control (ECC) technology represents a novel combustion management technology for reducing NO_X emissions by taking advantage of the electrical properties of flames to provide a combustion environment that reduces NO_X formation. Key to ECC's ability to manage combustion is the presence of cations in the flame. The high concentration of sodium in Fort Union lignite should result in high levels of flame cations, compared to other fuels, making ECC particularly suitable for application to lignite.

ClearSign's ECC technology offers other possible benefits resulting from better combustion management. More uniform and stable flames should result in needing less excess air for combustion support. This would result in better plant efficiency and reduced CO_2 emissions intensity. ***SaskPower*** is currently installing a CO_2 capture system at its Boundary Dam Power Station Unit 3 and is considering further retrofits on other units and any reduction in the amount of CO_2 that needs to be captured would enhance the viability of CO_2 capture. ClearSign has also reported evidence of ash agglomeration with their ECC technology. The resulting reduction in fine particulate formation and improved performance of existing particulate capture systems would be of considerable interest to ***SaskPower***.

SaskPower has a very strong interest in supporting the development and commercialization of the ECC technology. ***SaskPower*** is pleased to provide a total of $25,000 in cost-share for the first phase of the technology development, subject to co-funding from the North Dakota Industrial Commission and other project sponsors. Should the proposed work be successful, ***SaskPower*** would consider supporting further pilot tests more representative of lignite power plant combustion conditions and subsequent larger scale testing of the ECC technology at one of its power plants.

Please feel free to contact me if you have questions and require additional information.

Sincerely,

David W. Smith
Manager, Environmental Initiatives
SaskPower

cc. Blake Taylor
Director, Asset Management Generation
SaskPower