

FINAL TECHNICAL REPORT
November 1, 1999, to July 31, 2001

Project Title: **COMBUSTION TESTS ON COAL PREPARATION WASTES
FIRED THROUGH MICROCOMBUSTION UNITS**

ICCI Project Number: 99-1/1.1B-1
Principal Investigator: B. C. Paul, Southern Illinois University, Carbondale
ICCI Project Manager: Ken Ho, ICCI

ABSTRACT

Illinois coal fines waste from the #5 and #6 coal seams in Illinois were taken to a small gasification test facility in British Columbia. The purpose of the tests was to establish that small biomass gasifiers could be converted to run on coal wastes. Such Combustion Coupled Gasifiers (CCGs) can potentially power small power plants for distributive generation, including self generation at mine sites.

The success criteria set forth in the original proposal were (1)-ability to feed damp coal fines into the gasifier, (2)- an even spread of the fuel over the hearth, (3)-steady, even gasification temperatures in the gasifier, (4)-conversion of at least 90% of the fuel energy to heat, and (5)-ash that is removed without pile-up, slagging, or clinkering.

During tests, two fuel feed systems fed damp coal fines into the gasifier. The fines spread evenly across the hearth, although the cone in the fuel bed above the fuel feed point had a higher angle of repose than biomass. The gasifier ran with a steady even temperature. The CCG system converted essentially all the organic mater in the #5 coal waste to heat as specified in the success criteria. The #6 coal sample was not properly collected and was too fine in size and high in clay to allow even airflows needed for the gasifier to function. The ash removal systems had no problems drawing down the ash on either PLC or manual command. There were no slagging or clinkering problems.

Prior to commercial deployment, additional tests are deemed by the P.I. to be advisable. Tests showed that coal gasified more slowly than biomass. Design modifications made by Ethopower should minimize the cost impact of this problem, but most test work on the modified "loaf" design were with the defective #6 coal sample so these modifications cannot be considered fully proven.

The commercial potential of CCG systems using coal wastes will likely be sensitive to the ability to use dry scrubbers instead of wet. This will require additional sulfur removal at other points. Work done on this project with the Falcon Concentrator found 40% sulfur removal on the #5 coal. The gasification tests also showed that the gasifier effectively hosts the reactions known to capture sulfur with alkali metals under reducing conditions. Attempts to follow this finding up with the #6 coal tests were unsuccessful due to the problems with the air flows in the #6 coal bed. A new round of testing is needed to confirm this potential.

EXECUTIVE SUMMARY

The economic promise of this project was that CCG units would allow mines to use waste coal fines to self-generate power at a rate lower than mines could buy it from the grid. The combination of reduced cost for power and reduced waste handling would bring down the cost for producing coal from the Illinois basin. Combustion Coupled Gasifiers (CCGs) have been built by a small number of companies, mostly for use in gasification of wood and biomass. It was suggested for this project that units could be adapted to run on waste coal fines. This project was instituted to see if small biomass gasifiers could be converted to run on waste coal fines.

Several criteria were set as to what would constitute a successful test burn. (1)-“A successful demonstration will achieve a steady feed of coal into the gasification chamber”. (2)-“A successful demonstration will achieve ... an even spread of that fuel across the hearth” . (3)-“The temperature on the gasification hearth will remain even and avoid hot spots that lead to clinker formation”. (4)-“The gasifier will operate at an even steady temperature once initiated and the moisture flow will be controlled and managed to maintain the correct gasification temperatures and thermal efficiency in the 90th and preferably above the 95th percentile”. (5)-“Ash will be successfully removed without pile up, slagging or abrasion in the gasifier chamber”.

Equipment shake-down and refinement tests were run in December, January, April, May, and June. Full-day tests (as specified in the proposal) were run in January, May, and June. An Illinois #5 coal was taken from a preparation plant thickener and cleaned with a screen bowl for use in gasification tests. An Illinois #6 coal was taken directly from belt presses at a coal preparation plant. Tests run on the #5 coal achieved all five success criteria except that the oxidizer on the test unit was mis-sized for coal and could not hold steady temperature on syngas alone. Test runs on the #6 coal failed to achieve the thermal efficiency criteria specified for success because the ultra fine size and high clay content caused air flows to channel through the fuel bed. Sample collection procedures on the #6 coal were defective and probably responsible for the poor results. ICCI site visits were made in December before refinements needed for the successful January test runs were completed, and in June when attempts were being made to get a successful run with the defective #6 coal sample. While an ICCI witnessed test was not a success criteria, having third party technical evaluators witness and participate in one of the successful runs would have been a nice endorsement feature that was not achieved.

Largely through the persuasions of Dr. Ken Ho of ICCI, Ethopower (the commercial vendor for this CCG technology) made a major thrust to develop and optimize their gasifier for use on coal, even though no such commitment was part of the original proposal. Information from the first tests on #5 coal was used as a basis for building an entire new gasifier. The new gasifier design could not be properly tested because the #6 coal sample that was sent up for that purpose proved to be unsuitable for gasification. The principal investigator has recommended that the tests be done on a new #6 coal sample that has been properly collected and had more of the clay removed.

This project has resulted in tremendous strides toward making small modular CCG units run on coal. Effective feed and ash removal systems have been demonstrated along with syngas production. The reaction rate for coal is slower than that for biomass. This is probably a feature of the fuel and not something that can be greatly refined out of the gasifier design. The new gasifier design developed by Ethopower for use on coal can be expanded at moderate additional cost to compensate for this observed problem.

CCG units will likely need to be scrubbed to allow fueling with high sulfur coal. For small sized distributive generation plants these scrubbers will probably need to be dry. Since dry scrubbers generally do not remove as much sulfur as wet processes, additional sulfur control may be needed in some cases. This study found that 40% sulfur removal will often be achievable with the Falcon Concentrator at minimal cost. The gasification tests on the #5 coal also indicated the Eco gasifiers were suitable hosts for the chemical reactions that capture sulfur with alkali metals under reducing conditions. Attempts to carefully measure and document this capture were made with the #6 coal, but the #6 sample was not suitable for gasification and meaningful data could not be collected.

The industrial participants in this project are encouraged by the results of these tests and the experience gained. Working with the defective #6 coal sample did much to identify weaknesses and limitations of the system. This project has met its initial success criteria as listed in the original proposal and the industrial partners will conduct private tests with a properly collected #6 coal sample to confirm that the design improvements made really are commercially ready.

OBJECTIVES

The economic promise of this project was that CCG units would allow mines to use waste coal fines to self generate power at a rate lower than mines could buy it from the grid. The combination of reduced cost for power and reduced waste handling would bring down the cost for producing coal from the Illinois basin. Combustion Coupled Gasifiers (CCGs) have been built by a small number of companies, mostly for use in gasification of wood and biomass. It was suggested for this project that these units could be adapted to run on waste coal fines, and this project was instituted to see if small biomass gasifiers could be converted to run on waste coal fines.

As defined in the original proposal, “the primary objective of this project is to demonstrate that Illinois fine coal refuse can be fed, gasified, and combusted in a Close Coupled Gasification Unit”. In addition to the overall objective there were several associated objectives and criteria for success set. (1)-Environmental data collected from the test would aid in permitting the first unit installed in Illinois. Associated with this emission data objective was that the emission data would include particulate matter, opacity, CO, NO_x and SO₂. The success criteria in this area were that only SO₂ would require any additional control beyond that available in the unit itself. Several criteria were set as to what would constitute a successful test burn. (1)-“A successful demonstration will achieve a steady feed of coal into the gasification chamber”. (2)-“A successful demonstration will achieve ... an even spread of that fuel across the hearth”. (3)-“The temperature on the gasification hearth will remain even and avoid hot spots that lead to clinker formation”. (4)-“The gasifier will operate at an even steady temperature once initiated and the moisture flow will be controlled and managed to maintain the correct gasification temperatures and thermal efficiency in the 90th and preferably above the 95th percentile”. (5)-“Ash will be successfully removed without P.I.e up, slagging or abrasion in the gasifier chamber”.

INTRODUCTION AND BACKGROUND

Most Illinois coal mines spend around \$1 to \$1.50/clean ton of coal on electric power. Companies typically pay around 4.5 to 6.2 cents per kilowatt-hour for that power based on a blended rate. (Coal mines usually pay for electricity with at least a separate energy and demand charge plus other miscellaneous charges and penalties). Calculations originally given with the proposal for this project, and since refined as part of a conceptual design project completed last year, indicate that power can be produced for around 1.7 cents per kilowatt-hour using CCG based microgeneration power plants. Even during capital payback this can provide the 33 to 60 cent per ton savings promised by this concept.

The CCG microgeneration power plant concept is to build small power plants around 10 megawatts in size at a typical Illinois underground coal mine producing around 2 to 2.5 million clean tons of coal each year. The fuel for the power plant would be the waste coal fines from the coal preparation plant. The CCG system would secure the power savings for the coal mine using two major cost differentials. (1)-Power purchases from the grid must be transmitted from the large central power plant to the mine. This cost is typically around 1.5 to 2.5 cents per kilowatt-hour (although utilities currently do not

unbundle and spell the charge out separately and will not until deregulation has been more fully implemented). A CCG based plant would be located near the coal preparation plant and thus already essentially located on the mine site and able to distribute power directly into the mine's internal distribution grid. (2)-Because CCG systems use waste coal they essentially receive "free fuel" (and potentially negative value fuel if one considers the long-term costs that mines will incur in building and permitting new pond impoundments). A typical central coal plant in Illinois spends around 1.2 cents per kilowatt-hour for fuel. If the central plant is gas fired it will be spending around 1.7 to 3.2 cents per kilowatt-hour for fuel at around \$2.5/MBTU gas. (Recent price history has been considerably higher than this and too volatile to allow long range energy planning).

The savings from CCG based microgeneration plants would appear to be considerably greater than claimed. However, two important realities must be recognized. Most utilities are generating much of their base load electricity from older power stations that are mostly "paid off". By contrast the CCG based microgeneration plants will have to be built new at mine sites and will have a capital cost amortization schedule. One may also note that most utilities charge a distribution and customer charge that is around 0.5 cents/KWH for large industrial customers and considerably more to private homeowners. This savings will probably not be realized by coal companies because all power plants have down time and maintenance. The central utility grid appears to have power all the time because, except for break down induced black outs, (which usually come from failures on the distribution lines) the utilities schedule power plants to be down at different times. It takes about 10 interconnected power plants to equal the average availability of the power grid and mines using CCG based microgeneration will only have one. Therefore, mines will remain connected to the grid in order to maintain power during down times on their own stations.

The initials CCG stand for Combustion Coupled Gasification (initials and name are trade marks of Coaltec Energy). The central unit of a CCG based power plant is a gasifier combustor unit. Coal fines typically are not marketed because their fine size makes them hard to handle and because they are difficult to dewater, both of which characteristics cause problems with many mine's coal supply contracts. CCG based power plants avoid these fuel problems because they capture the coal fines at the preparation plant where they would have to be handled anyway to reject them to waste impoundments. A CCG unit does not require the low fuel moisture content of a typical power station because the solid fuel is not burned. A CCG unit has two major chambers. In the first chamber the fuel is heated to high temperature to induce breakdown of the carbon chains into synthetic natural gas. High moisture impacts the flame stability in conventional PC, cyclone, or even FBC burners. High moisture simply gasifies to steam at high temperature in a gasification chamber. In a Combustion Coupled Gasifier (CCG) the synthetic natural gas moves to the second chamber where it is ignited in a low NO_x burner. The evaporated fuel moisture moving with the syn-gas stream simply acts as a NO_x control agent.

A CCG unit discharges high temperature flue gas into a boiler running a steam cycle generation system. This part of the technology has an established performance record at the 10-megawatt scale that is just short of 110 years old in the United States.

One feature beyond the gasifier is new to small steam cycle power plants. Most Illinois coal mines are high sulfur and the fine coal they produce will generate sulfur dioxide gas in the low NO_x burner. Under the current commercialization plan the mine mouth CCG based microgeneration power plants will be non-utility generators. Under the Clean Air Act these plants will have to meet new source performance standards for sulfur dioxide emissions. Test results from this project indicate that SO₂ management will not require expensive wet scrubbers on these units.

Unlike many mine mouth generation concepts, CCG based microgeneration is well balanced to the needs of mine sites. The minus 100 mesh fines fraction (lower limit of spirals performance) which is rejected by almost all current preparation plants not employing flotation is typically about 3 to 5% of the run-off mine tonnage. At about 3% of the tonnage the electric demand of the mine and the energy content of the fines will roughly balance. Thus the CCG based power generation concept is well balanced with its fuel supply at Illinois coal mines.

CCG based microgeneration power plants are also well balanced with the capital cost structure of Illinois coal mines. A coal mine costs roughly \$70 to \$100 per ton of annual capacity to install. If a mine mouth power plant is installed at the mine site it will cost roughly \$500/ton of capacity to convert the mine production to electricity. With most of the very large corporations moving out of the Illinois coal basin in the last ten years, the coal industry is dominated by more aggressive medium sized companies that are probably ill structured to cover their coal mine investments by an investment five to six times the cost of the mine. Vendor quotations were solicited. Data now shows that CCG based microgeneration costs the same per kilowatt of capacity as a large coal-fired station at half the size. This will allow Illinois coal mines to self generate with an investment in the \$11 million range, which is quite reasonably scaled relative to a mine investment (a bit less than a coal preparation plant). When one adds potential offsets of waste impoundments that run several million dollars the balance of this concept seems particularly compelling.

EXPERIMENTAL PROCEDURES

This project differed some from a traditional research project in that its objectives centered on demonstrating the capabilities of an existing commercial machine. The original proposal set several tasks.

“The first project task is to obtain and ship a sample of three tons of fine coal refuse to the combustion consultants test facility. The most likely source of the material will be the Turris Coal Mine, although another mine can be the supplier if one of the other contacts appears to be a more enthusiastic potential buyer for the first plant. Parallel samples will be shipped to SIUC and commercial labs for additional characterization work”.

The second project task is precombustion sample testing. If the Turris feed stock is selected, most of the standard fuel value tests have already been performed. Combustion Consultants will conduct a series of bench scale gasification tests. They already have

computer simulators for gasification results and performance. Data from the bench scale tests and the Waterwide program will include evaluation of test results by simulation.

The third task would be design of grates and an injection system for distributing the coal paste into the gasifier.

Task 4 is construction of the special grate and injector.

Task 5 is installation of the equipment into the test facilities.

Task 6 is combustion testing. Multiple test runs will be done, each taking about 1 day. Their purpose will be to demonstrate equipment performance and deal with anything that did not work as anticipated.

Task 6 will blend into Task 7, which is the addition of sorbant to the grate with the coal. Because the gasification chamber and combustor are directly coupled, this technology does not have places for precombustion gas clean up like an Integrated Gas Combined Cycle power plant. These tests will check such issues as the ability of the ash removal system to handle the material load, any impacts of sorbant on ash fusion characteristics, which might be a problem for the hearth or grates, and of course the degree of SO₂ removal achieved. Ash from both Task 6 and Task 7 tests will be collected and shipped to SIUC for testing. Ash will be collected from augers at the bottom of the gasifier and from the ash removal system in the cyclocombustor. In addition to direct observations of equipment performance, the tests will supply information on energy input and output, gas volumes, NO_x, SO_x, CO and particulate emissions.

Task 8 will be for Combustion Consultants to prepare a report on results of the test.

Task 9 will be to characterize the ash from the combustion test.

During the course of this project, several complications were encountered that necessitated minor changes, but the project as completed includes essentially all the tasks and features in essentially the same form as quoted above from the original proposal. Part of the difficulty came from the fact that this project was highly commercial oriented compared to research orientations, resulting in much more power and control in the hands of commercial vendors rather than P.I.s directly responsible to ICCI. This situation left the P.I.s with much less control than has been found in the traditional ICCI research project.

The first issue to be encountered was the sample size, specified as 3 tons in Task #1. The original estimate from Waterwide Corporation was that 3 tons of coal would be needed. Turriss mine did indeed supply the test coal. The Turriss coal fines circuit discharges directly to a slurry impoundment so the rejected coal fines are never dewatered except by decantation and settling in a pond. The original plan for dealing with this was to bring the coal to the Coal Research Park and dewater it with experimental equipment there. This was quite feasible for a three-ton coal sample, but when the vendor decided he would need 20 tons, moving 10% solids slurry across half a state and then dewatering them in experimental units was out of the question. This forced the first major change. Arrangements were made with Decanter to take a demonstration unit up to the Turriss coal

mine and then run the demonstration unit for a couple of days off a slurry line slip stream to produce the coal. In many ways this change enhanced the information obtained from this project in that the screen bowl proves to be both a coal cleaning (ash rejection) and dewatering device. More information here is presented under Results and Discussion.

The second issue encountered was that Mr. Paul Williams of Waterwide pulled out of the project even after signing his scope of work and compensation. Fortunately Coaltec had been checking on other gasification technologies and had located a competitor who was interested in taking Waterwide's place in the testing program. With the understanding and support of Dr. Ken Ho, (project manager at ICCI) the adjustments were made to the new technology. The technology change had little impact on the scope of work, though obviously it created some delay.

In terms of the first task, the coal for testing was already prepared and the basic proximate and ultimate analysis needed were completed. The coal was shipped to Ethopower's test facility in British Columbia, Canada, rather than Australia. The change has proven rather fortuitous for this project because site visits and more direct communication about the test program was now possible and both the P.I. and ICCI had direct access to observations, rather than simply receiving a report from the vendor at the end of a test program. A joint visit by the P.I., Mr. Mike McGolden of Coaltec, and Dr. Ken Ho (Project Manager, ICCI) was made in December of 2000. The visit was originally made for the purpose of observing a test burn. While observations were made, the test observed was not fully successful. The visit, however, was highly significant to this program. Mr. Mike McGolden of Coaltec persuaded the vendor of the strategic business advantage they could obtain if they were the only small modular wood gasifier to be adapted to use coal. This discussion led Ethopower to a willingness to make a major effort to ready the technology for the task. Following Mr. McGolden's meeting with the Ethopower CEO, Dr. Ken Ho met with the CEO and the head of Ethopower's R+D program. Dr. Ho persuaded them of the need for much greater effort in achieving a commercial ready test burn. Through Dr. Ho's persuasion, Ethopower made a financial commitment to this project that quadrupled the matching industrial support for this project and led to a situation in which about 70 to 80% of the total cost of this program has been covered by private capital. In terms of obtaining maximum leverage for state research dollars, this level of matching support is almost unheard of in the research side of the state coal program. Much of the credit for the depth of the technical commitment Ethopower has made to this project goes to Dr. Ho of ICCI.

Task #2 of this project called for simulating the expected gasification process using software developed by the vendors. This task was done as written. Ethopower has a gasification simulation program they use for simulating the heat and material balances for testing. A sample simulation has been included in the Appendix. Additionally, Coaltec and the P.I. developed heat and materials balance software that examined further how the technology might be used in a scaled up state for a commercial project.

Tasks #3, #4, and #5 deal with design, construction, and installation of the equipment to inject a paste-like coal slurry into the test unit. Ethopower's technicians originally believed that this step could be bypassed. An attempt to use their existing system soon failed. When the proposal was originally written it was anticipated that the pasty texture of partially dewatered coal fines would be the cause of a problem with injectors on

existing equipment systems. When problems were encountered in British Columbia, it was because coal was so much denser than biomass that the weight stalled the drive system. It was indeed necessary to redesign, build, and install a new drive system on the machine. Distribution of the paste in the machine proved not to be a problem because in the Eco gasifier the paste simply cascades over a cone into the machine's burnout zone for completion of gasification. Waterwide would have required it to spread across a moving cascade grate that would carry it down at an angle slightly less than the natural angle of repose. The adjustment on the Eco gasifier to inject coal was far less than would have been the case on the Waterwide.

Following the initial solution to the coal injection problem, another problem arose. The Eco class gasifier used an electric eye to measure the height of fuel bed in the gasifier. Coal, however, begins to form tars as it gasifies and these tars can result in some agglomeration of the fuel. In the Eco gasification tests the binding action of the tars appeared to be responsible for a significant increase in the angle of repose for the material and a fuel bed that came to a much higher point than a biomass fuel. This property caused errors in the software logic of the Eco's programmable logic controller (PLC). The PLC procedure measured the height of the fuel bed at the center. When the fuel gasified, the pile height was supposed to fall allowing the beam of the electric eye to complete over the top of the pile and sending a message to the augers to introduce another batch of fuel. The steep angle of repose allowed the fuel to gasify down without triggering a feed command, resulting in low throughput and toward the end of a cycle an increasing degree of combustion in the primary chamber. The immediate fix for the PLC problem was to observe reaction times and rates and then set ash pulling and fuel feed to timed intervals. This reprogramming allowed the Eco class gasifier to meet the success criteria for injection of fuel, but by this point Ethopower was already building a next generation gasifier to incorporate what they had learned about coal gasification in the first experiments.

Tasks #6 and #7 involve doing actual fuel test burns. Completion of Tasks #3, #4, and #5 provided for success in the first two objective areas set forth in the original proposal in that the coal was steadily fed into the unit and distributed across the gasification hearth. The third, fourth, and fifth success criteria stated in the original proposal call for the tests in Tasks #6 and #7 to maintain an even temperature on the gasification hearth so as to avoid hot spots that lead to clinker formation, maintain correct gasification temperatures and achieve a 90 to 95% thermal efficiency in the unit and successfully remove the ash from the gasifier chamber.

The task description for Tasks #6 and #7 in the proposal also calls for attempts to control SO₂ emissions with sorbants. In this respect the test work that was completed deviated slightly from the original proposal, for the most part providing considerably more work and investigation than was originally promised. After approval of the proposal and before Mr. Paul Williams of Waterwide withdrew from the project, Mr. Williams indicated that he had done further investigation and determined that it was impossible to capture sulfur under reducing conditions that would be present in a gasification chamber. To compensate for this determination, the P.I. and Coaltec Energy set out to investigate fuel preparation techniques as a companionway to control sulfur. The importance of sulfur control is discussed further under Results and Discussion. The original three tons of slurry fuel that had been collected for dewatering and combustion tests was diverted to

sulfur control tests. Experiments were done with the Falcon Concentrator as a sulfur removal device and with hydrocyclones as dewatering and sliming devices. Most of the results and discussion of these experiments is found in previous midyear reports and will not be repeated here.

Tests conducted on the original Eco design in British Columbia achieved the success criteria set forth in the original project proposal in that a one-day test was run in which even gasification temperatures were maintained, the ash was removed without incident, the thermal efficiency goal was met, there was no clinker formation, the coal fed and distributed on command of the PLC and the promised emission measurements were collected by a third party. This was unfortunately not a test witnessed by one of the ICCI visits, although an independent third party lab took many of the measurements and logs. Material and data from this test is included in the appendix of this report. Ethopower also provided a report on this test work as required by Task #8 of the proposal.

The work actually done under Tasks #6 and #7 was far more extensive than was promised in the original proposal. Much of the extra work done in this area came as result of the recommendation of Dr. Ken Ho during his December visit. One of the most dramatic results of Dr. Ho's work was that Ethopower decided to build an entire new gasifier that would be more optimally designed to use coal.

Key reasons for building a new gasifier were that the PLC feed sequence on the old unit was based on timing and the research team at BC felt that true condition based PLC control was achievable and because the reaction rate for coal in the gasifier continued to lag behind the throughput and reaction rate achieved with biomass. More on why these factors were viewed as important can be found under Results and Discussion.

The decision to run a more extensive series of tests and to redesign the entire gasifier to run optimally with coal resulted in much more coal consumption than planned. The result was that the original 20 tons of coal was entirely consumed by the shake down and initial test runs on the new gasifier. Completion of the testing program on the new gasifier would require additional coal. Dr. Ho and ICCI personnel were very supportive and made arrangements for limited additional funding to get additional coal samples for the work. The additional money from the state was also matched by additional private funding.

The second coal sample, which was another 20 tons, proved to be much less than satisfactory (more detail under Results and Discussion). This resulted in part from decisions made by the P.I. in selection of the second sample and in part from poor sample collection procedures. The first coal sample was an ultra high sulfur coal (12.5 lb SO₂/MMBTU) from the Turriss Mine coal refuse (Turriss main stream coal product is not nearly so high in sulfur) from the Illinois #5 coal seam. The second coal sample came from Black Beauty's Riola Mine. The rationale for the selection was that the Riola mine had made a commitment to pursue installation of a commercial scale CCG based power plant, but wanted to be able to remove all the fine refuse from the combination dumps. The Riola mine seemed like an ideal sample. Since ICCI was investing additional money it seemed desirable to obtain additional information beyond simply running the same coal in the new machine. (The new machine had already been shaken down and tested successfully with the Turriss coal). Turriss coal was an Illinois #5. Riola was an Illinois

#6. By choosing Riola the project would have test results with the two major coal seams in the state. Riola used belt presses to dewater their fines. Screen bowls and belt presses are the two most popular dewatering devices for fine coal. Since the earlier sample was prepared with a screen bowl, choosing Riola would provide coal prepared by the two most popular dewatering methods. The Turriss coal was very high in sulfur. Riola was a mid sulfur (a little under 3 lb) coal. Choosing Riola would provide data on the sulfur behavior for both high and lower sulfur coal. Prior to making the selection of the Riola sample, a five-gallon sample was taken off the thickener while the plant was running. A size-by-size analysis was then done on the fines to make sure that the type of material was well characterized. The size consist was similar to Turriss with a slightly lower clay content than the Turriss coal before the use of the screen bowl. While the rationale for choosing to use the Riola coal was defensible, the Riola coal sample that was sent proved entirely unsatisfactory for the Eco class gasifiers and resulted in poor performance in the second round of testing.

Part of the unsuitability of the Riola sample was the result of poor collection procedures. As mentioned before, Riola uses “dry” combination dumps for their coal refuse. The coarse coal refuse and the belt press fines are both moved out of the plant on a single conveyor belt. To segregate a small sample directly off the belt presses inside the plant is easily done (and in fact was done to obtain the characterization sample), but in this case 20 tons of material were needed so the belt out of the plant would be needed (reconfiguring the conveyors in the plant on a limited budget was of course out of the question even if the mine could handle the operational disruption). The only practical way to get a fines only sample off the belt was to collect it when the rest of the plant was not running. Since the thickener must have time to settle and since the plant was already being shut down for new equipment installation under an IDCCA grant, getting a fines only sample would be easy. The communication within Black Beauty’s corporate structure was not complete enough. The sample was collected under the direction of Ezra Smith who is Black Beauty’s lead preparation plant man, and a man of impeccable credentials in the coal-cleaning field. The mine people understood that they needed to get a big sample of coal fines when the preparation plant went down and the belt was free to use on fines only. The mine people did not understand thickener-settling sequences and didn’t understand that coarser coal settles first and fine clays last. They told Mr Smith only that we needed a very large fines sample and did not understand enough to express the urgency of timing. Mr. Smith was not told about the work or the need for representative samples, only the need for a large fine coal sample off the thickener. Since the plant was being brought down for new equipment installation, primary attention was on new equipment installation and getting the plant back on line. After not quite three days, they found a break to pull the sample off the thickener. The problem was that by this time only ultra-fines and clay were left to settle. Since the additives to the thickener were not adjusted, the material dewatered poorly in the belt presses and a 20-ton tank of black soup was loaded and bolted down for shipment. The “coal sample” had little permeability to air and was about 62% incombustible on a dry basis. In retrospect, it was a mistake by the P.I. not to have the container opened and sampled with a Shelby tube with analysis before shipment. This action would have caused delays in the testing and visit schedule for the project, especially when the results came back showing that the container sample was not even similar to the characterization sample. Resampling would have put the project at least one month behind schedule and would have triggered an extension request.

Upon arrival in Canada, excess water was decanted from the sample and testing began. Another visit to witness tests was made in June but the tests observed were quite poor. Ash samples were collected under Task #9, but the ash samples on initial testing showed that reaction was incomplete and the samples did not represent the almost carbon free ash product that was found with the Turris coal tests. As a result of the unrepresentative nature of the samples, only limited testing was performed. The ash testing work that was done included loss on ignition and very detailed sulfur forms analysis. The loss on ignition tests indicated that only about one-third of the available carbon had reacted compared to the Turris coal which had less than 0.5% loss on ignition in its ash. With such an unrepresentative organic to inorganic ratio and so much unreacted material, obtaining meaningful leach tests or concrete tests would be impossible.

RESULTS AND DISCUSSION

Criteria for Evaluation of Success

The main purpose of the test program in this proposal was to demonstrate that a small modular wood gasifier could be operated with a coal refuse fuel. The chemistry of coal gasification has been known for over a century and is relatively simple. In principle, coal heated to high temperature in an oxygen-starved environment can be expected to gasify. Obtaining a machine that can host the reactions is much more problematic.

Most problems with coal gasification involve feeding material in, removing ash, controlling reducing conditions, and controlling temperature. This test program set some specific targets and criteria for determination of success. (1)-“A successful demonstration will achieve a steady feed of coal into the gasification chamber”. (2)-“A successful demonstration will achieve...an even spread of that fuel across the hearth”. (3)-“The temperature on the gasification hearth will remain even and avoid hot spots that lead to clinker formation”. (4)-“The gasifier will operate at an even steady temperature once initiated and the moisture flow will be controlled and managed to maintain the correct gasification temperatures and thermal efficiency in the 90th and preferably above the 95th percentile”. (5)-“Ash will be successfully removed without pile up, slagging or abrasion in the gasifier chamber”.

The test program that was actually carried out was far more extensive than originally promised. It involved testing with two different coals on two different but related gasifier designs. Data collected during testing do show that coal fines were fed into the unit, heated to high temperature under a reducing atmosphere and that a syn-gas stream of carbon monoxide, hydrogen, and diluent gases was in fact produced. The fact that the right chemistry did occur does not of itself prove that the Eco class gasifiers can be used for small-scale power and heat generation using waste coal fines. This report will examine the success criteria set forth in the original proposal in assessing what was and was not accomplished in the test program.

Injection and Distribution of Fuel on the Hearth

The first two success criteria deal with the unique size and texture problems of pasty damp coal fines and the problem that the fuel may not properly distribute once introduced into the gasification chamber. The initial Eco class gasifier is igloo shaped as shown in Figure 1 in the Appendix. The feed into the unit is accomplished using a screw auger. The second Eco class gasifier is termed a “loaf” design after its similarity to a loaf of bread (Figure 2 in the Appendix). The feed system on this gasifier uses a hydraulic ram to force the coal up into the gasification chamber. Upon entering the gasification chamber the fuel comes up into a cone with air injected into the cone from bottom to top. The coal is lifted through the cone by the force of fresh coal coming up into the unit beneath it. The coal will eventually mound up and overflow the cone. The partially reacted fuel bed cascades out in a thick layer over the top of an ash grate. Additional air is introduced just into this bed over the grate. This area acts as a “burn out zone” to complete the reaction. As the carbon reacts out only ash remains in the burn out zone and then opening the grates allows the ash to settle downward until it is drawn out of the unit.

In both the igloo and loaf arrangements the coal feed is in a batch rather than a continuous process. The auger or ram must be able to start on demand and force a pasty, abrasive, heavy material up against the entire bed above it in order to feed successfully. The feed needs to spread out against the cone once in the gasifier.

Only on the first attempts to run the igloo configuration gasifier were there feed problems. As mentioned in Experimental Procedures above, the coal was so much heavier than biomass that the screw auger stalled out. Replacing the hydraulic drive with a chain drive solved that problem and the loaf design’s ram feeders never had any problem pushing coal into the unit on demand. However, when a feed of mostly wet clay was pushed into the unit, the clay packed and rolled into balls similar to what is observed with damp fire clay content with coal on screening decks at coal preparation plants. The tendency of very damp clay to clump proved problematic in the initial runs of the Riola coal in the new loaf gasifier. The clay balls encompassed coal fines and were impermeable to air leaving an un-reacted center. The high temperature baked the clay balls into bricks. Most were small enough to fall through the ash grates, but some would not. Had the runs been longer than about a day (the time period specified in the original proposal) one could speculate that enough large bricks might be formed to stop ash removal and force the unit to shut down. It should be emphasized that the clay bricks formed in these runs were not clinkers and were somewhat friable. On noting the balling tendency, Riola coal was laid out on a pad about a foot or two thick and allowed to air dry. A term of just over one week of air-drying eliminated the problem of clay balling up.

Based on the results of many test runs it appears that the coal introduction systems on the Eco class gasifiers do work for coal fines. When the PLC control units sent the command to initiate and push feed into the gasifier, the screw auger and ram type feeders both responded without difficulty. A limitation needs to be made for very high wet clay content (62%) which promotes balling in the ram feeders and makes incombustible bricks. The defective Riola sample was never tested in the igloo design gasifier, but it is known from other materials handling operations around coal preparation and mineral processing plants that clay will generally roll into balls in screw augers so one would logically suspect that the Igloo design gasifier would have had a problem had it been tested.

The second criterion for success in the original proposal was that the fuel would distribute properly across the hearth. There is no way to directly observe whether the coal immediately spreads out against the edges of the cone when entering. However, the air is injected into the gasifier chamber by a blowing system. Airflow measurements provide an indication of quantity, and amperage measurements from the blower motors provide an indication of backpressure on the system. For coal compared to biomass the amperage drawn by the fans was distinctly higher for the same quantity of air. If the material did not spread out against the cone, short circuit paths would be expected to open up giving lower amperage with preferred air channels. This was not observed. One observation that does suggest air channeling came during the second ICCI site visit when the defective Riola coal sample was being run by less experienced operators. When the ash grates were opened a cloud of coal ash blew out, indicating a preferred path for air flow that led down to the ash grate rather up through the bed according to design. The gasifier is supposed to run under a slight vacuum and when the stack damper was adjusted for more draw the problem disappeared. Since a very slight draw at the top of the fuel bed was all that was required to direct the air flow up through the bed it is unlikely that there was a lot of empty space at the bottom of the cone.

The gasifier has port windows in it allowing the observer to see the reacting fuel in the gasifier. By visual observation the fuel at the top of the bed has spread out and distributed itself evenly across the chamber. By comparison to a biomass fuel, the angle of repose for coal is considerably steeper and coal has a higher point. Samples from inside the gasifier bed during gasification could not be taken so the reason for the higher angle of repose cannot be given conclusively. It is offered as a hypothesis that the coal is coming to a higher angle of repose because of agglomeration by tars. The apparent texture from visual observation through the port window would support this theory. On gasification coal frequently begins to form long chain hydrocarbon tars. Tars and agglomeration is one of the mechanisms believed to be involved in formation of clinkers. Avoiding clinker formation in gasification is important because clinkers generally draw poorly through ash grates and accumulate until the gasifier must be shut down and a manual clean out performed to clear the clinker build-up. From an economic and practical operation standpoint clinkers can be a fatal flaw in a gasifier.

Despite indications that the gasifier did form tars and agglomerate coal fines, no clinkers were ever found. There was no difficulty in ash coming down when the bed grates were opened, and no residual clinkers found during clean out when the gasifier was being readied to run a different fuel. Again, enough sampling inside the gasifier to say why clinkers do not form is not available. Two hypotheses are offered for the missing clinkers. Both of the fuels tested were high ash. The Turris coal sample was 35% dry basis ash and the Riola sample was 62% dry basis ash. This is far more ash laden material than is typically fired through any of the large conventional fixed bed coal gasifiers (Lurgi for example). Dirt does not form agglomerating tars and a high "dirt" content spreads the tar product thinner, perhaps leaving too little tar to form a clinker. Another hypothesis has to do with oxidation. Note that the gasifier design introduces air at the bottom of the cone so that almost immediately on introduction into the hot gasification chamber the fuel is hit with oxygen bearing air. These are fine coal particles with reactive surfaces. Even though the air stoichiometry is reducing there should still be enough oxygen present to oxidize particle surfaces. Surface oxidation of coal is

significant in clinker formation because tars and particle melting normally will not fuse oxidized surfaces together. The clinker issue is further discussed during a review of the ash removal systems.

The tars and angle of repose did have the effect of failing the logic used to program the PLC interface to the machine. The electric eye in the igloo configuration was to measure across the top of the bed and when the bed level had dropped enough the signal to the PLC unit was to trigger the command for the screw augers to turn on and push more fuel into the gasifier. The high angle of repose allowed the fuel to pretty well burn out without triggering more feed. A timed fuel addition sequence was programmed into the PLC instead of the electric eye response. This result led to the use of an adjustable and more penetrating gamma source for measuring bed height in the loaf gasifier configuration. While the gamma source appeared to work well enough during shake-down tests with the Turriss coal, when the Riola coal was substituted the PLC logic again failed, this time apparently because the ash content was so high that the fuel bed level did not change enough to trigger the sequence. It is now known that the problem was far worse than just the 62% ash. The Riola coal sample of mostly ultrafines and clays was largely impermeable to air flows. Of the 38% of the coal that was reactive two-thirds never converted to syn-gas. Obviously there was almost no change in bed height under these conditions. The PLC sequence was converted back to timed fuel addition and ash extraction.

While saying the PLC was programmed to add fuel at timed intervals does not mean that the fuel addition system did not work, it does mean that the unit cannot dynamically adapt to add fuel at the optimal interval in response to changes in ash content or reactivity of the fuel. This would appear to be one area in need of improvement in a commercial system.

Steady Even Temperatures

The gasification unit was to maintain a steady even temperature. Temperature is measured in the gasification unit at two key points, above the fuel bed in the syn-gas, and in the “burn out” zone of the fuel bed just above the ash grates. In test work done on both the igloo and loaf designs the temperature above the bed would be consistent with gasification. With the Turriss tests done in January, the temperature over the bed was in gasification ranges and around 50 degrees higher than is typical for biomass. The temperature in the “burn out” zone dropped to below 300 just slightly above the ash grates suggesting that reaction was fairly complete. With the Riola coal the temperature in the gasification temperature was higher than the Turriss tests. Based on measurements that were available and discussions with the operator, it is the P.I.’s interpretation that this reflects the air channeling through the coal bed and pushing reactions closer to complete oxidation than would be desirable for maximum syn-gas production. The Riola coal also had very high temperatures at the bottom of the burnout zone (600° F) suggesting that the coal had not been well converted and that reactions were still going on. Despite the less than optimal performance on the Riola coal, most of the gasifier runs did maintain gasification temperatures and reducing conditions through most test runs. Sampling done by third party testers (Lan Franco) as well as with internal detectors and simple observation did show that the temperatures established under reducing conditions did promote gasification.

One failing observed on the test unit was with the oxidation unit. The test unit in BC utilizes a natural gas igniter to initiate the syn-gas burn and to bring the unit to temperature so that syn-gas combustion will be automatic. (The oxidizer is heavily lined with refractory that adsorbs considerable heat from a cold start-up. As a test unit the equipment is constantly shut down and cold-started). The natural gas igniter also performs a permit function of the BC test unit in that it guarantees a complete burn of any gasification products prior to atmospheric release. Since the test unit is used on such a wide variety of fuels under experimental conditions, the BC regulators were probably wise in requiring it. Several aspects of the igniter system design and of the oxidizer itself appeared quite unsatisfactory for the test work done on coal. The igniter was effective in initiating a syn-gas burn and of bringing the refractory up to temperature. The damper design on the igniter was, in the P.I.'s opinion, defective. The dampers could not be shut completely which meant that during a "stable" run air was being drawn through the igniter in an uncontrolled fashion. This allowed large amounts of dilution air to be added in unmeasured, undocumented, and uncontrolled fashion. While the Turriss coal tests did show highly acceptable NO_x emissions, the oxidizer could not possibly have reached its full potential. The oxidizer is supposed to add air in stages assuring that hot spots with an oversupply of oxygen never develop. (The condition causes NO_x formation). One cannot add air in uncontrolled fashion to the entrance of the oxidizer and achieve such a condition.

Another problem with the uncontrolled air addition through the igniter was oxidizer temperature. The oxidizer ran at around 1800° F. Heat and material balances done by the P.I. on use of the CCG unit in small power plants suggests that running below heavy NO_x production temperatures and below the refractory limits will promote more efficient systems. The oxidizer temperatures in these tests, therefore, do not represent the most likely operating conditions for a commercial operation. Of course the low temperatures also potentially distort the NO_x formation measurements on the unit. This is probably the most serious weakness of the air emission measurements taken during these tests.

The lower than commercial scale operating temperature of the oxidizer was also the result of syn-gas production lower than the oxidizer was designed for. The oxidizer on the test unit was designed to accommodate syn-gas production from waste plastic, which is about a 21,000 BTU/lb fuel. No other common byproduct fuel reaches these production potentials and the test unit oxidizer runs below temperature on biomass as well as coal (typical biomass feedstocks have only about 25% of the BTU content for which the oxidizer was designed). Coal potentially has a higher energy content than most biomasses. However, based on samples collected at Turriss, Riola, and a few other mines that may serve as host sites for commercial CCG power plant operations, the waste coal fines that will most likely be used will probably be in the 5,000 to 6,000 BTU/lb range as delivered. Thus for commercial applications coal will probably not put out more syn-gas than biomass. In all likelihood coal will put out lower syn-gas volumes. Measurements of reaction rates taken on tests with the Turriss coal in January and again in April all indicate that the coal matrix breaks down more slowly than biomass. Thus the BC test unit oxidizer was especially mis-sized for good results with coal.

While the gasifier was on many occasions run to the steady temperature requirements listed for success in the original proposal, none of the test data indicates that the oxidizer

was ever run at a steady even temperature on syn-gas alone for a day long run. With the size of the oxidizer, coals slower break-down to syn-gas, and the air leakage problem through the igniter it would not be theoretically possible to do a day long run with syn-gas only on that particular test unit. Ethopower did get emissions test data with syn-gas only, but natural gas additions were needed regularly to hold the oxidizer temperature. On a commercial unit these defects would be easily corrected. Simply size the oxidizer for coal waste instead of plastic. Use reaction rate data from these tests reflecting coal's slower reaction, and put dampers on the igniter that can be closed tight enough to seal out most uncontrolled air leakage.

Thermal Efficiency

This proposal set as a target a 90 to 95% efficiency in recovery of heat energy from the fuel. These success criteria of itself may sound peculiar for a gasifier since most students of gasification are more interested in efficiencies relative to the amount of syn-gas produced. A CCG unit is, however, a Combustion Coupled Gasifier. The CCG unit is unlike large design gasifiers, which convert a solid fuel to a syn-gas that is then sent to a gas clean-up process. In large gasifiers, the syn-gas is then usually sent to some chemical process, gas supply line or to a turbine. In these large gasifier applications it is indeed the syn-gas generated from the fuel that is a primary concern. Keeping a concentrated syn-gas stream is one of the reasons that most large coal gasifiers use air separation plants to provide a pure oxygen feed free of diluent nitrogen.

CCG units by contrast move the syn-gas directly into a burn chamber without any gas clean up. Thus the gasifier in a CCG unit is part of a staged combustion process, rather than chemical synthesis process. The output of a CCG unit is heat. The proposed commercialization objectives on which this project was justified use heat output for power generation or industrial applications. Had the Waterwide unit actually been used for the testing there is no potential to recover syn-gas ahead of the cycloburner at all. Indeed Waterwide initiates the syn-gas burn at the top of the gasification chamber to drive the hot gas plume through the cycloburner. With the Eco class gasifiers the combustion phase can be separated if a syn-gas chemical stream is needed and in such an application cold gas efficiencies would indeed be critical, but in the applications for which the CCG was proposed it is acting as a heat output unit and thermal efficiency measurements are the appropriate measure.

Even for heat output purposes gasification in a staged combustor can be an important advantage in environmental cleanliness and fuel tolerance. The Eco class CCG system achieves its highest burn temperatures in an oxidizer where air is added in stages to burn a moist gas stream. Gas reburns are often used to make conventional combustors have cleaner emissions. The syn-gas burn is both a source of additional heat and a source of emissions clean up for the primary chamber, which runs under reducing conditions. Adding most of the oxygen downstream of the gasification chamber where the fuel is removes flame stability as a primary issue just so long as there is enough heat to sustain the gasification reactions. It also limits turbulence around the ash and fine coal reducing particulate carry-over. The important point to be understood about a CCG unit is that whereas a large gasifier must output as much syn-gas as possible from the gasification chamber, a CCG unit can allow partial oxidation and reaction in the gasification chamber and still have the unit function as a very clean burning heat production unit.

Radiant heat losses around the unit were minimal. The test unit was not coupled to a boiler so direct steam raising measurements were not available. One effective way to measure the fuel conversion efficiency for this case is to look at the amount of un-reacted carbon in the ash (LOI). A high LOI would indicate that a large amount of the carbon in the fuel remained un-converted, which would mean that the heat production efficiency was poor regardless of how low the radiant losses from the unit were. A low LOI would indicate that most of the carbon has been converted out of the fuel.

The Turriss coal was tested mostly on the igloo design gasifier. Emissions testing and ash sampling were both done in January of 2001. The ash samples from the test ran less than 0.5% LOI. This number represents a particularly resounding success when one considers that 3% LOI is considered a very good fly ash from a convention power plant combustor and the LOI in the bottom ash is usually much higher than that. Small conventional combustors used in power plants are often well over 12% LOI.

The LOI results from the January tests were at first subject to suspicion. Ethopower collects their ash samples in an open pan. With direct oxygen contact possible, the warm, or hot ash could easily continue reacting and reducing carbon content. During the second site visit in June of 2001, Dr. Ken Ho devised a sampling procedure that collected ash under a nitrogen blanket and then sealed the container. This procedure would naturally stop reaction of the ash. In order to determine whether the earlier samples from the Turriss coal could be trusted, sampling on the Riola coal ash was also collected without nitrogen blanketing and the container was not sealed tight. The nitrogen blanket samples and the open-air samples were collected immediately after each other. Each sample took about 3 to 5 minutes to take so the samples were separated in time by about 5 minutes. Both samples were taken from the same ash dump sequence. Ash samples were taken at several points during the June test burn. The LOIs on the samples collected under the open air and nitrogen blanket conditions were the same to a small fraction of a percent. The nitrogen blanket sample actually had a slightly lower LOI, but this is almost certainly due to just random deviations in the test method or homogeneity of the ash and does not represent any post sampling reactions. In the June test the thermocouples at the bottom of the ash bed read 600° C, while for the Turriss coal tests in January the read was around 200. Although the ash coming out of the sample port during the June test with the Riola coal was definitely not 600° C (the bottles were quite warm to the touch and ash fell on one worker's bare hand during sampling without burning his skin) the ash from the Turriss tests would be expected to have been even cooler and less reactive than the Riola test burn in June. These results suggest that the LOI levels measured for the Turriss coal during the January test runs are probably reasonably accurate. The fact that the thermocouple readings on the Turriss coal test were declining at the bottom of the ash bed also suggest that the reaction was fairly complete and that the ash was cooling even while still in the gasifier.

While the Turriss coal achieved the success criteria for heat output from the fuel, the ash samples from the Riola coal indicate that the tests on this coal were not successful. In fact the LOI levels in the ash show that only about one-third of the organic content of Riola coal ever reacted in the gasifier. The high temperatures at the bottom of the "burn out" zone of the gasifier suggest that reactions were incomplete. During the June test witnessed by Dr. Ho of ICCI, when the less trained operators ran the unit with the wrong

stack damper settings and the air short circuited and blew clouds of ash out the bottom when the grates were opened, some of the ash particles that flew out were still on fire. All these observations support the conclusion that the loaf gasifier did not properly convert the Riola coal and that in terms of the thermal conversion criteria the Riola coal test failed.

Differences between the Turriss and Riola Coal Samples

Given that one coal gasification test was fully successful in converting carbon, and the next coal test failed, it naturally follows to try to determine why the second coal. The gasifiers that ran the two tests had slightly different shapes but were essentially the same machine. Although the first runs of Turriss coal on the loaf design were not sampled and tested for air emissions and ash, all read outs and other behaviors suggest that the Turriss coal ran well on the new machine and would have yielded a successful gasification test for the June 2001 ICCI visit had the original sample been 40 tons and not 20. These characteristics point to the coal itself as being different. While there are some differences between an Illinois #5 and an Illinois #6 coal, tests with these two coals on other large gasifier systems have not been known to yield such widely differing results. It is the P.I.'s submittal that the Turriss coal gasified well because it was mostly 100 X 400 mesh in size with a moderate clay content and the Riola coal gasified poorly because it was mostly ultra-fines with a high clay content. The samples of the coal taken during the screen bowl runs at Turriss suggest that the Turriss feed had approximately the same size consist. The ash content of the Turriss coal was about 35%. The bulk ash content of the Turriss thickener is about 52% ash. Clearly the screen bowl rejected considerable ash with the water. The d50 of the screen bowl cut appeared to be slightly finer than 400 mesh. Given the size of typical clays, this suggests that most of the ash material rejected was clay. The screen bowl "deslimed" while it dewatered.

By contrast, the steady state samples taken from the thickener at Riola showed about 49% ash. The "coal" used in the second round of testing in this project turned out to have 62% ash. The size by size analysis of the Riola fines show that the only way to have obtained such a high ash content would be to draw most of the sample from the minus 500 mesh fraction. When one adds the fact that the plant was shut down and the thickener run for nearly three days before the coal sample for the second round of tests was collected one knows that only fines and clays would have been left. The sample dewatered poorly with normal thickener reagent dosages, which further points the fact that the ash was mostly clay. The balling up behavior on the hydraulic rams also shows that the material is very high in clay. While some size by size work could be done with the coal samples collected, these samples have been dried and agglomerated particles formed. Mortar and pestle grinding could be done to break the agglomerates and then the sample could be re-slurried in a slightly alkaline water to re-disperse the clays, but the process would be suspect for altering the size consist of the sample.

The size consist of the two samples is likely the source of the problems with the Eco class gasifier on Riola coal. The Eco class gasifier is a fixed bed design, in some ways resembling the Lurgi gasifier only at a much smaller scale. Reducing condition fixed bed-firing arrangements is also used in blast furnaces. All these well established fixed bed gasification technologies place strict limits on the fines content of the fuel because the fines reduce the flow of air slowing reactions, and more importantly what air does

enter will channel resulting in poor reaction. For the British Gas Lurgi gasifier, fines are defined as anything minus 0.25 inch in size with an upper limit in experimentation of about 30 to 40% fines. Dr. Crelling of the Department of Geology at SIUC has done work on blast furnace applications with similar limits.

Of course the Eco gasifiers are much smaller than either a blast furnace or a Lurgi gasifier. Neither of these larger commercial gasifiers would have been able to run on the Turriss coal fines, but the January 2001 tests with the Turriss coal meet the success criteria set up in the original proposal for this project. Test work done on the Turriss coal with both the igloo and loaf designs of the Eco gasifier did show noticeably increased backpressure on the blower systems compared to similar charges of biomass. There were concerns in operation of the gasifiers that as airflow was increased the air flows would eventually break-down into channeling paths causing reaction rates to plummet and completeness of reactions to fail. This did not happen within any of the setting ranges used on either the igloo or loaf gasifier designs.

The Riola coal was tested only on the loaf design gasifier. Data and observations show that airflows did break down into preferred channels with this coal. The most persuasive result is the high LOI levels in the ash showing that only one-third of the organic material reacted. The Riola coal had a low energy output compared to the Turriss and although some of the result would be anticipated due to the higher ash content, this cannot explain it all. During Dr. Ho's second visit, an inexperienced crew ran the gasifier. While this is not a desirable situation for a good successful demonstration it is a good way to see operating condition extremes that some might advocate as answers but an experience operator would never do. When attempts were made to increase the airflows, the air short-circuited and blew through the ash grates when they were opened (The P.I. and Dr. Ho were both ash coated during one attempt to take an ash sample). The question of whether the unit could have obtained a more complete reaction if more residence time was allowed was answered because of another operator error. The machine's ash hopper was not emptied out when the machine converted to coal. The result was that the hopper soon became full and had to be emptied. The problem was not realized until the time to add additional coal. The coal feed was stopped and all manpower shifted to the ash hopper problem. A debate about whether removing a non-airtight hopper from the end of an auger would cause air to move into the gasifier through the grates followed. People then scattered to try to find insulation to stuff in the augers when the bin was pulled away. When the "circus" was over the gasifier had been starved for feed for between 45 minutes and an hour. At this point attempts were made to measure the syn-gas formation in the gasifier. The tests showed oxygen concentrations in the teens with carbon dioxide and very little CO. The implication is that when the residence time was increased the air continued to follow its preferred courses, depleted the most easily released carbon around those channels and converted to combustion rather than gasification. The incident gives cause to believe that poor carbon conversion is not a residence time problem.

Ash Removal

Many gasifier designs fail because of problems in the ash removal system. The Eco class gasifiers remove ash by mechanically lining up two plates with large holes cut out. The ash falls through the holes and into a screw auger that removes it to a bin. There were several issues with how this system might fail on coal. Coal and its ash can be highly

abrasive and interlocking. In none of the tests was there any tendency for the ash to interlock and jam. The only problem encountered in operation of the augers was that the early loaf design stopped the auger before the ash was conveyed all the way to the ash hopper. This was done to create a plug of ash that would prevent air from short circuiting back into the gasifier. Although the ash plug did not interfere with testing, it was a problem with final clean out after the testing and the auger was extended all the way to the hopper. It seems rather unlikely that opening the ash grates will disrupt the reducing atmosphere in the gasifier anyway. There is significant backpressure on the fans that force air into the fuel bed pile in a distributed fashion from the bottom of the cone to the top. For air to enter through the grates it would have to move back through the ash-flooded auger and then through the entire ash bed from the bottom. The only motive force available to induce such an airflow is a slight draft induced vacuum above the fuel bed.

Another concern might be that coal ash would have a very high angle of repose that would cause “rat holes” through the bed in the burnout zone. “Rat holes” never appeared in coal testing or the ash of any other fuel. It is, however, quite likely that there were somewhat dead zones of burned out ash that did not move evenly down into the ash removal system. This is inferred from the clean-out sequence after the testing because there are areas around the edge of the unit where the ash does not drop out simply by opening the grates and activating the augers. These areas require operators to push the ash into the augers.

Faced with evidence that there are extraction dead zones in the ash bed of the gasifier, one must ask about impact. Because the ash grates in the Eco gasifier are thick, the ash bed acts as an insulating layer that protects the plates from warpage. In operation ash rapidly builds up an ash layer for this protection. None of the materials tested on the Eco gasifiers, including coal, showed any signs that preferred flow paths for material through the burn-out zone caused either a build up of material in the gasifier during longer operating runs or caused the burn out zone not to function in consuming organic material out of the fuel.

Another concern with the use of coal refuse in the Eco gasifiers was the much higher ash content. The Eco class gasifiers were built for biomass with up to 5% ash. The Turriz coal was 35% ash and the Riola coal was 62%. There were thoughts that the volume of ash would either overwhelm the removal system, or fill up the gasifier with so many inert that it would not work well. Even for the Riola coal where all the ash and two-thirds of the organics had to be removed through the ash system the augers were not overcome. On the Turriz coal there was almost complete organic conversion despite the 35% ash. The Results and Discussion section has further discussion under commercialization issues. While ash removal did not seem to disrupt the removal system, there were some systems that were affected by the large ash volumes.

The largest potential problem with ash removal in the Eco or any other gasifier is related to clinker formation. Tars and hot spots can in theory produce large agglomerated coal blocks and clinkers in a gasifier. Even though the size holes in the ash grates of the Eco gasifiers are fairly large, clinkers can be quite strong. Significant clinkers can shut down the entire ash removal system and gasifier. If clinkers failed to fall through the ash grate the clinkers would gradually accumulate as boulders above the holes in the ash grate until

they so obstructed the ash removal system or took up so much room in the burn-out zone that the gasifier ceased to work and had to be shut down. A large rotary gasifier project by the state with Allis Chalmers in the 1980s failed because bowling ball sized clinkers formed and could not be removed through the ash system and could not be ground down and handled well enough to permit continuous operation. The Wabash River IGCC project in Indiana has also had significant problems with clinkers in the ash removal system. In the case of the Eco gasifiers no clinkers were ever found in any of the tests either during operation or during subsequent clean out. Mechanisms to explain the missing clinkers were discussed above under the subsection of the Results and Discussion dealing with fuel injection and distribution. While these results are a significant cause for optimism it should be pointed out that this proposal only called for one-day tests, and although some of the operating “days” have been rather long, none of the tests were long enough to allow a clinker build-up to shut down the gasifier even if clinkers were forming. The P.I. calls note to the fact that no clinkers showed up during post test clean-out of the unit and although one day is not long enough to shut down a gasifier with clinker formation, it is long enough that at least a few clinkers should have shown up somewhere if they were going to accumulate and shut the unit down every few days.

Based on the specified one-day tests proposed for this project, and the success criteria calling for the ash removal system to remove all ash, this test program must be considered to have met these success criteria.

Commercial Readiness

The original proposal submission was intended to confirm the ability of small biomass gasifiers to be run on coal. In the larger picture, such gasifiers could run small waste fuel fired power plants eliminating the need for long haulage and handling of low value feed stocks and providing power to moderate sized industrial loads without the use of long transmission networks. The potential market for these gasifiers and efforts of Dr. Ho of ICCI and Mr. McGolden of Coaltec have led to strong industrial support for this project. In fact about 70% of the work on this project has been privately funded. This private funding feature was not part of the original proposal and probably would not have been possible without the efforts of Dr. Ho of ICCI.

One effect of the tremendous outpouring of private support has been a significant rise in expectation from the original proposal. The original proposal was to conduct a basically successful gasification run with coal waste on a small biomass gasifier. The rudiments of a successful gasification run were spelled out in five areas, each of which has been reviewed in the foregoing discussion in this section of the report. Each of the five success criteria was met in this project.

While the basic success criteria in the original proposal were met, some of the hopes and expectations that has developed since then has not been met. When the equipment vendor was changed from Waterwide, with test facilities in Australia to Ethopower with test facilities in British Columbia it was suddenly realistic to visit the test site and witness successful test runs. This lead to ICCI sending Dr. Ho two times to Canada to witness a successful test run. Neither time did Dr. Ho actually see the tests run completed to expectation.

The first site visit was in December of 2000. With the Christmas travel season approaching arrangements were made well in advance and before Ethopower had actually gasified the Turriss coal successfully, but well within the projected schedule for testing. At the time Ethopower had little long-term interest in coal and the testing schedule slipped when the hydraulic drive failed to lift the coal into the gasifier. The ICCI and Coaltec contingent arrived in time to see the improved drive system lift coal into a gasifier and create a reaction with no verification of syn-gas production, energy output, emissions sampling, or ash sampling. While the test provided good reason to think that success might be achieved, the work done at that time did not meet the task requirements of the original proposal. Work did satisfy all the success criteria as stated in the original proposal, in relationship to the feed rates and reaction rates. From a commercial standpoint, the failing was that even though Ethopower did gasify coal in a box, the throughput being achieved by their unit was so slow relative to the output from biomass that only a huge reactor would support even a small commercial application.

The first ICCI visit should not be viewed as a failure. The accomplishments of Dr. Ho and Mr. McGolden have already been pointed out. Dr. Ho obtained a commitment for private funding that in cash would have paid for his business trip to Canada and his salary at ICCI for about three years. The P.I. is not familiar with a previous case of an ICCI project manager ever leveraging so much private support into a project that they oversaw.

With subsequent test runs in January, Ethopower did achieve all five of the key success criteria as discussed above. They also completed the work scope of the original proposal except for failing to provide an ash sample for testing at SIU. Ethopower had also made a major commitment to coal gasification and was building a new gasifier design (the loaf). One of the most significant observations made from the successful January test runs was that coal was not reacting as fast as biomass. This meant that for a given amount of reactor space the fuel throughput would be less for coal than biomass. This would lead to a higher cost per unit capacity, which could interfere with the economics.

One key change in the loaf design was the amount of reaction area and the cost of building for that reaction area. The loaf provides more reaction area in a similar space than the igloo design, and can be fabricated for considerably less money. Although the increased area and decreased cost do not offset the fact that the coal reaction rate is half that for biomass, the changes do compensate for around half the difference. The loaf also incorporated a gamma source for measuring bed height and hydraulic rams instead of a limited feed capacity chain auger.

The new loaf design was initially tested using Turriss coal but the coal sample soon ran out when the testing program expanded to improvements in the entire gasifier design. The Riola coal sample was sent to continue the work and to provide an opportunity for Dr. Ho of ICCI to witness for himself a successful test. The Riola coal sample was a bad sample and would not work in the gasifier as has been extensively discussed in the sections above. In order to provide for all ash sampling and emissions data to be done on a witnessed test much of the sample collection and measurement was held off until another visit could be scheduled for June 2001. These tests could not be successful because it was impossible to get an even air distribution through the gasifier with the fine sample and high clay content. The result was that Dr. Ho did not get to see the gasifier work properly on his second visit. Work done outside the scope of this program suggest

that had the coal sample been good Dr. Ho would have been able to see all five success criteria met at the same time, with the data collection and sampling promised in the work scope executed in front of him at the same time.

The bad Riola coal sample is very unfortunate in terms of a commercial ready gasifier. The bad sample meant that most of the initial effort to ready the new loaf gasifier for use on coal was wasted struggling with a coal that could not work. A successful test run in front of an impartial outside technical evaluator would have been a tremendous endorsement to the commercial readiness of the system. While not performing the test successfully in front of Dr. Ho does not mean that the test was not performed successfully, it does mean a major missed opportunity.

The project has met its original goal of demonstrating the use of a small biomass gasifier for coal. It has run tests that meet all five success criteria in the original proposal. Unfortunately, this success was with the igloo gasifier design in a test that missed the opportunity for an outside witness. The testing, including the problems with the Riola coal sample, identify three issues that will need to be repeatedly and reliably addressed before the technology can be deployed as proven.

The first issue is reaction rate. Most of Ethopower's work to date has been built around the idea that reaction rates are proportional to the square footage of the gasifier area. Using these criteria, the highest reaction rate reached with Turris coal was 35 lbs/hr per square foot. Biomass fuels can get into the low and mid 50s by that same measurement. The data that was acquired only as part of the ICCI test program is not sufficient to determine whether that is simply the result of limitations on the distribution of air through fine coal or whether coal is fundamentally slower and more difficult to break down into syn-gas than biomass. Work done since the ICCI sponsored studies suggests that it has to do with the chemical structure of coal and not the air distribution. This being the case, small biomass gasifiers converted to coal will continue to be larger than units than similar capacity biomass units. The new loaf design allows this problem to be addressed by adjustments in the length of the gasifier that are not particularly expensive after the fundamental gasifier size is selected. Also in most of the niche markets reviewed to date, waste coal fines and gob enjoy enough of an advantage in terms of materials handling to easily offset the additional cost of steel. The slower reaction rate needs to be considered, but is probably not critical to whether the gasifiers have economically clear potential.

The second issue is sulfur. Most biomass is lower in sulfur than coal. When one considers that these small sized modular coal gasification plants will generally feed on coal preparation wastes and that most of the nation's coal preparation plants are on coals east of the Mississippi. that are higher in sulfur, the sulfur issue becomes even larger. When one then considers that the ICCI project focused on coal fines as a fuel then one is talking about coal preparation plants that exclude comprehensive fine coal circuits. These coal preparation plants generally work on coals from thicker seams where internal dilution is less important and coals that are sold mostly for steam applications. These conditions are present more often with the high sulfur coal mines and are especially prevalent in Illinois.

Sulfur is an important issue from an economic standpoint because one of the things that make CCG power plants competitive with larger central power plants is that their cost per

unit of capacity is about the same. Combustion Coupled Gasifiers move syn-gas (complete with H₂S) directly into the combustion chamber without the gas clean-up phase found in IGCC plants. Under these conditions SO₂ will be produced, and under both U.S. and state law those SO₂ emissions will be regulated. Small scale wet scrubbers for SO₂ are generally not readily sized or economic for 5 to 25 megawatt power plants. Work done on this project and in conjunction with IDCCA suggest that the ability to use dry scrubbers on small modular power plants will be key in making them economic. Because dry scrubbers do not clean as deeply as the state of the art wet scrubbers on large power plants the ability to control sulfur in other ways as well is important to commercial economics.

This project added work with the Falcon concentrator finding about a 40% reduction in sulfur emissions. This reduction was robust over a fairly wide range of solid to liquid ratios that are consistent with thickener underflow during a pump down sequence. The Falcon concentrator is a simple enhanced gravity concentrator with a comparatively low operating cost. It is easily less costly than an incremental cost from dry to wet scrubbing and runs for well under an order of magnitude less per ton of avoided SO₂ than a scrubber.

The test data from the January gasification runs also show that large amounts of sulfur were captured in the ash during gasification. Well documented reactions with calcium and magnesium that work under a reducing atmosphere are known to be capable of the reductions observed. Although the Eco technology was not designed to have this feature, the test results suggest that the chemistry occurs well in the design. With the results on the igloo design of the Eco being so favorable with Turris coal, plans were made to carefully measure and document the sulfur adsorption on the runs with the Riola coal in the loaf design in June. Unfortunately, the air distribution through the Riola bed failed and only reactions in channel zones were observed. The ash from the tests was studied for sulfur forms, but with only about one-third of the carbon converting to syn-gas it is difficult to say what the tests mean, and even if the data were interpretable it would be for an operating condition that would never be used commercially.

CONCLUSION AND RECOMMENDATION

The ICCI test burn program with modular Combustion Coupled Gasifiers (CCG) provided definite indications that small biomass gasifiers can be adapted to function on Illinois coal wastes. The tests and scope of the testing project did achieve the five success criteria set forth in the original proposal and did cover all the promised Tasks. Although not a commitment of the original project proposal it was hoped that this test program would demonstrate that CCG technology was commercially ready for use in the Illinois coal industry and that demonstration runs could be observed first hand by ICCI personnel that could provide independent verification to the State. This later ambition was not achieved.

The test program undertaken in this project did cover the tasks set forth in the original proposal. The first task called for collection of a large coal sample and shipment to a CCG test facility. The size of the sample was increased, but the task was completed effectively with an Illinois #5 coal waste sample. There was a major failure in quality

control on collection of the second coal fines sample from the #6 coal, which resulted in mostly clay with some ultra-fine coal being shipped. This defective coal sample caused the later rounds of testing to fail due to the inability of the test unit to produce syn-gas from clay or to distribute air effectively through the ultra-fine material.

The second task in the project was to do pre-combustion tests on the fuel and to predict gasification behavior with proprietary software computer runs. This was done for both the #5 coal sample and the #6 coal sample. The pre-combustion testing work on the #6 coal sample contained a major omission, which allowed the defective coal sample to move into testing undetected. Small samples were taken from the belt presses before any large samples were collected to make sure that the fuel would be suitable (this step was also done with the #5 coal). When the 20 ton #6 coal sample was collected, the quality was not rechecked against the original sampling data with the result that the defective sample was shipped and introduced into the testing program without detecting the clay and size consist problems. Project management issues related to this breakdown are an issue for the Project Management Report.

The third task was to develop fuel feed systems suitable for moving damp coal fines into the gasifier on demand. Ethopower was able to do this by increasing the power on their biomass augers, but ultimately chose to do this by developing a new ram feeder system. Mechanically, neither system had any difficulty running any amount of coal needed into the gasifier on demand. The detector-based PLC logic for the feed system, however, either failed or could not be demonstrated. The initial igloo design used an electric eye to measure drop in the fuel bed (as the fuel gasified) and signal the PLC to feed additional fuel. The coal caked and formed a steep cone in the gasifier, blocking the beam and thus the automated fuel feed command. The new loaf design used an adjustable height gamma source to measure drop in the fuel bed and trigger the fuel feed command. With the defective #6 coal sample, 62% was clay, and airflows were so badly channeled that only one-third of the organic material reacted. This meant there was almost no change in fuel bed height even when all the air accessible organic material was burned out. Even though the detectors and PLC worked, the logic on which the automatic sequence was based failed because the gasifier reacted all the accessible carbon without causing a significant change in bed height in the gasifier. For experimental purposes the PLC failure was managed by issuing feed commands at timed intervals. While suitable for experimental work, this is not a commercial ready automated logic system.

The fourth task was to construct new fuel injection systems and grates to enable a biomass gasifier to handle damp coal fines. Ethopower in fact modified the entire gasifier. A new fuel injection system was constructed as promised. The grate design was not a problem with the earlier "igloo" configuration, but when the shape was modified to the "loaf" configuration the grate had to be redesigned to in line sliding plates. This alteration was made and does improve the economics of using the gasifier for coal, since it allows a bigger unit to be produced for the same or lesser cost than a smaller unit in the "igloo" configuration.

The fifth task was to install the new equipment. This was done as promised.

The sixth task was to conduct multiple daylong test burns with the gasifier. There were numerous preliminary tests done to adjust problems and figure out the best operating

parameters. In terms of major tests that were run for a full day, there were tests in December, January, April, May, and June. Witnessed test performance was not promised in the original proposal but the movement to a British Columbian test enabled tests in December and June to be witnessed by Dr. Ho of ICCI. The best test run was made in January using the “igloo” configuration and the #5 coal. This test achieved the five major success criteria as stated in the original proposal. The mechanical aspects of coal feed system functioned properly though the automated software control did not function to commercial readiness as discussed above. The fuel distributed evenly across the hearth of the gasifier in both the igloo and loaf configurations. Caking of the coal caused an unusually high angle of repose in the fuel bed that foiled the electric eye system for fuel feed in the igloo design as discussed above. The initial April run with the #5 coal on the loaf design appeared to indicate the gamma detector arrangement will work for automated PLC control, but the #5 coal was depleted before a suitable PLC program could be written and commercially proved. The #6 coal sample was too high in clay and fines to be suitable for gasification and none of the results from this coal can be used to demonstrate commercial readiness. The January and April test runs showed steady even gasification temperatures and good gasification conditions. The fourth success criteria were that 90 to 95% of the fuel would be converted to heat. This was achieved with the #5 coal, but not with the defective #6 coal sample. The fifth criteria were that the ash removal system would remove ash effectively. There never was an issue with ash flowing down through the grates when they were opened, nor was there ever a problem with clinkers hanging up. The ash pull down was insufficient to prevent the steep angle of repose of the caked coal from foiling the electric eye mechanism for PLC control of the feed, but this was a problem of lack of flexibility in the function of the electric eye detector which needed to be adjustable for a steeper angle of repose with coal. Early April tests on the loaf configuration gasifier with Turris coal indicate that the gamma system was working to overcome this problem. The ash pull down system also did not function well on fuel that would not gasify. Although the ash grates could easily have removed even the 62% ash in the defective #6 coal sample, the problem of air channeling through the coal bed made it impossible to demonstrate a properly functioning ash removal system. If the grates were not opened frequently the fuel and ash bed would build up, block the gamma detector, and thus more coal feed, and then allow all the accessible organic to combust rather than gasify. If the gates were opened frequently enough to trigger a steady flow of feed, the organic material would not be close to consumed at the bottom of the bed, resulting in drawing flaming coal ash out of the ash removal system. While air channeling with only one-third of the organic material reacting made it impossible to draw ash correctly at any rate, the 62% ash is an issue of itself. In biomass systems the fall in the fuel bed level triggers both the fuel feed and ash dumping commands from the PLC. With 62% ash even if the fuel gasifies properly, there will not be enough of a drop in the bed to trigger additional fuel feed or ash dumping. The logic of using fuel bed drops to control automatic feed would fail with very high ash material at any rate.

The seventh task was to attempt to adsorb sulfur into the ash under reducing conditions. Mr. Paul Williams, after originally suggesting it, later said it could not be done, which was the reason that a series of tests were run with the Falcon on the #5 coal to see if sulfur removal could be achieved. The sulfur issue appears to be important to CCG based power generation because wet scrubber technology is not well sized for and is very costly for small power plants. Dry sorbant processes, on the other hand, are probably better

sized for small power plants than large. An independent contractor checked the January test runs with the #5 coal for stack emissions. Around 70% of the sulfur was missing from the flue gas stream and sulfur content of the ash was unusually high. It was determined that in the #6 coal tests, attempts would be made to characterize sulfur forms in the ash and to get a mass balance on the sulfur. While the attempt was made, most of the #6 coal did not react and the experiments on the #6 coal would be considered to have failed in terms of producing the data desired. The seventh task was thus performed but a good mass balance which would really be needed to draw quantitative conclusions about sulfur capture in ash was not performed on the #5 coal and could not be meaningfully gathered as representative data from the #6 coal run.

The eighth task was to have a report written on the test work. This was done for the January test and data was supplied for the June test for use with this report. Tests in December and June were witnessed first hand allowing for reporting based on independently witnessed data. While the January tests and reports would have to be considered experimental successes, the independently witnessed tests would not be. The idea that a unit can perform a successful test burn that cannot be repeated in front of outside people would normally be considered a cause for concern. In terms of declaring the technology commercially ready, it is a serious concern regardless. From an experimental standpoint none of the poor performances witnessed on site visits is difficult to explain or hard to believe could have been readily fixed for the January and April tests, which had experimentally encouraging results. The December visit was scheduled far enough in advance that when Ethopower had to rebuild the feed augers (which they originally were sure would be unnecessary) they were behind on testing. Ethopower was just discovering that the caking of the fuel was causing the fuel bed to stand steep and block the electric eye even when the fuel was consumed. Ethopower did not have time to try to calibrate a timed removal of ash. The result was that the visit in December found a coal bed that fed into a gasifier at a slow and unmeasured rate until someone decided to pull ash and manually enter a feed command. The visit saw mechanical systems for fuel and air feed, fuel distribution, and ash removal that were mechanically functional, but that had no software to run the PLC and support any of the functions in a commercially ready way. There was also not enough experience to know what kind of reaction rate could be sustained. Although not measured, there can be little practical doubt that the reaction rate seen in December would generally be too slow for a commercial system. To fix the problems seen in December one would only have to gain some experience with timed commands for fuel feed and ash removal to get an experimentally successful test, which was done for the January test work. In terms of the June test, Ethopower was struggling with a fuel (defective #6 coal sample) that was largely incombustible and that was so fine that it was impossible to get an even airflow. Under such conditions nothing can be successful.

The ninth task was to collect and characterize ash samples. Ash was collected and tested from the January run with excellent results. The carbon reaction was about 99.9% complete. Few commercial technologies even approach such a complete reaction, and Ethopower was running 35 lbs/hour per square foot of bed surface, which is a commercially viable reaction rate. The ash showed high sulfur content as would be anticipated from the low sulfur dioxide emissions. Unfortunately, the ash sampling program was not done according to any specific protocol, no sample was sent to SIUC for test work and thus when issues that warranted further testing arose there was no ash to

test. The loss of opportunity to get critical mass balance data is really a project management issue and will thus be discussed in that report. Attempts were made to get good fuel and ash sampling for the June test and in fact a battery of tests was run up to the point that it was apparent that the gasifier would never be run commercially under the observed conditions. At this point further testing of the ash was stopped.

It is the P.I.'s opinion that this ICCI study was a valuable step toward converting modular biomass gasifiers to run on coal wastes. Had expectations remained limited to the original proposal the project would have been considered a complete success. During the project, however, enthusiasm and expectation grew to an objective of showing that the technology was commercially ready for immediate installation. Had hard work and effort not been lost on the defective #6 coal sample, and had some miscommunication of expectations been overcome, it is the P.I.'s opinion that the commercial ready objective would have been met also. As it is, the commercial ready objective is not met. The new gasifier design has not been tested on a commercially realistic fuel sample and the PLC control software is not developed to the same extent as the mechanical systems on the Eco gasifier. It is the P.I.'s opinion that Ethopower can be successful in demonstrating their technology with another test.

DISCLAIMER STATEMENT

"This report was prepared by Dr. Bradley C. Paul of Southern Illinois University, Carbondale with support, in part, by grants made possible by the Illinois Department of Commerce and Community Affairs through the Office of Coal Development and Marketing and the Illinois Clean Coal Institute. Neither Dr. Bradley C. Paul, Southern Illinois University, Carbondale nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Office of Coal Development and Marketing, Illinois Clean Coal Institute, nor any person acting on behalf of either:

- (A) Makes any warranty of representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or
- (B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring; nor do the views and opinions of authors expressed herein necessarily state or reflect those of the Illinois Department of Commerce and Community Affairs, Office of Coal Development and Marketing, or the Illinois Clean Coal Institute.

Notice to Journalists and Publishers: If you borrow information from any part of this report, you must include a statement about the state of Illinois' support of the project."