FINAL TECHNICAL REPORT
September 1, 2002, through July 31, 2004

Project Title: **INDUSTRIAL ENGINEERING APPLICATIONS FOR ENHANCING UNDERGROUND COAL MINING PRODUCTIVITY**

ICCI Project Number: 02-1/1.1A-3
Principal Investigator: E. Bane Kroeger, Southern Illinois University
Other Investigators: Tomasz Wiltowski, Southern Illinois University
Project Manager: Joseph C. Hirschi, ICCI

ABSTRACT

In the competitive coal mining industry, selling price determines profitability. As economies of scale have been realized at western surface mines, underground coal mines in Illinois have had to lower production costs to compete. Consequently, Illinois mines have adopted new mining methods and switched to larger, more powerful mining equipment. This caused underground coal mine productivity to increase from 1.13 tons per man hour in 1979 to 3.99 tons per man hour in 1999, an overall increase of 250%, or approximately 6.8% per year, allowing many mines to keep producing coal. However, further improvements can come more cheaply and easily through mine productivity training.

To that end an underground coal mine productivity training program was developed. The program focused on continuous miner production systems, the most popular mining system in Illinois and throughout the world. Industrial engineering analyses identified bottlenecks or unnecessary delays particular to each participating mine. Working with mine management, methods and procedures to reduce or eliminate delays and solve typical production problems were developed.

Five Illinois coal companies and seven underground coal mines participated in this project. The project team visited each mine to collect industrial engineering data for the production system being used. Using this data as input, a computer model of the production system was created. Then a sensitivity analysis of the various production parameters was performed to determine those parameters with the most significant effect on productivity. Training sessions highlighted what mine supervisors could do to properly manage these issues.

Training sessions were provided to upper management at all five companies, to production supervisors at six of the seven mines, and to the hourly work force at one of the mines. Additional training has been requested and will take place after this project has concluded. Those participating in the training sessions have all had positive comments about the program. Based on these comments, the miner productivity training brings substantial value to the underground coal industry in Illinois and should be continued.

## EXECUTIVE SUMMARY

The Illinois coal industry produced 31,135,859 tons in 2003 from thirteen underground mines and seven surface mines. Two of the underground mines use the longwall method of production where it is typically assumed that 80% of production comes from the longwall and 20% comes from continuous miner development units. Table 1 further describes this industry profile highlighting the importance of continuous miner production systems in Illinois.

Table 1. Illinois Coal Mine Production in 2003.

| Type of Mine | Extraction Method | Coal Production | % of Total |
|---|---|---|---|
| Surface | Truck and Shovel | 5,197,656 | 17 |
| Underground | Continuous Miner | 18,722,452 | 60 |
| | Longwall | 7,215,751 | 23 |
| Total | | 31,135,859 | 100 |

The overall objective of this project was to increase underground coal mine productivity by using industrial engineering concepts to provide training on efficient operation of a continuous miner section. Through more efficient operation, section productivity can be increased, lowering production costs and making Illinois coal more competitive. More specifically, the project aim was to conduct individualized training at five different underground mines in Illinois.

In addition to the standard reporting required by ICCI, the project had three major tasks. The first task was to develop a general outline for a training program that covered fundamental principles of mine productivity and could be marketed to mine operators. An experienced mine consultant was contracted with to provide this service. The result was a set of five PowerPoint® presentations titled as follows:

1. ICCI Training Program – Introduction
2. ICCI Training Program – Cycle Times
3. ICCI Training Program – Action Plans
4. ICCI Training Program – Problem Solving
5. ICCI Training Program – Rework

The second task consisted of marketing this training program to mine operators. Initial marketing efforts consisted of telephone calls and letters sent to all underground operations in Illinois. When this did not generate a satisfactory response, the project team made personal visits to six mine sites. Once this personal contact was made, the mine operators immediately recognized the value of the training program and permitted the project team to spend time in the mines collecting industrial engineering data on the operational parameters of their continuous miner sections. This was done at six different mines operated by five different companies.

The data obtained during these mine visits was input into a computer model developed at SIUC by Dr. Y.P. Chugh with funds from a separate ICCI grant. The model was used to perform a sensitivity analysis on critical operational parameters leading to recommendations for improvement specific to the mine being studied. These recommendations were presented to mine management who then worked together with the project team to develop a specific training program for their mine personnel.

The third task consisted of the actual training. Of the six mines visited, training was provided to supervisory personnel including production foremen at five of these mines and to supervisory personnel from a seventh mine, a sister mine to one of the visited operations. Additionally, training was provided to the entire hourly work force at one mine. In all, the miner productivity training program was presented eight times to mine supervisors and six times to hourly workers.

For the most part, the training sessions lasted between one and two hours and consisted of the following:

1. PowerPoint® presentation on important productivity parameters and specifically the importance of cycle times
2. A hands-on demonstration of the computer model and performing sensitivity analysis
3. An open discussion giving the participants the opportunity to relate their personal experience to the ideas being discussed.

Once mine operators throughout the Illinois Basin became aware of the training program, interest increased significantly. At the end of the project period there were requests for follow-up visits from several operations as well as requests for training from a few Illinois operations that had not yet participated in the training. The comments from the mines visited thus far have all been very positive. Based on these comments, the miner productivity training program is both of value and pertinent to the underground coal mining industry in Illinois.

Actual meaningful numbers showing productivity improvement results have been difficult to obtain from the participating mines due to constantly changing geologic and market conditions that affect production levels at the mines. Furthermore, a majority of the training was conducted during the last three months of the project. Thus, there had not been sufficient time to fully realize the expected productivity gains by the project completion date. However, the first mine to participate has reported productivity increases averaging 17% over a six month time period as a result of both this training program and steps that they were already taking to promote better productivity practices. If all the recommendations were adopted at the mines visited thus far, the total production from these mines would increase by over 2 million clean tons per year. This additional production would come at no additional cost, thereby significantly reducing production costs making the increased production readily marketable.

## OBJECTIVES

The overall objective of this project was to increase underground coal mine productivity by providing training on efficient operation of a continuous miner section through the use of industrial engineering concepts. Through more efficient section operation, the productivity from the section can be increased, lowering the cost of producing coal from that section. This in turn can make Illinois coal more competitive. The specific objective of the project was to visit five different mines in Illinois and provide productivity training sessions to those mines.

In addition to the standard reporting required by ICCI, the project had three major tasks as follows:

1. Program development
2. Marketing the program
3. Training mine personnel

## INTRODUCTION AND BACKGROUND

Coal mining has been an important industry to Illinois for many decades. It is a market driven industry, with the price of the coal being one of the most important factors. To stay competitive, Illinois mines have had to lower the cost of producing coal. This has been accomplished by switching to new mining methods and to larger, more powerful mining equipment. This has caused underground coal mine productivity to increase from 1.13 tons per man hour in 1979 to 3.99 tons per man hour in 1999, which is an overall increase of 250%, or approximately 6.5% per year. This has allowed many mines in Illinois to keep producing coal. Even after making changes, several mines in Illinois did not get the production gains they were expecting. This is due in part to inefficient work practices that could be corrected through miner productivity training.

The key discussion during this miner productivity training program was how to run an efficient continuous miner section. All underground coal mines in Illinois utilize continuous miners for either longwall development or primary production. Because of this, the miner productivity project focused on continuous miner production systems. However, the industrial engineering concepts utilized during this project can be applied to any type of mining system, be it underground or surface mining, longwall or continuous miner methods.

The productivity training program looked at the entire continuous miner section to identify bottlenecks or unnecessary delays and determine methods to reduce or eliminate these delays with particular emphasis on those sub-systems that were identified by mine management as limiting productivity. This information was then compiled into a presentation that provided alternative solutions to solve the problems or eliminate the delays.

## EXPERIMENTAL PROCEDURES

The project was completed by first contacting the mines around the state by sending a letter that introduced the program to the appropriate mine personnel. The letter of introduction was followed by phone calls to arrange a presentation of the training program to mine management. During this meeting, the program was presented to mine management and initial mine visits were scheduled. Mine visits were conducted to obtain snapshots of the activities from each of several continuous miner sections at each mine. The data obtained from these snapshots was analyzed and input into a mine model spreadsheet to determine how well the sections were operating. Once analyzed, the generic presentation was modified and presented to mine management. At this meeting, the productivity training sessions for the frontline supervisors were scheduled and the length and desired content of the sessions was determined by mine management.

The first part of the productivity training program consisted of a presentation focusing on the key ways to improve mine productivity and safety using industrial engineering concepts. The second part of the program focused on the areas that were identified in the walkthrough as areas that needed improvement. For the second part of the training program, project staff utilized a mine model spreadsheet that modeled the productivity from a miner section in its current state. Changes were made to the mine model spreadsheet and predictions of productivity with the changes identified were discussed.

## RESULTS AND DISCUSSION

**Task 1 – Coursework development:** The coursework materials will be developed and printed for handout and usage.

This first task involved the development of training modules on a variety of topics for underground coal miners. These modules were developed by project staff in consultation with Illinois mines. The goal of the modules was to provide training sessions that were broad enough to be used at all the mines yet detailed enough to be tailored to the individual mines. The modules were developed so that they could be provided in as little as one hour to as much as eight hours in length.

The first module or presentation was an introduction that focused on the rationale behind increasing productivity from a mine. The second presentation focused on cycle times and how small improvements in a cycle that is completed several hundred times a shift can vastly improve the productivity from a mine. The third presentation highlighted just a few action plans for making productivity improvements and discussed how to develop action plans for other issues. The fourth presentation covered the costs of rework and how doing things correctly the first time can save substantial time in the long term. The last presentation was developed to improve the problem solving skills of the workforce.

This task was completed during the fifth month of the project.

**Task 2 – Marketing training programs to the mine sites:** Visits will be made to the mines to present the training program and schedule future training sessions.

This was the most important, difficult, and time consuming task of the project. To begin this process, project staff met and compiled a list of the underground mines operating in Illinois and identified the key personnel at a majority of these mines. A letter that introduced the training program was sent to those contacts. The letter was followed by phone calls to arrange a presentation of the training program to mine management. At this meeting, an initial mine walkthrough was scheduled.

For the remaining mines, project staff contacted the mines and asked to be transferred to the person responsible for this type of training. The training project was then discussed with this person. Several asked to read through the training materials, so copies were forwarded upon request.

As stated above, this was the most difficult task to complete on the project. This was mainly due to reluctance at the mines from the misconception that the training program would be too academic for the workers and would not be of benefit to the mine. Project staff struggled with this misconception until the early part of September 2003, when the first mine agreed to a presentation and walkthrough. Once the walkthroughs and training sessions were successfully completed in mid October 2003, marketing the training program to other mines became easier as the mine managers at the first mine began to talk with their counterparts at other mines.

<u>Mine 1:</u>

The first mine where walkthroughs were conducted employs 383 workers and produces 2.85 million tons of clean coal per year. The mine operates five single crew (walk-between) continuous miner production sections working two production shifts per day. At the time of the walkthroughs, the mine was transitioning from mine panel pillars on 70 by 70-foot centers to pillars on 60 by 60-foot centers. They were also switching from cable shuttle cars to larger battery ram cars. The engineering staff at the mine was trying to estimate the production increase gained by switching to the smaller pillars and larger battery ram cars.

Once the data was collected and input into the mine model spreadsheet, mine managers wanted to analyze seven different scenarios. The descriptions and summaries from the models analyzed are provided in Table 2.

The scenarios included the changes to both the mining layout and the switch to larger battery ram cars. Case 5 was used as a benchmark for how much the productivity could be increased by making the planned changes, which increased the production by approximately 14.5%. In addition to the changes that were already planned, project staff made suggestions on how to decrease unexpected delays, which would increase the production another 8.2% above the planned changes in Case 5. Project staff also suggested alternate haulage patterns, having the battery ram cars turned around whenever possible before waiting at the change out point. This could increase the production over Case 5 by 19.6%, which is a very significant amount. Although not included as a formal part of the mine productivity training presentation, the combined effects of decreasing the unexpected delays from 130 to 100 minutes per shift and having the cars turned around before waiting at the change out point were analyzed. The model predicted the production from each section could be increased to 2,625 raw tons per unit shift, which would be a 27.6% increase over Case 5. Because neither of these changes requires any capital expenditures from the mine, these are the kinds of suggestions the mine management were seeking.

**Table 2.** Scenarios analyzed for Mine 1 with the mine model spreadsheet.

| **Case Number and Description** | **Unit Shift Production (raw tons)** | **Unit Shift Mining Rate (feet)** | **Production Increase (%)** |
|---|---|---|---|
| 1. Base Case-70x70' centers, shuttle cars | 1,797 | 309 | |
| 2. 70x70 centers, battery ram cars | 1,956 | 336 | 8.8% |
| 3. 70x70 centers, shuttle cars, faster loading | 1,894 | 326 | 5.4% |
| 4. 60x60 centers, shuttle cars | 1,880 | 323 | 4.6% |
| 5. 60x60 centers, battery ram cars | 2,058 | 354 | 14.5% |
| 6. 60x60 centers, battery ram cars, less delays | 2,205 | 379 | 22.7% |
| 7. Case 5 with having cars turned around | 2,409 | 414 | 34.1% |

The mine managers were encouraged by the results from the models and the changes recommended were adopted. The productivity from the mine has closely matched the values predicted by the model. Based on the production increases predicted by the mine models, the production from this mine could be increased by 0.97 million tons per year.

<u>Mine 2:</u>

Because of holidays and vacations at the mines in November and December, the next meeting with mine management did not occur until February and was followed by walkthroughs at Mine 2 on February 23 and 25, 2004. This mine employs 241 workers and produces 1.57 million tons of clean coal per year.

This mine operated two walk-between continuous miner sections working two production shifts per day at the time of the visit. This mine was transitioning from diesel ram cars to larger battery ram cars. The engineering staff at the mine needed an estimate of how many tons of coal were being loaded onto the cars and also what the production benchmark should be using the new haulage vehicles. The mine management also wanted to estimate what effect mud and water (bad roads) had on the production. With this in mind, seven scenarios were analyzed with the mine model spreadsheet. The descriptions and summaries are provided in Table 3.

During the walkthroughs at Mine 2, it was noticed that the new batter ram cars were not being fully loaded by the continuous miner. This was most likely occurring from the coal cutting fairly easily at the mine and the switch to newer more powerful continuous miners. The coal loading rates (17.5 tons per minute) onto the cars was one of the highest measured at any mine in Illinois. Because of this, the continuous miner operators were not moving the tail conveyor from side to side to evenly fill the ram car bed. This caused payload on the cars to only be 10.2 tons. The mine had previously weighed a loaded ram car and determined the cars should have an average load of 12 tons. When this value was entered in the mine model spreadsheet, the model predicted a 9.5% increase in production could come from fully loading the cars.

**Table 3.** Scenarios analyzed for Mine 2 with the mine model spreadsheet.

| **Case Number and Description** | **Unit Shift Production (raw tons)** | **Unit Shift Mining Rate (feet)** | **Production Increase (%)** |
|---|---|---|---|
| 1. Base Case-80x100’ centers, 4 battery ram cars | 1,700 | 284 | |
| 2. Dropping to 3 battery ram cars per section | 1,562 | 261 | -8.1% |
| 3. 4 battery ram cars, fully loaded | 1,861 | 311 | 9.5% |
| 4. 4 battery ram cars, slower loading rate | 1,644 | 275 | -3.3% |
| 5. 4 battery ram cars, deeper cuts | 1,705 | 285 | 0.3% |
| 6. 4 diesel ram cars | 1,560 | 261 | -8.2% |
| 7. 4 battery ram cars, less delays | 1,875 | 313 | 10.3% |

The combined effects of decreasing the unexpected delays from 173 to 143 minutes per shift and having the cars fully loaded were analyzed. The model predicted the production from each section could be increased to 2,051 raw tons per unit shift, which would be a 20.6% increase over the Base Case 1. Again, this is a very significant increase with no capital expenditures required. Based on these results, the annual production from the mine could be increased by 0.32 million tons per year.

Since the visit, the mine has switched to dual crew supersections operating both continuous miners simultaneously on a single unit. Management has requested the mine be revisited and data collected from the new mining arrangement to determine where improvements could be made.

Mine 3:

The third mine visit was conducted on March 9, 2004. This mine employs 125 workers and produces 0.96 million tons of clean coal per year. The mine operates two walk-between continuous miner sections producing coal two shifts per day. The mine managers had some specific issues that they wanted covered in the training sessions, so once operating data was collected, scenarios covering those items were analyzed using the mine model spreadsheet. The descriptions and summaries are provided in Table 4.

The mine was transitioning to larger battery ram cars and wanted to obtain an estimate of the production increase from using the larger cars. The mine currently uses four battery ram cars on each section to haul the coal from the continuous miner to the feeder. The results from the model showed that for most cuts in the mining sequence, the fourth car was not needed except as a backup when a car needs to change batteries. The model also predicted that for their mining sequence, when they had only three open crosscuts in front of the feeder, only two cars were needed in the second cut in a crosscut because of the change out distance. The empty cars had enough time to make it from the feeder back to the change out point before the loaded cars cleared the change out point.

**Table 4.** Scenarios analyzed for Mine 3 with the mine model spreadsheet.

| **Case Number and Description** | **Unit Shift Production (raw tons)** | **Unit Shift Mining Rate (feet)** | **Production Increase (%)** |
|---|---|---|---|
| 1. Base Case-60x70', small battery ram cars | 2,146 | 340 | |
| 2. Large battery ram cars | 2,341 | 371 | 9.1% |
| 3. Large battery ram cars, 4 x-cut belt moves | 2,324 | 368 | 8.3% |
| 4. Large battery ram cars, bolting closer to face | 2,365 | 375 | 10.2% |
| 5. Large battery ram cars, lower bolting delays | 2,551 | 404 | 18.9% |
| 6. Large battery ram cars, cars turned around | 2,728 | 432 | 27.1% |

The mine also had problems with delays in roofbolting. Several times during a shift they reported the mining cycle was delayed by the roofbolting because the mine is installing five bolts per row with a steel strap. Project staff visited both bolters working on each section and analyzed their cycle times. All four bolters used different procedures to support the roof and their cycle times varied accordingly. One of the goals of this project is to standardize the procedures used for the roofbolting cycle.

As with the other mines visited, if the recommendations made by project staff are fully implemented at this mine, the mine model spreadsheet predicts a productivity increase of 27.1% over the Base Case 1. This would result in an annual production increase of 0.26 million tons per year.

<u>Mine 4:</u>

Visits to the fourth mine occurred on May 10 and 11, 2004. The mine employs 762 workers and produces 6.2 million tons of clean coal per year. The mine operates four continuous miner sections with two production shifts to develop longwall panels. The mine operates both diesel ram cars and cable shuttle cars. Because the mine does not use the continuous miners for primary coal production, this visit focused on the problems unique to longwall development. Three-entry development sections are driven forward from the center entry with crosscuts being turned to the left and right from the main entries. This is to keep the haulage equipment from widening the outer intersections during haulage.

The main recommendations made for this mine were related to the cut sequence. From shift to shift, the supervisors were not following a set mining sequence, which created bottlenecks and severely limited the development rate.

Mine 5:

The fifth mine visit occurred on July 14, 2004. The mine employs 190 workers and produces 1.4 million tons of clean coal per year. This mine operates two dual crew supersections that produce coal on two production shifts with periodic production from a third shift. The main goal of management was to identify practices to increase production that were inexpensive and easy to implement. Another goal was to standardize production practices between the sections as much as possible. The mine managers had other specific issues that they wanted covered in the training sessions, so scenarios covering those items were analyzed using the mine model spreadsheet. The summaries are provided in Table 5.

**Table 5.** Scenarios analyzed for Mine 5 with the mine model spreadsheet.

| **Case Number and Description** | **Unit Shift Production (raw tons)** | **Unit Shift Mining Rate (feet)** | **Production Increase (%)** |
|---|---|---|---|
| 1. Base Case-70’x60’ | 2,372 | 403 | |
| 2. Quicker continuous miner moves | 2,430 | 413 | 2.4% |
| 3. Decreasing the cut depth from 35’ to 30’ | 2,306 | 392 | -2.8% |
| 4. Reducing unexpected delays | 2,769 | 471 | 16.7% |

The combined effects of decreasing the unexpected delays from 178 to 130 minutes per shift and reducing the continuous miner tram delays from 4 minutes to 3 minutes was analyzed. The model predicted the production from each section could be increased to 2,836 raw tons per unit shift, which would be a 19.6% increase over the Base Case 1. Again, this is a very significant increase with no capital expenditures required. Based on these results, the annual production from the mine could be increased by 0.27 million tons per year.

Mine 6:

The sixth mine visit occurred on July 15, 2004. This mine employs 247 workers producing 2.2 million tons of clean coal per year. The mine operates two dual crew supersections that produce coal on two production shifts with periodic production from a third shift. The main goal of management was to identify practices to increase production that were inexpensive and easy to implement. Another goal was to standardize production practices between the sections as much as possible. The mine managers had other specific issues that they wanted covered in the training sessions, so scenarios covering those items were analyzed using the mine model spreadsheet. The summaries are provided in Table 6.

The model predicted that by decreasing the clean-up times from the continuous miners on each unit, the production from each section could be increased to 2,578 raw tons per unit shift, which would be a 6.5% increase over the Base Case 1. Again, this is a very significant increase with no capital expenditures required. Based on these results, the annual production from the mine could be increased by 0.14 million tons per year.

**Table 6.** Scenarios analyzed for Mine 6 with the mine model spreadsheet.

| Case Number and Description | Unit Shift Production (raw tons) | Unit Shift Mining Rate (feet) | Production Increase (%) |
|---|---|---|---|
| 1. Base Case-60'x70' | 2,420 | 492 | |
| 2. Adding fourth car | 2,430 | 494 | 0.41% |
| 3. Better cleanup times | 2,578 | 524 | 6.5% |
| 4. Decreasing the cut depth from 25' to 18' | 2,274 | 462 | -6.0% |
| 5. Loading the cars with more coal | 2,532 | 516 | 4.6% |

**Task 3 – Training operations personnel at the mine site:** Training sessions will be scheduled at the mine site utilizing the materials developed in Task 1.

In all, the miner productivity training program was presented eight times to mine supervisors and six times to hourly workers. The first training program was provided in three sessions for supervisors at Mine 1. The first session was held on October 15, 2003. There were nine frontline supervisors and two mine managers in attendance. The second session was October 16, 2003. There were six frontline supervisors and three mine managers in attendance. The third session was October 17, 2003. There were five frontline supervisors and one mine manager in attendance.

The second training program was provided at Mine 2. The first session was held on March 26, 2004. There were eight supervisors in attendance. Two more training sessions were conducted for frontline supervisors on April 14, 2004. There were nine supervisors and one manager in attendance for the second session and seven supervisors for the third session. The mine wanted their hourly employees to hear the presentation, so training sessions were provided on April 27-29, 2004. There were six sessions in all, with about 13-15 hourly workers in each session.

The third program was provided at Mine 3. Supervisors from a sister mine participated in this program. A set of training sessions were provided to the frontline supervisors on May 5 and 12, 2004. There were five supervisors and two managers in attendance at each of the sessions.

Personnel and production scheduling problems at Mine 4 prevented any training programs from being presented to the supervisors or hourly work force. Mine management did express a desire to provide the training session to mine supervisors at a later date.

The fifth and final training program for Mines 5 and 6 took place after the actual end date for the project but while the final report was being edited and approved so the results are being included in this report. Six sessions were held on August 12 and 13, 2004 for mine supervisors. The first three sessions were held at Mine 5 with 10, 13, and 7 supervisors in each of the sessions. The last three sessions were held at Mine 6 with 10, 12, and 8 supervisors in each of the sessions. Training sessions for the hourly workers has been scheduled for the early part of September 2004.

## CONCLUSIONS AND RECOMMENDATIONS

The mine managers that have participated in the productivity training sessions have all had positive comments about the program. Based on these comments, the miner productivity training is both of value and pertinent to the underground coal mining operations in Illinois.

From the experience gained during this project, the following recommendations should be incorporated into future training programs such as this.

- Because of the number of underground coal mines in Illinois, half should be visited each year on a rotating schedule.
- The mines that were visited during this first year of the project should be encouraged to provide the training program to their hourly employees, as this is the group that governs the productivity of the mine.
- If time permits, the mines that were visited during this first year of the project should be revisited during the second year to document any possible increases in productivity and to check if suggested procedures were implemented.

If all the recommendations provided by project personnel were adopted at the mines visited thus far, the total production from these mines would increase by over 2 million clean tons per year. This increased production would come at no additional cost to the mines, thereby significantly reducing production costs, making the increased production readily marketable. Assuming a hypothetical production cost of $18 per ton for base case conditions, a 2 million ton per year cumulative increase at these mines realized at no additional costs would lower the cost per ton to $14.70, which would be an 18.4% decrease in the cost of coal production from these mines.

## DISCLAIMER STATEMENT

This report was prepared by E. Bane Kroeger from the Department of Mining & Mineral Resources Engineering at Southern Illinois University – Carbondale with support, in part by grants made possible by the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute. Neither E. Bane Kroeger, the Department of Mining & Mineral Resources Engineering, Southern Illinois University – Carbondale, nor any of its subcontractors nor the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development, the 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 Economic Opportunity, Office of Coal Development, 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.