

**Achieving the Benefits of Improved Extracted Coal Quality
to Mine Profitability and Power Generation Economics**

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**2002 Society for Mining, Metallurgy, and Exploration, Inc. (SME)
Annual Meeting & Exhibit**

**February 25, 2002
Phoenix, Arizona**

ABSTRACT

Companies that deploy cutting-edge technologies tend to lead the competition with more efficient operations and better financial performance. The mining industry has been improving productivity through good times and bad, driven by innovation. Despite improved performance, customers still demand improved product quality—at lower prices.

This paper presents the economic benefits (operational and financial) of technologies that improve geophysical interpretation, productivity, product quality, and lower risk in coal mining and coal bed methane (CBM) production. The improvement in coal quality provides additional benefits at the power plants—the major customer segment.

INTRODUCTION

During the winter of 2000–2001, natural gas prices quadrupled in the United States. OPEC reduced crude oil production to maintain current levels of prices, which doubled in one year (1999–2000). Californians saw a major utility file for bankruptcy, and rolling blackouts were a common event. Unfortunately, this energy crisis weakened the growth engine of the new digital economy, which is in need of large quantities of electricity. Many experts point to the fact that the unanticipated higher demand for electricity caused by the buildup of digital equipment contributed to the crisis. As Bill Paul, special energy correspondent to CNBC TV and *The New York Times* reported, “this is a crisis of infrastructure.”ⁱ The world needs more gas pipelines, transmission lines, power plants, and more energy sources such as coal.ⁱⁱ

This is good news for the coal industry. Higher prices of natural gas caused coal-fired (and nuclear) plants to dispatch at higher capacity factors. Coal prices moved up as well—a phenomenon that hasn’t happened that often, and despite the current drop in natural gas prices given the mild 2001–2002 winter (prices are down 50 to 60 percent this winter), prices for coal have softened, but not retreated to past levels, giving some hope that coal will remain King—not only soft and hard coal, but now there is considerable interest in CBM. Despite a doubling of drilling rigs since late 1999, long-term natural gas supply is not growing fast enough, thus, the new interest in CBM, which now represents 8 percent of natural gas supplied. Power plant design engineers have been rethinking fuel strategies that favor coal (many orders for gas turbine plants have been cancelled). After a five-year hiatus when no new coal plants were ordered in the United States, many new coal units are being funded, and some coal companies such as Peabody are expanding their business horizons to participate in the power generation. Having changed its name to Peabody Energy, it has

announced construction of two major projects. But more important, there is renewed interest in clean-coal plants.

Our political leadership has recognized these new developments. As one of his first executive directives, newly appointed US Department of Energy Secretary Spencer Abraham announced a \$95-million program that will provide grants for projects to improve efficiency at coal-fired power plants.ⁱⁱⁱ This is the tip of the iceberg of the \$2 billion, clean-coal technology (CCT) expenditures President George W. Bush promised during his campaign in 2000.^{iv} And an encouraging trend is the growing recognition that clean-coal technologies include not just those for coal combustion, but technologies and mining equipment that produce cleaner coal. CCT starts “in the mine.”

While this, too, is good news, we need to understand all the drivers and business dynamics. The industry faces serious challenges—especially over environmental concerns. The need to reduce SO₂ and NO_x from coal-fired power plant emissions has favored (and will continue to favor) natural gas over coal. Pending regulations to curb heavy metal and mercury waste, and the Kyoto-related greenhouse gas restrictions on the horizon, also favor gas and alternative energy sources. The Bush Administration’s call for advanced CCT will help, but coal executives need to consider there are risks that threaten profitability.

While the higher level of coal prices should improve financial performance for coal companies, we need to see economic recovery in 2002. Some economists believe the lower prices of natural gas coupled with the 11 adjustments by Federal Reserve to lower interest rates will renew significant energy demand. That’s why coal management must continue to improve productivity, control costs, and mine cleaner coal. BHP’s Chief Executive Paul Anderson recognizes these issues, and driven especially by his concern of world economic slowdown has challenged his management to further reduce costs by 2 percent over the next three years.^v

Coal mining operations must produce a product that meets market requirements at a reasonable economic value. But there is a serious challenge developing. Geologists are telling us the coal reserve base in America is deteriorating. Despite being the “Saudi Arabia of coal,” future mining will be in reserves that are deeper, thinner, and gassier seams, and ones that are laced with anomalies. Twenty years ago the reserve base was estimated to be at least 350 to 400 years; now it is 275 years.

At the same time, the mining engineers are designing mine plans to deploy the super longwall panels where faces are wider (up to 1,200 feet) and the panels are longer (some are contemplating 4 miles or 20,000 feet). To make these panels operate efficiently, engineers are seeking the perfect block of coal. And therein lies the

challenge. At a time when mine operations require better reserves, the search is more complicated because there are fewer “perfect panels” out there. The problem is that these panels will contain more anomalies and thus a higher percentage of waste will be in the run-of-mine product.

However, there are new technologies that both the geologists and mining engineers need to meet this challenge. One addresses the need to scan or image ahead of mining to better understand the quality of the reserve. The second, that interests the mining engineer, is mounted on the cutting drums of the mining machines to provide real-time information/intelligence to guide the extraction process to avoid anomalies and improve run-of-mine coal. Improved run-of-mine coal is more economic because less waste is produced. Coal preparation costs improve because less waste is processed in the preparation plant. And for those companies that can ship a lower ash, lower sulfur product to the power plant customers, the cost of electricity is also reduced. Plant efficiency improves as seen in a better heat rate. Ash handling costs go down, as well as plant maintenance costs.

But perhaps the most important benefit is that these technologies improve reliability. In other words, they reduce risk: the risk of mining interruption caused by undetected anomalies; the risk of interruption caused by undetected roof and floor conditions. Risk reduction improves operational performance, which also improves financial performance. And when financial performance improves from a reliability standpoint, the cost of capital goes down, providing another layer of real economic benefit to mining companies.

The following outlines a technology and property development strategy. It starts with CBM production, mine planning, and operations that reduce waste and improve mine quality. The technologies include radio-imaging method (RIM™), which is used to improve coal seam assessment that can lead to better and more reliable CBM and coal mining plans. Additionally, it addresses a new measurement while drilling (MWD) tool, the Drill String Radar (DSR), which is used to assess coal thickness and roof and bottom conditions. It will then address horizon sensing; new technologies that make mining machines “smart” and able to improve quality and efficiency. It will then discuss the benefits to the power plant customers, and finally, the benefits to the financial institutions that are looking for improved financial performance.

TECHNOLOGY AND RESOURCE DEVELOPMENT STRATEGY

To achieve a significant economic benefit in leveraging technology, an overall plan is needed, from the property to the power plant. The first step is to drill and develop the property for CBM production. The second is

to complete the geological interpretation to prepare a least-cost mine plan. The final step is to mine within the coal seam to reduce mine waste and improve coal quality. Each step involves the use of innovative technology that reduces costs and improves quality.

The new interest in CBM is driven in large part by economics and reduced risk. Given the porosity of coal and its cleat structure, coal seams contain or hold a factor of four or five times the quantity of methane compared with other structures. And coal seams are found at depths of less than 2,500 feet. Thus, wells can be developed with relatively shallow drilling. CBM can require processing to remove impurities, but some gas pipeline companies are interested in blending CBM.

For the mining company, developing CBM production prior to coal production has a significant safety and economic benefit. During mining, methane is a serious hazard requiring a large volume of fresh air to dilute methane concentrations. By reducing the methane during CBM production, the coal company can save on ventilation costs. With many companies now deploying super panels for longwall operations where lengths of up to four miles are being considered, ventilation requirements may be the limiting factor. But with lower in-seam methane to deal with, the longer panels are viable with reasonable energy costs.

The second step of improving the pre-mining geological assessment is becoming critical. Today several coal companies have experienced serious production shutdowns due to geological anomalies. Sand channels that scour the seam, or in some cases completely eliminate the seam, have not only reduced or halted production, but in many cases, equipment has been damaged, requiring costly replacements.

Finally, detecting the coal seam horizon in real time while continuous miners (CM) or longwall shearers cut coal provides several benefits. First, the cutting of rock can be reduced, which improves yield and translates into a lower cost of clean coal. Second, there are safety and health benefits because the operators can do a better job while maintaining their remote mining position. Finally, maintenance and bit costs will be lower as less rock is mined.

APPLYING DRILL STRING RADAR

CBM is generally produced via vertical boreholes. To induce gas flow, fractures are created in the seam, which can extend long distances through the seam. However, a growing number of companies are employing horizontal drilling techniques where the borehole approaches the seam on the vertical, but is then directed into the seam. CBM production is greatly enhanced.

While horizontal drilling is becoming more popular, there is a need for improving the drill string guidance because current technology does not ensure the drill bit will stay within the coal seam, and current technology does not provide important data such as coal seam thickness and detection and identification of the host structures (roof and floor). Estimates indicate that up to 30 percent of the drilling cost or time is spent on repositioning the drill string to regain positioning within the seam. Also, the ideal position for the horizontal hole is to be at the mid-point of the seam.

The DSR is an innovative tool being developed and tested in Russia. It operates in real time as a MWD.

During drilling operations, the tool will transmit the coal thickness data via a radio signal. As mentioned above, this will enable the operator to keep the drill string along the “center line” of the seam. Through MWD operations, the capture of the coal thickness data is valuable information for subsequent mine planning.

APPLYING RADIO-IMAGING METHOD

Prior to coal mining operations, the companies need to develop a mine plan that reflects the realities of the geology. Today’s practice of assessing “proven” reserves from strictly vertical boreholes on half-mile centers has an unacceptably high risk of misunderstanding the extent to which anomalies are present and, worse yet, sand channel systems that might prohibit longwall operations. As mentioned above, several coal companies have reported production problems as a direct result of lack of intelligence about the geology.

With the property drilled for CBM production, there is an excellent opportunity to improve the reserve assessment through the use of RIM. The system can be used for creating images between boreholes on quarter mile centers. And as CBM producers increase the number of horizontal holes, there is greater opportunity to conduct RIM surveys between horizontal holes. In some mines where horizontal holes will be drilled on the longwall panels for methane drainage, RIM surveys can be applied there as well.

At the Stolar Global Center for Geological Interpretation (SGCGI), the results from a database of 500 RIM surveys conducted over the past 15 years indicates that an anomaly occurred every 1,000 feet of longwall panel length, and in 8 percent of the surveys, the anomaly was significant to the point that mining operations had to be halted.

Today, with the super panels, which are twice the width and now at least two to three times the length, the probability that serious anomalies will be identified has increased more than a factor of two. The SGCGI is

predicting that 15 to 20 percent of the super panels could encounter “show stopper” anomalies. The risk is too great that one out of five (or six) longwalls could be halted. The financial community has expressed its concern that such operational risk needs to be reduced to ensure continuing financing.

HORIZON SENSING

Fortunately, the coal industry has done an excellent job at cost reduction and control. Over the past two decades, coal management has responded with process improvement and re-engineering that deployed advanced technologies. In strip mining, larger and more productive equipment increased productivity and lowered cost. In underground mining, a shift to longwalls and super sections has had equally dramatic impact. In the United States, productivity for the past 15 years has improved on average about 7 percent per year.^{vi} It’s hard to find any other industries that can claim such dramatic results. For many coal companies, innovation and improved productivity have meant survival. Studies have shown that companies that innovate to reduce costs tend to lead their competition in financial results.^{vii} This is true for the coal industry.

The acknowledged “next plateau” of innovation, greater production, and productivity is the automation of mining equipment. Other industries (auto, chemical, steel, etc.) have employed automation to increase production, reduce labor costs, and improve product quality. It is not uncommon to find factories where production occurs unattended—so called “lights-out factories.” The key has been to identify tasks that are repeated and then employ robotic equipment capable of performing these tasks. Financial returns for such operations are attractive.

In coal mining, engineers have worked long and hard to identify specific tasks and processes where automation can be applied. Progress is being made. However, producing coal from an underground mine has one significant difference when compared with a factory above ground: the mine environment is in a constant state of change with respect to physical dimensions and locations of machines. The seam height is always changing, the seam horizon is always changing, and the primary production equipment is always moving. In a factory, there is a greater degree of stability. The distance of the shop floor to the roof is constant. The location of the production line is the same every day. The factory robots don’t have to detect changes in the shop’s conditions, they just repeat their tasks at the programmed time.

The variability of geology means that automation in a mine is a greater engineering challenge. While repeatable tasks can be identified and potentially automated, the machines require an extra capability of flexibility. They

have to change with the changing mine environment. For example, a longwall shearer may be faced with seam undulation so each pass or cut needs to be a different height. Memory programming is not necessarily the most efficient in such a situation. For true efficiency, the longwall shearer must be able to detect the coal horizon on each pass to set the preferred cutting height. Or better yet, the machine must be able to change mining height continuously as it moves across the face, perhaps adjusting cutting height through a range as much as 10 to 30 cm.

This concept of detection and continuous adjustment is a step beyond automation. Machines not only do repeatable tasks, but they behave in an intelligent fashion; the machines are flexible or agile. This is the world of “smart mining” or the equivalent of “lights-out” or “hands-off” operations.

To achieve such a state of “smart mining,” industry experts have identified six core technologies. These are:

1. Communications—especially wireless for signals between digital signal processors (DSPs) and control panels
2. Control Algorithms
3. Diagnostics
4. Navigation—the use of gyros to keep CMs on straight headings
5. Imaging Ahead of Mining—having accurate three-dimensional views of the coal seam, especially for super panels that run the greatest risk of having anomalies and washouts
6. Horizon Sensing—the ability for the machine to detect, identify, and respond to the coal seam horizon

While we could spend considerable time on all six technologies, and spend considerable time on advancing the concept of “smart mining,” for the balance of this paper we will direct our discussion to one core technology, specifically horizon sensing. We will further explore the need for and definition of horizon sensing, the underlying technology and the R&D collaborative that developed Horizon Sensors™ (HS), the economic benefits of the applications (case studies), and the beta sites and in-mine experience to date.

HORIZON SENSORS DESIGNED TO ADDRESS MARKET NEED

One of the great lessons of technology and invention given to us by Thomas Edison is the importance of developing products to solve a recognized business problem. The world has many interesting scientific discoveries seeking practical application. Edison pointed out that such were of little value. Instead he worked on only inventions that he knew the market needed and would pay for.^{viii} Following Edison’s example, Stolar Horizon, Inc. (Stolar) initiated a multi-year process of developing Horizon Sensors technology to meet the business need.

As all underground miners know, the cutting of coal is one of the more hazardous operations. The hazards include exposure to methane liberation, coal and rock splintering and outburst situations, airborne dust, and considerable noise. While systems are in place to reduce these hazards, it’s generally agreed that the more remote the operators can be, the better. However, remote locations have the disadvantage in that the operator cannot see the bits actually cutting the coal, and therefore does not have full control of operation. A technology that enables the machine operator to have better remote control of the cutting operation is desirable.

Additionally, underground miners know that roof and bottom conditions are greatly impacted by how the coal is cut. Conditions can vary greatly from mine to mine, and some operations cut “rock to rock,” while others want to selectively leave roof coal, and some bottom coal. As Figure 1 depicts, a CM operator faces many different geologies that dictate specific cutting strategies. And given the growing focus on producing cleaner coals, some mines selectively cut horizons to leave behind a greater percentage of waste rock and lower quality coals that may contain greater percentages of ash and perhaps trace metals.

The point is that unless the operator is close to the cutting, it is virtually impossible for him/her to see the various horizons and direct the cutting accordingly. As the experts of automation and smart mining have pointed out, the obvious need is for the operators of cutting machines (CMs, longwalls, borers, etc.) to have horizon sensing technology that detects the geology.

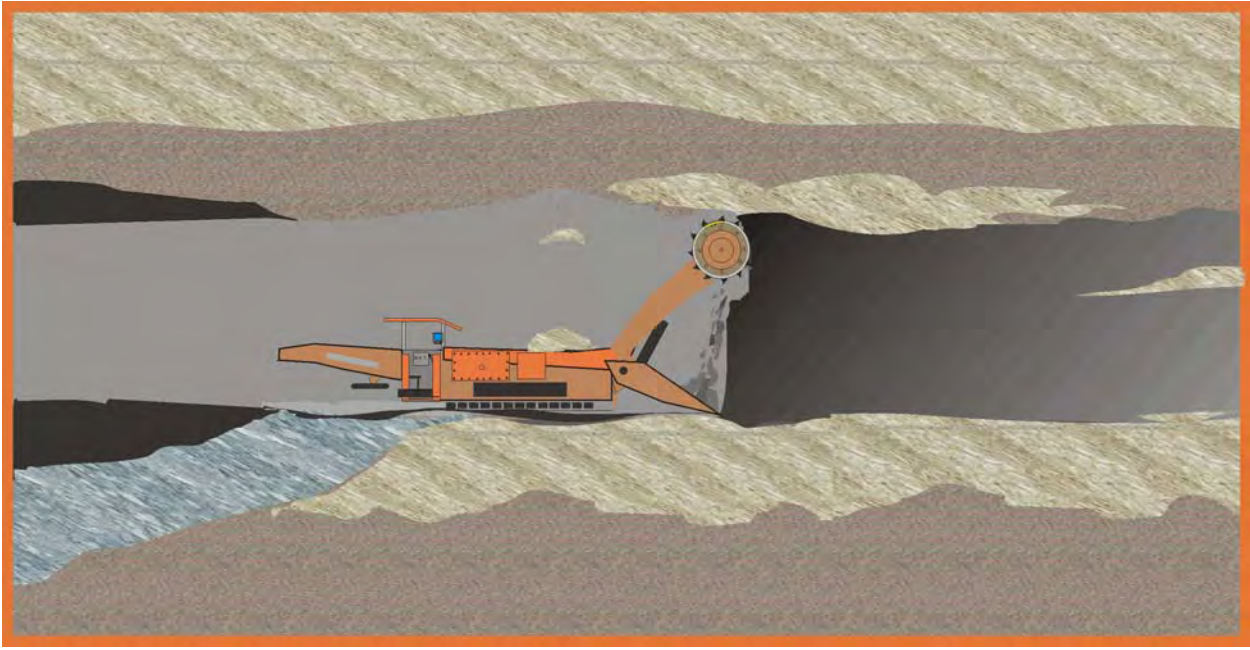


Figure 1. Vertical cross section illustrating continuous miner

A COMBINATION OF “CUTTING EDGE” TECHNOLOGIES

To achieve horizon detection, Horizon Sensor units deploy a combination of electromagnetic (EM) science, high-tech processors, and control software. The EM technology can continuously transmit and receive radio signals that provide data and readings that are converted to digital outputs. The core of HS is essentially a customized DSP. In the rapidly moving, high-tech and Internet world, DSPs are used in many products, such as hand-held devices, cell phones, pagers, etc.

The HS DSPs are mounted in the cutter heads or cutter drums of the machines. This location is different from where other horizon sensing products have been mounted. But these other products have not been effective, in part because they have been mounted on the back section of machines. These products have not been able to achieve meaningful readings from such remote locations. In the cutter head/drum, inches from where the actual cuts are being made, is the right location for HS. Once the measurements are made and converted to digital format, the data are transmitted via wireless communication to the control box that includes a graphical user interface for the operator.

Given the complexity of the hardware, software, and communication system, Stolar had to employ a collaborative research and development strategy to gain scientific capabilities beyond its organization. In fact, the complexity required a team of world-class organizations—no one organization had what it takes. The Stolar R&D partners include an illustrious group: NASA,

Sandia and Los Alamos National Laboratories, and the Institute for Measurement Systems Research (NIIS)—the Russian advanced technology center. For the mining industry, this is an unprecedented R&D collaborative, but again, one that was necessary because of the required combination of skills and knowledge. Turning to the United States Industry Coalition (USIC), Stolar not only was able to assemble and manage this impressive group of research partners, but considerable funding was made available because of the importance of the need to develop horizon sensing capability.

POINTS OF ECONOMIC VALUE

Coming back to Thomas Edison’s rule that an invention must have economic value, Stolar has given great consideration to understanding the value of Horizon Sensors. Independent analysis and case studies show that there are three places where value can be captured: 1) in the mine, 2) in the preparation plant, and 3) in the power plant. And as a point of reference, value can take form in a number of ways, such as cost reduction or an increase in sales price. But whatever the form, the focus is to increase profits and shareholder value. Such analysis is the foundation for showing shareholder value-added/analysis, popular with many Chief Executive Officers.

“In the mine” is the first location coal executives think of when a discussion centers on cost reduction or production increases. As everyone knows, for the past many years “cost reduction” has been the mantra, but with the growing demand for coal and the energy crisis conditions, increasing production is an objective of many

operations. Horizon Sensor applications enable both cost reduction and volume increase.

There are several Horizon Sensor “in-mine” economic benefit opportunities such as:

1. Greater yield—probably the greatest capture of value is that horizon sensing allows the operator to reduce waste and improve run-of-mine quality; this benefit can be considered as either cost reduction or volume increase, or both.
2. Longer bit life—keeping the bits out of rock will cause the bits to last longer.
3. Reduction in fines—advanced versions of the HS will have bit force detection for optimum bit spacing, and operators that have better control can reduce the need for excessive cutting.
4. Improved efficiency—especially for CMs leading to an optimum cut and load cycle.

As an example of demonstrating the importance of improving yield, we turn to analysis conducted on coal production coming from the Pittsburgh Seam. As a case in point, the Pittsburgh Seam over the years has been one of the world’s greatest coal resources of wealth creation, but it also has generated considerable mine waste. Analysis shows that a 1-percent improvement in yield over a one-year period is worth \$75 million. The annual production from the Pittsburgh Seam is about 75 million short tons per year, and has an average value of \$19 per short ton. The value of improving yield is a simple calculation.

For a specific mine, the economic benefit can exceed \$1 million per annum. The total savings for a mine are derived from less material usage, labor savings, and most important, improved productivity. In a longwall coal mine, the primary focus for Horizon Sensors needs to be the longwall(s) unit(s) itself because these units represent the greatest portion of the mine production. However, improving CM productivity is also important because more productive CM sections reduce panel development time.

In the preparation plant, value is captured when a cleaner run-of-mine coal is produced by the underground (and surface) operation. The first point of value is that the preparation plant’s capacity for producing clean coal is effectively increased. Less waste into the plant means more clean coal out. Also, a cleaner run-of-mine coal for most plants means a reduction in processing supplies, less waste to dispose of, and less wear and tear on the plant’s equipment, leading to reduced long-term maintenance costs. Our analysis shows that the savings at a coal mine can be \$0.10 per ton over 7 million raw tons inputted to the plant.

Finally, there is considerable value to the end users of coal when quality is improved. This is true for both steam and metallurgical coal consumers. But given the fact that the greatest volume of coal goes to steam markets, we focused our economic benefit analysis on power plants.

Over the years, Electric Power Research Institute (EPRI) in Palo Alto, California, has sponsored considerable research investigation on the economic benefits of cleaner coals delivered to power plant operations. The EPRI Cost Quality Management Assessment (CQMA) modeling effort and various offshoots are well known to coal marketing executives. The modeling of quality effects on power plant economics has become quite sophisticated. For example, a coal with less ash content can reduce a power plant’s bus-bar variable costs, measured in cents or mills per kW-h. Cost reductions at the power plant for ash-related items can be found in several areas including:

1. Ash and waste-handling systems
2. Ash and waste disposal (the cost of waste disposal has been escalating as environmental regulations have become more restrictive)
3. Boiler and boiler tube maintenance (a reduction in corrosive ash material will enable longer life)
4. Boiler efficiency (less ash improves heat transfer dynamics within the boiler)

As an example, analysis shows that for an 800-MW western US coal-fired power plant, a decrease in ash content of 1.5 percent of total weight has an economic benefit or value equal to \$2.6 million of annual savings.

Additionally, for lower sulfur content in coal achievable in part through more selective cutting strategies, power plant costs savings include a reduction in lime usage where scrubbers are in use. Lower sulfur content can also mean the purchase of fewer greenhouse gas credits (SO₂) to meet emissions limits. Actually, in some cases, cleaner, low-sulfur coals can create or generate emission credits adding considerable value. These costs savings at coal-fired power plants are real. Evidence of such recognition includes the recently announced \$95-million Department of Energy (DOE) program for improved coal-plant efficiency. End users of steam coal highly value such improvements.

BETA TESTING

The Horizon Sensor technology has undergone beta testing at several mines. As part of the US DOE and National Mining Association (NMA) Mining Industry of the Future program, Stolar has been working with several coal company partners. The beta test mines include

underground operations in South Africa (Sasol), Pennsylvania (CONSOL), Wyoming (FMC trona), and New Mexico (Peabody surface mine). The results of these sites have aided the development of Horizon Sensor Model 3 (HS-3) for commercial applications. Today, a commercial unit is in operation at Monterey Coal mine in Illinois, and the technology has been identified by the State of Illinois as a CCT.

Of particular importance in the development of HS was the testing done at a Sasol underground coal mine in the Republic of South Africa. Through two separate trials in August and October of 2000, the Stolar-Sasol team identified design and operational improvements for the Horizon Sensor. This effort led to a reconfiguration for ease of installation and maintenance, as well as mechanical design aspects for long-term, trouble-free operation. Figure 2 is a photograph of the HS units mounted on a CM cutter head.

Additionally, the HS-3 unit underwent accelerated life-cycle testing at Sandia National Laboratories. We believe this is the “first ever” of such testing of a device for mine application. As one of its competencies for testing and proving the designs of nuclear weapons and space vehicles—hardware that requires absolute reliability and “zero” failure—Sandia has the processes and test facilities to quickly identify design flaws. Sandia can essentially test and certify the life expectancy of a

component. Stolar management decided to leverage Sandia’s testing capability to ensure high performance of the HS unit. Stolar also retained as a technical advisor Glenn K. Rightmire, retired professor of mechanical engineering at Columbia University’s School of Engineering and Applied Science. Professor Rightmire, a long-time consultant to the mining industry on design issues, has not only provided input to design specifications, but also advice and expertise as a member of the Stolar-Sandia team that conducted the life-cycle test effort.

The HS unit and associated technologies are being modified for application on longwall shearers. The unit will allow the shearer operator to identify the “optimum” horizon on longwall panels. Super panels of today, having dimensions of 20,000 ft x 1,200 ft x 11 ft, can contain more than 10 million short tons of coal and provide considerable economic benefit.

In addition, the HS unit is available for use on bore-type CMs commonly applied in trona, potash, and salt mining extraction. The HS technology can survey in-seam impurities found in these soft-mineral deposits. Once the impurity is detected, the mine management can take measures to alter horizon or face mining procedures. The HS technology is advantageous in mineral extraction where mining the correct horizon improves product quality, ground control, and safety.



Figure 2. Cutting drum (without bits) with sensor mounted on surface

There are considerable benefits to the use of Horizon Sensors. This is a critical technology for meeting today's business needs of increasing production and productivity in the short term, but also for advancing "smart mining" in the longer term. Stolar Horizon, Inc., is a company on the cutting edge of horizon sensing.

RISK REDUCTION AND FINANCIAL VALUE

The final piece of economic value that we need to address is that associated with operational risk reduction and a more predictable financial performance. This topic has been gaining visibility and acceptance with the banking community in the United States as well as in Europe.

As indicated above, there is considerable risk in mining and the greatest risk is usually found in assessing or dealing with the geology. There are numerous examples of where misunderstood geology has caused production shutdown resulting in lost profits and poor financial performance. For example, Professor Dagdelen of Colorado School of Mines, published an excellent paper addressing this issue in the gold industry. He examined 40 projects that he valued at \$2 billion of initial investment. At a later date when he examined the projects, which were classified as "troubled" (that is shut down or producing less than was originally projected), Professor Dagdelen estimated that the value of these projects had fallen by approximately \$1.5 billion to \$500,000 million. He determined that 73 percent of the "problems" were geology related in that the reserves were not properly analyzed and understood prior to initial operations. Assuming the 73 percent of geology issues is evenly distributed throughout these projects, one would conclude that approximately \$1.2 billion of value was destroyed due to bad information about the reserves.

In the coal industry there are many examples as well. *Coal Age* recently reported in its September 2001 issue situations where poor coal reserves and anomalies have interrupted and shut down production at Consol's Rend Lake and Mine 84 mines. The article did not quantify the cost of such production interruptions or shutdowns, but the Mine 84 situation was extremely costly because it involved lost production during an attractive coal market. The probability of such problems occurring is increasing given the above-mentioned deterioration of the coal reserve base and the desire to mine larger super panels. These two trends are increasing risks, which require attention and improved analysis to offset and reduce the risk factors.

In the financial community, a popular measure of value is the Shareholder Value Equation, which is defined by increased profits minus the cost of capital.

$$\text{SHAREHOLDER VALUE INCREASE} = (\text{REVENUE} - \text{COST}) - (\text{WEIGHTED COST OF CAPITAL})$$

In this case new technology impacts shareholder value two ways. First, as shown above the technologies can reduce operating cost thus improving profits. Second, as risk is lower, the financial community will be able to lower the cost of debt and equity. To illustrate the financial impact, we use an example of a new coal mine in the Pittsburgh Seam in Western Pennsylvania that might require \$200 million in initial investment. If the weight average cost of capital is reduced by 100 basis points, the net present value of such a reduction is worth \$20 million over the life of the project (assuming at least a 15-year life). Some bankers believe the lower risk might lower the cost of capital well beyond 100 basis points, so the \$20 million saving might be considered conservative. It also is a significant "real saving" to the mining firm to provide considerable financial cover and payback for the cost of securing the new technology.

i CNBC, Power Crisis, co-hosted by Bill Paul, aired November 23, 2000.

ii "The Third Energy Crisis," delivered by Glenn G. Wattlely, November 15, 2000, at EPRI Power Generation Seminar, Washington, DC; *Wall Street Journal Reports*, aired December 4, 2000, NBC programming.

iii *Wall Street Journal*, February 7, 2001, "Coal Plants are Offered Grants to Raise Efficiency, Cut Pollution."

iv Associated Press, February 6, 2001, Washington, DC, "GOP Senators to Pitch Energy Bill."

v Dow Jones Newswires, February 7, 2001, Melbourne, Australia, "BHP Committed to 2% Cost Cut Plan Over Next 3 Years."

vi Source Data, National Mining Association, *Facts About Coal, 1999-2000*; estimates by Stolar Horizon, Inc.

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viii Josephson, Matthew, 1959, *Edison A Biography*, John Wiley & Sons, Inc.