A VIEW OF UNDERGROUND COAL MINING IN THE 21ST CENTURY

By

Dr Lewis V. Wade1

ABSTRACT

The intent of this address is to look forward into the 21st Century and present certain thoughts as to how underground coal mining might be conducted. The views in this talk are based principally on the author's experience with mining practices in the United States.

It may be difficult to accept, but the 21st Century is a mere 12 years away. What new techniques will be available? To develop an understanding of the way in which technology has been and could be changing, a two-stage analysis is made of mining technology for U.S. Coal. The first phase covers the period 1975 to the present, while the second includes 1960 to 1975. This historical perspective includes a view of underground production by mining methods, considerations of labour productivity, and a review of accident and fatality rates.

Several topics are important features of this historical analysis. Among the most significant are: (1) the introduction of longwall mining technology into U.S. underground coal mines, (2) the use of computers to assist in mine planning and design activities, (3) major efforts to improve health and safety performance, with emphasis on underground dust control, and (4) improvements in mining equipment with an eye towards increased reliability and up-time performance.

Based on that historical perspective, projections are made in three increments. The first being immediately at the turn of the century, the second being a dozen or so years beyond that, and the third being at the quarter point of the 21st Century.

The turn of the century should see incremental improvements in the configuration of current mining systems. Of particular interest would be the issue of longwall layout and entry consideration. This time period should also see the increasing use of the computer to assist in mine planning design and practice, with particular focus on the application of expert systems. The short-term forecast includes ever increasing up-time and system reliability as well as the use of mine-wide monitoring systems, both from a safety as well as from a production point of view.

In 25 years underground coal mines may realise the benefits of significant changes in mining system configuration, borne of the relaxation of the requirement of having men at or near the production face. Such mines will probably build upon the possibility of the real-time use of information to control the overall process of underground mining.

In the longer term, advanced technologies such as borehole mining may provide selective access to coal seams. The mining systems of this period will focus on extracting the value of a deposit with minimal disruption of the environment and low risk to the mine worker.

This analysis concludes with a discussion of what is the most effective path to follow from what we have now to what we would like to have, i.e., more productive, safer underground mining systems. The path to tomorrow's mining that will remove the restrictions of conventional thinking and free the creative processes that will lead to new, efficient technologies.

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INTRODUCTION
The intent of this paper is to look forward into the 21st Century and present thoughts as to how underground coal mining might be conducted. The views in this talk are based principally on the author's experience with mining practices in the United States, and makes projections on what developments might be forthcoming for that country, with potential application around the world.

It may be difficult to realize, but the 21st Century is a mere 12 years away. What new technologies will be available? To develop an understanding of the way in which technology has been and could be changing, two-stage analysis is made of mining technology for U.S. Coal. The first phase covers the period 1975 to the present. The second includes 1960 to 1975. This historical perspective includes a view of production by underground mining methods, considerations of labor productivity, and a review of accident and fatality rates.

Several topics are important features of this historical analysis. Among the most significant are: (1) the introduction of longwall mining technology into U.S. underground coal mines, (2) the use of computers to assist in mine planning and design activities, (3) major efforts to improve health and safety performance, with emphasis on underground dust control, and (4) improvements in mining equipment with an eye towards increased reliability and up-time performance.

Based on that historical perspective, projections are made in three increments. The first is immediately at the turn of the century, the second is a dozen or so years beyond that, and the third is at the quarter point of the 21st Century.

Forecasting the technology used to mine coal some 30-odd years from now poses significant difficulties as anyone who has reviewed crystal-ball forecasting attempts in other fields can verify.

The factors that can determine the development of this technology include aspects such as demand for coal, price of alternative energy sources, ability of environmental technology to allow continued use of fossil fuels, and the success of technological innovations in coal mining and other fields.

Technology development is difficult to accelerate in most industries. In the mining industry it is particularly difficult because of the constraints of high risk, and the constant requirement to produce a commodity that does not differ from that produced by numerous other competitors all engaged in trying to produce it for the lowest possible cost.

The life cycle of a specific technology having practical applications starts with a discovery point; perhaps resulting from a theoretical development or a series of experiments. Some growth may immediately follow the discovery, but often the needed application is delayed for considerable time. The eventual development usually increases slowly at first until an adequate technology transfer has been achieved to produce dynamic growth associated with widespread usage. Ultimately, the "state of the art" levels off and the particular technology is regarded as mature. Further improvements are difficult to achieve.

Because of small profit margins, most improvements in a mature technology are made to keep a competitive advantage, and few corporations can devote the capital needed for high-risk projects to reaccelerate the technology. Gradual improvement may be noted, but dynamic growth is absent. A discovery in this technology or in a related technological field is needed to again initiate dynamic growth.

Because of the high-risk factors inherent in mining, companies tend to be conservative, and require new technology to be adequately proven before large sums of money are spent on implementation. Developments tend to move slowly before final acceptance and full utilisation by the industry. This is
illustrated clearly by the following brief review of a few developments in the United States over the last 100 years.

During the 20th century, the progression of room-and-pillar coal mining in the United States from pick-and-shovel coal winning with mule haulage to continuous miner coal winning with conveyor or shuttle car coal haulage has been a very slow, evolutionary process, with most of the significant improvements occurring in the first half of the century. In the area of coal winning, the first heading driver was developed by Jeffrey in 1913, the first successful coal loader was built in 1917, the first continuous miner was used in 1948, and the first coal plow was used in 1951. In mine transport, the first belt conveyors began in 1917, and the first all-conveyor coal mine operated in 1933. Extensible belts came into use in 1950. Rubber-tire haulage began in 1935, and the first Joy shuttle car was operated in 1939. The first roof bolts were developed in 1946. Since 1950, almost all production improvements in room-and-pillar coal mining have been incremental improvements to existing equipment. My predictions for new developments in the coal industry in the next 40 years are much more optimistic, due in part to the world-wide technology explosion and the advent of longwall mining, a system that promises much greater productivity through continuous operation.

With due consideration of these factors, or perhaps in spite of some of them, I believe that by the turn of the century we should see incremental improvements in the configuration of current mining systems. Of particular interest would be the issue of longwall layout and entry consideration. This time period should also see the increasing use of the computer to assist in mine planning, design and practice, with particular focus on the application of computer systems. The short-term forecast includes an ever increasing up-time and system reliability as well as the use of mine-wide monitoring systems, both from a safety as well as from a production point of view.

It is possible that within the 25-year time frame you could begin to see mining system selection being significantly impacted by considerations of resource conservation. Should such requirements come about it would be possible to begin to look at a bias towards mining systems that extract a greater percentage of the resource.

In 25 years underground coal mines may realize the benefits of significant changes in mining system configuration, borne of the relaxation of the requirement for the production face. Such mining will probably build upon the possibility of the real-time use of information to control the overall process of underground mining.

In the longer term, advanced technologies such as borehole mining and in situ combustion may provide selective access to the energy of coal seams. The mining systems of this period will focus on extracting the value of a deposit with minimal disruption of the environment and low risk to the mine workers.

I will now discuss the various elements of the U.S. industry, past, present, and future, and try to persuade you that the developments I project are not only feasible but likely occurrences. I will conclude with a discussion of what is the most effective path to follow from what we have now to what we would like to have, i.e., more productive, safer underground mining systems. The path to tomorrow's mining systems requires the research to solve the problems of today as well as studies that will remove the restrictions of conventional thinking and free the creative processes that will lead to new, efficient technologies.

**HISTORICAL PERSPECTIVES**

If we look back about a dozen years or so, about the same amount of time as we have until the year 2000, we would observe significant changes in key features of underground mining. About this time (1975-1977), productivity in U.S. underground coal mining had reached a low point of just a little over 1.0 ton per employee hour. This level of output was lower than the productivity level that had been attained in 1960, and was only about one-half of the output attained in 1969. Many reasons have been advanced for the decline in productivity, some of them nontechnical. Some people believe the Federal Coal Mine Health and Safety Act of 1969 was one of the chief reasons. Others point to causes such as high demand for coal, questionable management practices, and a younger workforce.

The years since 1977 have seen sustained improvement in productivity. We passed the old 1969 peak of just under 2.0 tons per employee hour in 1984, and have seen an additional 30 pct improvement to reach a level of roughly 2.6 tons per employee hour. An impressive as this improvement has been, both the Department of Energy (DOE) and the National Coal Association (NCA) predict that coal mining productivity will increase by 25-30 pct before the turn of the century, and that most of this improvement will come from technological advances.

The earlier period of this retrospective look at U.S. underground coal mining constitutes the period from 1960 to about 1972. The first 10 years saw the steady growth of mechanization as more mining sections adopted the productive continuous miner instead of conventional shot firing. After reaching a peak in 1970, productivity went into a serious decline that required almost 15 years for recovery.

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Just as many reasons are advanced for the previous decline, several are proposed for the current improvement. Coal demand is down. The mines must be more productive to remain open. Only the most favorable seams are being mined with equipment that is in the best condition. More attention is being given to mine operation planning. Workers have more incentives to be productive.

There is also a technological side to the story. More mines are using modern technology, although the technology of conventional and continuous mining tends to be similar to that employed in previous decades. The late 1970's and early 80's has seen a dramatic change in the application of longwall mining in the United States. This movement has resulted primarily from the higher productivity of longwall technology compared to continuous or conventional operations. In 1976 for example, there were 71 longwall faces working in the United States and only 8 pct of these used shield supports. In 1987, longwall faces totalled 101, but more importantly, 97 pct of these were shield installations. The average panel width in 1976 was about 406 ft, while in 1987 it was on the order of 600 ft, an increase of 50 pct.

Taking an historical perspective, the use of computers to positively affect the mining industry is a trend that can be noticed over the past years. Professor Ramani of Penn State University, in a paper given at the World Mining Congress in Stockholm in 1987, characterized the adoption of computer technology by the mining industry as lagging an extra decade compared to the normal 10-year delay experienced in other industries. Still, computer usage in the 1970's increased in all areas of mining, metals, nonmetals, and coal. The functional areas with the most expansion were exploration, mining, processing, valuation, and marketing. Although applications of computers to areas of mining information systems, corporate management and management support systems accounted for only 10 pct of the literature presented in the symposiums on computer applications, the potential for application of computers and operations research for senior management decision making is projected as an important growth area for the future.

Initially, computers had their impact from a technical point of view in providing design assistance to the practical mining engineer. Looking at the layout of underground workings, consideration of the design of ventilation systems, and the design of underground coal transport systems, all were made easier by the use of the number crunching capabilities of digital computers. More recently, there has been a trend towards the use of computers to monitor systems status in real time. Additional applications involve the use of computers in real time to monitor the status of production systems. For example, use of computers to monitor belt condition and belt availability has started to receive widespread use within the industry.

Another interesting area for computers is in conjunction with automatic data acquisition systems that are being used in connection with geophysical equipment and mine drills. Computer processing systems aid in downstream data processing for real-time visualization of the information in mine planning activities. The use of computers for process control is the highest degree of application, and this state of development is coming in more areas of mining.

If we look retrospectively at the safety record of underground U.S. coal mines, and consider the influence of underground coal mining have been the result of a systematic approach to the problem of safety. By this I mean realizing that the system in which we work is highly variable and highly in need of management in a way to demonstrate drastically different behaviors. The approach taken has been to design and systematically implement a safety system. This is evidenced in the area of the systematic application of roof support. One example is the requirement of minimum roof bolt plans and the following of those roof bolt plans for geologic situations. Another example would be the systematic application of rock dust to deal with the problems of the igniting of coal dust. Again, rock dust is applied systematically, not just when high-risk situations might be detected.

The use of water sprays in a systematic way to work the dust problem is another example of establishing a plan of action and following that plan of action regardless of the local situation. In my opinion, it has been the consistent approach to safety that has been responsible for certain of the improvements realized in underground coal mining safety performance over the past 12-25 years.

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Also, a trend realized in terms of the application of roof support in underground coal mines has been towards designing for the worst case situation. At the one end of the spectrum the use of shield supports is an attempt to totally put the productive system was well as the person in an envelope of steel, thereby not having to deal with the vagaries of the local geology. Even in room-and-pillar mining there have been attempts to go to roof trusses and significant strapping between roof bolts—again in an attempt to cover the vagaries of nature by putting an artificial structure between the productive system, the person, and the surrounding geologic environment. This approach reduces the potential for fatal injuries.

The U.S. underground coal industry is safer today in terms of fatalities than ever before, and up until last year, the same could be said for the nonfatal, lost-time injuries. During the 4-year period 1978-1982, incidence rates for this accident category were about 10 to 12 per 200,000 hours. During the next 4 years the incidence rates were all under nine per 200,000 hours. The fifth year (1987) saw the incidence rate for this category jump over 12 again, back to the same level that had been common in the earlier period, and a complete reversal of the apparent trend.

Although I have looked back to 1960 for the fatal injury picture in safety, the nonfatal lost-time analysis has only been carried out for the past decade due to changes in the Mine Safety and Health Administration's data base that make comparison of statistics on these types of injuries very difficult.

FUTURE TECHNOLOGIES FOR U.S. UNDERGROUND COAL MINING

In this look at the future, I have chosen to use three perspectives: short-term which would be 12 years from now (roughly in the year 2000); mid-term which would be 25 years from now (looking at the year 2010-2015); and long-term which would be 35-40 years and beyond.

In general, in the short-term period I would expect to see optimization of existing elements of current production systems. These improvements would not only be in the configuration of those elements, but also in the control of them. In mid-term I would see new systems come into play; systems that still attempt to physically remove the commodity (in this case coal) from the ground, but which are no longer limited by current constraints, such as having miners at or near the point of production. I would, therefore, see a new generation of underground extraction systems developed that would not simply be the optimization of existing elements or of existing systems. In the long-term I see systems that would noninvasively remove from the ground the desirable attribute of the particular commodity in question, not necessarily the commodity itself. In this case, I would be looking at systems that would remove the useful energy from the material as opposed to bringing the material in bulk form to the surface.

PROJECTIONS TO THE YEAR 2000

Two fundamental approaches are available to increase the productivity of a mining system: (1) you can improve the instantaneous production potential of the system; or (2) you can increase the amount of time that the system is in production. Breaking down the amount of production time of that system, the system could be out of production because of unplanned down-time (this would be breakdown), or it could be out of production based upon planned nonproductive time, where, based upon the configuration of the system, it is necessary to move equipment as part of the basic system configuration.

In my opinion, while there have been trends over the past dozen years to try to increase the instantaneous production potential of a particular piece of equipment, i.e., deeper web shearsers, the majority of the improvement has been aimed at keeping the production system in coal a greater percentage of the time. This has taken the form of increasing system reliability, thereby decreasing down-time. Examples of this would be a decided trend in the industry to use higher capacity systems, i.e., in the minds of industry more reliable systems, (for example, higher capacity roof supports, particularly shield roof supports would be thought to be more reliable pieces of equipment). This trend should continue along these lines in the near future.

In addition to decreasing unplanned down-time, there has also been a decided trend to try to keep the systematic nonproductive time of the equipment to a minimum. Examples of this trend are provided by increasing lengths of longwall faces and panels, the changed plans for continuous miner operations, and the use of continuous haulage systems, so that the continuous miner can mine more continuously. This last feature would also extend the distance a continuous miner can go without turning, thereby keeping in coal a greater percentage of the time. Also, I think the movement towards longwall mining as a means of production shows a movement toward a system with more time in the coal. The nature of the longwall system with its available continuous haulage and continuous roof support potential creates a system that has less planned nonproduction time than would a comparable continuous miner system.
Also in the short term I see changes in the roof support, life support, coal winning, mine design, and transportation elements of underground coal mining.

In the area of roof support, I see trends toward the design of system-protecting or person-protecting structures so that, regardless of how the natural strata might be flawed, adequate support would be provided. This, again, is the continuation of the concept of putting a person or a productive system in a steel box. In addition, increased problems will be placed upon the roof support element in this span as one considers that mining is liable to focus on deeper and geologically more difficult reserves. These situations will encourage the idea of putting the person and productive system in protective envelopes rather than trying to deal with geologic variability.

In the area of life support (the maintenance of an acceptable environment for people working at or near the production face), I see advances coming in the area of the systematic application of mine environmental monitoring with an eye toward early identification of problem areas so that remedial action can be taken. Again, learning from our look back in the area of systematic roof support or systematic rock dusting, I think improvements can be realized in the short-term through the systematic monitoring of the mine environment. This involves dust levels, oxygen deficiencies, methane levels, and the early sensing of mine fires. Since most of the technology is available, I see the benefits from the systematic application of such technologies.

Concerning the coal winning function, the only change I see on the short-term horizon is in the area of the use of water to assist in the winning operation, while at the same time accomplishing significant environmental benefits. I think water-injection assisted cutting on mechanical cutting systems is something that will increase in the next 10 to 12 years. Also, in the area of coal winning, concepts such as deeper cutting (which have benefits of reduced dust, reduced potential for frictional ignition, and more energy effective) could begin to have impact upon the scene within the short term.

Concerning transportation, in the short term I see attempts at bulk transportation with increased flexibility so that the continuous transportation system can more closely track the point of production.

In the area of mine design, I see creating configurations that allow the productive element to remain productive for greater percentages of time. Improvements in longwall face length, panel length, and increased break-to-break distances in room-and-pillar development are examples of mine design changes that I would see continuing along current trends in the next 10 to 12 years.

Also in the area of mine design from a broad perspective, in the short term frame as it relates to longwall mining, I see increased emphasis on higher-speed entry development for retreat longwall mining. As we move towards establishing the retreat section face as a continuous coal producing facility, we need to be prepared to see that the subsequent panels can be developed at a rate that is consistent with the advances made in face retreat speeds.

The means for achieving certain improvements in mine design could well be the increased use of the expert system. The expert system represents to me a structured means of quantifying past experience, making use of design logic, and bringing these two together in a structured fashion to effect decisions. Expert systems are already making their way into the industry with regard to such things as methane drainage and dust control. I see further expansions of expert systems to layout and configuration, ground control, etc.

One also needs to be cognizant of the environmental impacts of mining. Most important of those impacts in this time period I would see as surface subsidence. Mine design and layout considerations need to take into account the surface requirements as they relate to subsidence. In the 10 to 15 year timeframe, we see improvements in our ability to fine tune mining systems so that they result in subsidence in a way that is consistent with other land uses.

There are two fundamental methods for dealing with the potential adverse effects of mine subsidence. One is to limit the amount of subsidence by either limiting the amount of coal extracted or by putting something back in to replace the coal. On the other extreme is the removal of all the coal so that the subsidence event takes place in a short and controlled time period. Certainly in the short time frame, the 10 to 12 year time frame, I see movements towards full extraction leading to the occurrence of very predictable short term subsidence. This would involve movement towards mining systems that would, with regard to longwall, either not develop chain pillars as an integral part of the mining system, or remove those chain pillars with longwall extraction or immediately following longwall extraction.
Consistent with thoughts of using water to assist in cutting, I also see increased attention being given to the use of water as a transport medium. While there has been a great deal of activity devoted to hydraulic transport of coal, I think that in the time period in question, these considerations will be revisited with the possibility of increased use of water as an in-ground transport medium.

Before leaving the discussion of near-term potential developments, some attention should be devoted to the concept of automation as it relates to underground mining. It is reasonable to assume in the short term that we will see an increasing trend towards the automated control of particular operations within the underground mining system. I see this trend principally taking the form of computer controlled repeating sequential operations. I believe through such computer control one will move towards more reliable operation that rules out the possibility of human error. In the short term I see such operations geared towards control of equipment position within the framework of the deployed mining system. Also I believe that there will be increasing trends towards gathering information concerning the natural strata condition and beginning to use this information to control processes. The most obvious application of such geologic information in the short term would be a move toward horizon control of coal winning equipment.

In a recent paper on technological forecasting, Suder and Qualmann applied decision modeling approaches to the problem of predicting the percent of market share that longwall mining would achieve. The year 1950 was chosen as an initial point when the longwall share of the market was 1%. The mechanism of an expert panel was used to project that the year 2000 would be the terminal year when the longwall technology of today would have achieved its maximum technological development. Application of their method provided an estimate of 54% by the year 2000, judged to be the peak year for application of the technology. Higher estimates of market share of 63% were rejected by considering that some U.S. mines will simply not be able to use longwall mining due to seam conditions and the nature of the U.S. industry. This value represents one estimate of the future application of a mature technology, and does not seem to be unreasonable considering that the percent of underground coal production coming from longwalls increased from 9% in 1982 to 18% in 1986.

Also within this time frame I would expect to see increasing trends towards automation of particular elements or operations of the overall mining system.

Concerning the intermediate period of our look forward, it would be reasonable to expect to see continuation of certain of the trends mentioned in the first time period, that is, increasingly reliable systems and element optimization. I do think though, that the 25-year time period is far enough into the future that we would start to see major changes with regard to system configuration.

In that timeframe, I would expect to see systems configured in ways that are not constrained by having to provide a safe and healthful environment for a person at or near the production section. I see a movement towards the maintenance of limited bases of operation underground, with significant extraction taking place out of those bases using primary cutting techniques, on the order of auger mining techniques. In this case, I would expect to see those limited-manned accesses or machine accesses underground tremendously supported, so that no vagary of nature could cause an instability. I would further expect to see actual production extraction taking place with little or no roof support, again, using circular or nearly circular openings to remain self-supporting for brief periods of time while the extraction is accomplished.

Paralleling the previous discussion with a view of where I see the different elements of mining systems going in this intermediate period I provide the following: In the area of coal winning, I would expect to see primary extraction accomplished using auger-type mechanical systems assisted with water or possibly totally water-based extraction systems. Again, I would envision a coal-winning system, that is the principal production system and not the development of the safe protected entries, to be a system that can create an opening that is by its shape self-supporting for a short period of time, i.e., circular in nature. The system will also have the capability of digging itself out of a moderate squeeze or pressure situation. Again, this is consistent with the belief that the primary extraction will take place without a person at the production face.

In the area of life support in the well-protected areas, I would see the maintenance of a high-quality working environment, almost a laboratory environment. Out in the main production areas, I would see limited attention paid to the maintenance of a life-supporting environment. I do see the use of water cutting as a means of eliminating problems associated with ignitions.

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In the roof support area, again, I foresee over support in the protected entries and almost no support in the actual production area save for the configuration of the opening itself. As it is possible that the environmental concerns over surface subsidence would grow, it is not inconceivable to imagine a productive system that as part of its operation fills or partially fills the production voids.

Concerning the broad area of system or process control, I would expect to see the use of information in real time to control the processes discussed above. I would expect to see the application and deployment of arrays of sensors that would have the ability not only to assess the status of an operation but also to begin to provide information that could begin to control the process in real time. For example, information concerning geology might be sensed during actual coal production and that information factored into the design of subsequent extraction events in that area.

Also, given the fact that a person will generally be remote from the majority of the area of extraction, I would expect to see a great deal of on-board diagnostic sensing relative to the machine status, and performance so that machines could be kept at peak operating efficiency.

As mentioned in the beginning of this section, while it is interesting to imagine totally different concepts and configurations, it is also likely that the intermediate period would involve continued improvement of the technology and the development of new technology that might take place during that period and, in my opinion, include the following: In the roof support area, the use of chemical modification of the area of opening to provide a thin yet extremely competent perimeter ring to an underground opening. This might involve the injection with site solution and in-place polymerisation to create a ring of support around an opening or it might have to do with the use of heat to chemically modify the rock immediately around an opening to create a self-supporting protective shield.

Also in the roof support area, it is not inconceivable to look at design change in phase of material to provide roof support. The simplest example of this would be the use of water made into ice for brief periods, time to provide support.

Certainly production systems that are evolving into use into this time period will involve greater deployment of sensors and the use of information from those sensors in real time to control processes. Given the fact that the geologic situation is highly variable, it is essential that if mining is to become a controlled process this will require the use of a great deal more information in real time than is currently used. I see that tendency continuing to grow in this intermediate time period.

**The Long-Term (30-40 Years)**

The third phase of this preview involves the period of time 35 to 40 years hence. The farther one attempts to look into the future, the more tenuous his projections become, because of the number of broad assumptions that must be made. These assumptions involve, among others, the overall state of the world's economy, which will determine gross energy needs; the relative economics of energy from coal, as compared with energy from other sources, which will determine coal's potential share of the world's energy market; environmental limitations, which may or may not restrict coal's contribution towards fulfilling the world's energy needs; and the development of new technology, which will determine how we exploit coal.

The overall state of the world's economy 40 years hence is beyond the scope of this discussion. It will be assumed that a steadily growing world economy will require a steady growth of energy production. This is a reasonable assumption.

The future relative economics of coal, as compared with other energy sources, involves more conjecture. If one looks back 25 years, there were two alternative energy sources which looked promising. The first was oil shale, which showed promise as late as the mid-1970's. While oil shale was never a serious threat to coal markets, it did threaten to replace a share of the conventional petroleum market. The death of oil shale was purely economic. The technical feasibility has been proven. The second promising energy alternative was nuclear power, based on uranium, which was a significant threat to coal markets. Although uranium still supplies a significant share of the world's energy output, this share is much lower than was predicted two decades ago. The growth of nuclear power has essentially stopped, particularly in the United States, due to both economics and environmental concerns. Solar power continues to be a potential rival to coal energy, although recent developments in this technology have been slow. But who can predict the situation 35 to 40 years down the road? Even concepts such as harnessing the winds and tides, or tapping the vast geothermal sources deep within the earth, could benefit from significant technological breakthroughs, although their feasibility seems limited at this time.
Assuming that coal can economically fend off competition from alternative energy sources, there are environmental concerns that must be addressed. Thanks to successful research during the past two decades, technological solutions to the problems of air pollution from SO2, other stack gases, and particulates have been developed. However, when any fuel is burned to produce energy, large amounts of carbon dioxide are produced, leading to the much-discussed greenhouse effect. Will future research produce a technological solution to this problem or will we be limited in the amount of energy that can be generated by combustion?

Assuming a positive resolution of these concerns, what will the coal industry scenario be 35 to 40 years hence? Considering the technological explosion the world has experienced in the past 40 years, looking 40 years into the future is indeed a risky business. As I see it, the third time phase of this preview will be a significant departure from phases 1 and 2, which involved (phase 1) incremental improvements in today's underground mining systems, and (phase 2) implementation of new underground mining systems. Mining 35 to 40 years hence will involve noninvasive mining of coal or in situ processing of the coal rather than bringing it to the surface.

Noninvasive mining of coal through boreholes drilled from the surface is technically feasible today, although production rates and economics need improvement. The system, developed by the Bureau of Mines, is called borehole mining. It involves drilling a borehole to the valuable mineral, introducing a tool containing water jets and a jet pump, rotating the water jets to erode the material from the solid and form a slurry, and pumping the slurried mineral to the surface for processing. The system has been used for mining uranium sands and phosphates. Coal is a good candidate for borehole mining with water jets because it is soft. Borehole mining is very attractive because it is selective, does not disrupt the ground surface, and does not require workers to go underground. Water jets are but one technique of removing the mineral values through a borehole. Other possibilities would utilize mechanical energy, thermal energy, or even dissolution with solvents. As the technologies of robotics and remote control continue to mature, borehole and other systems of noninvasive mining will become increasingly feasible.

The next concept beyond noninvasive coal mining is a system which would not remove the coal, but would treat it in place. Two examples of this are in situ gasification and in situ combustion. In situ gasification is technically feasible today, but is impractical because of abundant supplies of cheap natural gas. If world supplies of natural gas run short while there are still abundant coal reserves, in situ gasification technology will be available as an alternative source of gas. A successful gasification demonstration in Wyoming gasified nonsmaller subbituminous coal in a 30-ft bed. A second test, also in Wyoming, successfully gasified coal in a steeply pitching seam. A demonstration of this technology is planned by Energy International, an offspring of Gulf. Despite its current technical feasibility, significant application of in situ gasification is a long way off because of economics. Supplies of natural gas will dictate when it will enter the picture.

The second alternative for treating the coal in place is in situ combustion, where the energy of the coal is brought to surface in the useful form of heat. Although it seems to be a relatively straightforward concept, three considerations must be dealt with before in situ combustion can become a reality. First, the combustion must be closely controlled to assure efficient heat generation and an effective heat collection and transportation system must be devised. In situ oil shale rototting technology exists which may help in situ combustion of coal. Second, methods must be developed to keep a controlled coal mine fire from getting out of control. Uncontrolled coal mine fires in the United States and the rest of the world today attest to the resulting waste of resources and environmental degradation. Third, an efficient way to use the heat generated by in situ combustion will be needed. A mine-mouth electrical plant or the heating of a nearby community are possibilities.

These noninvasive mining techniques offer significant benefits to the environment and to the health and safety of the working force. If and when they become viable will depend on world needs and economics. In the meantime, it is essential that the technological barriers to implementation of these mining techniques be overcome through a well-conceived, long-term research program that identifies these barriers and methodically works toward their solutions. Because of the high risk and indefinite payoff of this type of research, it will fall to the public, rather than the private sector to make the major effort in this area.
THE PATH TO FOLLOW

Given the goal of more productive, safer underground coal mining systems, what is the most effective way to get from here to there? As a research director, my approach to the problem is a well-balanced program of mining research with short-, medium- and long-term components. Shorter-term research with a reasonably certain payoff is essential to the health and viability of today's industry, whereas long-term, high-risk research is necessary to assure that a body of technology is ready when needed to supplant current systems that would no longer fulfill our future needs. Short-term research should have heavy participation from the private sector to assure that critical problems are being addressed. Long-term research is done mostly at public expense because the potential payoff often does not justify industry's participation. The research effort can conveniently be broken down into health and safety, production, and environmental research.

Today's mine environment is safer and more healthful than ever before, but short-term improvements are still needed. Dust is still the major health threat to miners. We must find ways to reduce the amount of dust generated during cutting, particularly in longwalls, and better ways to protect the miners from the dust that is produced. Lowering cutting, improved cuttershead design, better dust collection, and improved ventilation design are all parts of the solution. Roof falls are the major cause of fatalities in underground coal mines. Better design of openings and improved temporary and permanent supports are needed to solve this problem. Good strides have been made in the design of safer equipment during the past two decades and further improvements are likely to be minor. A more recent emphasis has been on human factors, which focuses on the person operating the equipment. Improving a person's alertness, mental attitude, and interaction with equipment is a promising avenue toward accident reduction. Training is an important part of the human factors effort. Fires and explosions are potential disasters in any underground coal mine. Short-term efforts to combat fire disasters include fire prevention, detection, and extinguishment, and improved fire warning and evacuation procedures. Explosion research involves less incentive cutting techniques, improved methane detection, and improved barriers. All of these short-term health and safety efforts have a commonality. They strive to protect a person who is exposed to certain health and safety hazards during the course of mining. The mid- and long-term improvements in health and safety will involve removing the person from the hazard. In the mid-term this may mean placing the person in an absolutely protected environment underground, from which the mining operation will be run by remote control. The Bureau of Mines is pursuing an initiative in robotics and remote control to develop technology for such a mine. Massive retraining of personnel will be required, as the tasks performed by a remotely-located miner will be much different from those of the miner at the face. In the long-term mining approaches discussed previously, the miner is removed from the mine completely, thus eliminating the traditional health and safety hazards. Thus, health and safety research will not require heavy emphasis.

Near-term production research will concentrate on incremental improvements to existing mine subsystems. More efficient cutting systems to win the coal from the face and keeping these machines in a cutting mode a higher percentage of the time are the keys to productivity gains. Materials handling productivity improvements are needed only to the extent that coal winning efficiency is improved, but the search for lower-energy, lower-cost materials handling systems will continue. Likewise, from a production standpoint, current roof support techniques are adequate to keep pace with state-of-the-art coal winning. Mid-term production research will focus on new mine designs rather than on improvements to existing subsystems. Designs will be developed in which the miner operates in a restricted, absolutely protected area, while the coal winning and materials handling activities occur in areas which need to be stable enough only to assure uninterrupted production activities. The equipment will be designed to be recoverable in case of a cave-in. Retreat mining will probably be used to minimize problems with equipment recovery. These next-generation mine designs will rely heavily on remote-control, remote-sensing, and robotics technology which is being worked on today. These technologies will either be integrated into current-generation coal mine machinery or used with newer concepts such as water-jet coal winning and hydraulic transportation of coal slurry. Roof control efforts will be limited to improved design of openings or some minimal form of artificial support for temporary stability. Long-term production research will primarily be pioneering in nature, with concepts such as in situ burning or improved in situ gasification being tested at the basic research level. It is in this area that we must encourage our researchers to be inventive and not be afraid to go down a few blind alleys. Because of the very conceptual nature of the research required here, it is difficult to predict the avenues that will be taken.
Near- and mid-term environmental research will continue to concentrate on correcting past mistakes and the day-to-day side effects of current mining, which create problems in the areas of surface and groundwater pollution, solid waste disposal, subsidence, and other factors which reduce the level of gainful utilization of our land surface. However, new mining systems need to treat environmental control as an integral part of the system. In effect, this would be akin to doing preventive maintenance rather than corrective maintenance on the problem. No new mining system should be developed which does not consider potential environmental problems and build in preventive measures.

CLOSING THOUGHTS

This has been a brief look into the future of underground coal mining, as seen through the eyes of a research director for a United States Federal Agency. Those observing the industry from different vantage points would probably come up with different forecasts. My expectations for the mid-term and particularly the long-term are admittedly ambitious, but I am convinced that they are technically attainable. Certain pressures exerted by society will encourage their coming about. Despite significant improvements in the working environment in coal mines in the past several decades, it is becoming increasingly difficult to attract people to working-level careers in coal mining. Despite the best efforts of operators, researchers, and regulators, current mining systems will continue to present health hazards and even today's loser accident and fatality rates will become an unacceptable price to pay. To remain an economically viable alternative in the face of competing energy sources, the coal industry may require more than incremental improvements in technology. As the world becomes more crowded and more concerned about the quality of life, increasingly severe environmental constraints will require that environmental protection be built into future mining systems, rather than being added as an afterthought.