THE VIRGINIA CENTER FOR COAL AND ENERGY RESEARCH
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

MEETING PROJECTED COAL PRODUCTION DEMANDS IN THE USA

UPSTREAM ISSUES, CHALLENGES, AND STRATEGIES

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FOREWORD

The National Commission on Energy Policy (NCEP) has long recognized the critical role that coal serves in the U.S. energy economy. Coal powers more than half the nation's electric system today and remaining reserves are adequate to supply many decades more. As a low-cost, domestically secure, and relatively abundant resource, coal is an important energy supply option in this era of increasing economic and geopolitical insecurity. At the same time, NCEP recognizes that coal's contribution going forward will depend on the development and deployment of new technologies to manage the global climate risks otherwise associated with carbon dioxide emissions from coal combustion. NCEP has been a leading voice for implementing pragmatic policy solutions that steadily transition our nation toward a low-carbon energy system. Successful commercialization of carbon capture and storage (CCS) technology, in particular, offers a path forward for reconciling continued use of coal with the need to reduce carbon emissions.

Beyond the climate-related challenges that are currently the subject of much debate, there are a host of related and mostly underappreciated issues associated with a continued reliance on domestic coal. Given that most policy efforts related to coal in recent years have focused on airborne emissions from coal-fired power plants, a large gap exists in the understanding of the total coal cycle. In particular, the implications of continued, or quite possibly increasing, coal consumption on the nation's producing infrastructure do not appear to have received much attention. With this in mind, NCEP felt that an evenhanded study of coal production by a panel of nationally recognized and independent experts would be of tremendous value. Specifically, NCEP commissioned this report to explore different aspects of the coal supply chain and to highlight critical "upstream" fuel cycle issues that need to be addressed to ensure that the domestic coal industry can continue meeting the nation's energy demands while delivering the social benefits and environmental performance demanded by the public.

NCEP recognizes the vital importance of good information for sound policymaking. It is our hope that this report will be seen as a constructive, balanced assessment of a set of issues that at times can become overtaken by emotion or dogma. We also wish to stress, however, that the study committee's analysis and recommendations were developed independently. As such, this report does not represent NCEP's view or position on any particular issue. Given the caliber of the study group and the extent of the peer review process, we expect that this report will provide a strong foundation for future efforts to bring industry, government, and the nonprofit community together to advance improvements in the upstream coal sector that could provide a host of positive benefits for all. We thank Professor Michael Karmis of Virginia Tech, who chaired this study, and the members of the research team for their hard work and thoughtful exploration of these issues.

Sasha Mackler, Research Director,
and Nate Gorence, Policy Analyst,
National Commission on Energy Policy

December 2008

PREFACE

The National Commission on Energy Policy (NCEP) commissioned this report to review and identify critical "upstream" fuel cycle issues that need to be addressed to ensure that the domestic coal industry can continue meeting the nation's energy demands while delivering the social benefits and environmental performance demanded by the public.

The central focus of the study was to address matters important to ensuring a coal production system consistent with the nation's long-term energy and environmental goals and objectives through 2030.

The Virginia Center of Coal and Energy Research (VCCER) of Virginia Tech was contracted to conduct this study by establishing a committee of experts (the Report Committee) to research the topic and complete this comprehensive report. The Report Committee met over the course of 18 months, receiving input from various interested parties and stakeholders.

The final report reviews upstream issues, identifies problems, discusses progress and strengths, and recommends areas of improvement. The volume comprises eight chapters, written by experts in the particular chapter area. By focusing on what have come to be known as "upstream" issues of coal production, rather than "downstream" issues of coal utilization, it fills a void in the body of existing literature. An additional objective distinguishes this report from other recent reports. Each chapter was written to be not only a reference guide to basic information on the area in question, but also a comprehensive account of the state of knowledge in the area. As such, the report should be valuable to policymakers, interested and concerned citizens, and academics for use as a reference guide to the basic issues and as a textbook in the classroom.

This study was concluded in the fall of 2008, as the United States and the world entered an unprecedented period of economic crisis and uncertainty. The short-term impact of current economic conditions on pricing and global demand for coal is far from clear. Many observers believe, however, that the impact on price from a decline in demand for coal is likely, in the long term, to be offset by the continuing challenges of coal production globally. “The long-term global demand for coal is very strong and developing countries will continue to grow at rates that will stretch global supplies of coal,” noted Consol Energy’s CEO Brett Harvey (Consol Energy, 3rd Quarter Report, 2008). “While there is uncertainty in today’s economy, any easing of demand growth is likely to be offset by diminished global coal supply,” according to Peabody President and Chief Commercial Officer Richard A. Navarre (Peabody Energy, 3rd Quarter Report, 2008). The basic conclusions and the upstream topics examined in this study are fundamental to coal production. The current economic crisis heightens the timeliness and importance of this report.

I am indebted to each of the authors comprising the Report Committee for their dedication, diligence, perseverance, and patience in developing, drafting, and finalizing the report. John Craynon, who provided research and other valuable support to the Report Committee, and Willis Gainer, who provided his knowledge and experience during the preparation of this report, are also recognized for their contributions.

I would like to acknowledge the support of the National Commission on Energy Policy and the Joyce Foundation. Particularly, the discussions, suggestions, and questions of Sasha Mackler and Nate Gorence were invaluable to the progress of this study.

Ellen Kappel of Geosciences Professional Services and Brad Kelley of the Virginia Center for Coal and Energy Research provided important editorial assistance. The task of taking drafts from different authors and compiling a comprehensive, seamless report was substantial, and their dedication was essential to the completion of this document.

The report would not be as comprehensive without the input of many experts, either as reviewers, participants in two kick-off meetings, or as sources of data and information. I am indebted to their time and efforts on behalf of the Report Committee. Finally, on a personal note, everyone I mention here carried out their tasks with wit, patience, and a sense of camaraderie, truly making this project a pleasure to carry out.

Michael Karmis
Chair, Report Committee

Executive Summary

INTRODUCTION

Realistic projections of future U.S. energy use consistently predict that coal will likely continue to play a significant role in the nation's energy supply mix for decades to come. Coal's relative abundance and low cost compared to other conventional domestic energy resources are almost certain to drive continued—and possibly expanded—reliance on this fuel going forward. For that reason, much attention has focused on the need to develop technologies for managing coal's downstream environmental liabilities, the most challenging of which are carbon dioxide emissions associated with current forms of coal use. In particular, carbon capture and sequestration (CCS) has emerged as the leading candidate technology for reconciling continued coal use with increasingly urgent concerns about global climate change. In fact, the view expressed by Congressman Rick Boucher (D-Va.) in introducing federal legislation aimed at supporting CCS development is widely shared by policymakers and energy experts: "Given our large coal reserves, its lower cost in comparison with other fuels, and the inadequate availability of fuel alternatives, preservation of the ability of electric utilities to continue coal use is essential." Less frequently mentioned in these debates, however, are the upstream issues associated with large-scale coal use. These issues include coal reserves determinations, coal extraction and processing technologies, impacts on local communities, workforce issues, including the health and safety of mineworkers, and the direct environmental impacts of coal extraction and processing.

To explore these upstream issues and to develop recommendations aimed at ensuring that future coal production systems are compatible with social, economic, and environmental objectives at the local and national level, in June 2007, the National Commission on Energy Policy (NCEP) sponsored a comprehensive study of the major upstream issues associated with coal production.

NCEP contracted with the Virginia Center for Coal and Energy Research (VCCER) of Virginia Tech to assemble a committee of experts (the Report Committee) and to conduct the study. This report presents the findings of the Report Committee.

The report focuses not only on the coal mining industry, but also on the entire coal sector, including government, equipment suppliers, academic institutions, communities near coal mining, environmental groups, and other parties involved in upstream coal issues. Specifically, the report discusses in detail six major upstream aspects of coal production that could affect the ability of the U.S. coal sector to meet current projections of likely production demand to 2030. Issues covered include: coal resources and reserves (Chapter 2); mining technology and resource optimization (Chapter 3); coal preparation (Chapter 4); health and safety issues (Chapter 5); environmental protection, practices, and standards (Chapter 6); and workforce challenges (Chapter 7). In each of these areas, industry leaders, government agencies, academics, interested citizens, and others provided valuable input for identifying and framing the issues discussed in these chapters. Their input, and that of the Report Committee, also informs the policy recommendations offered at the end of each chapter, as well as the overarching themes and recommendations articulated in the study's concluding chapter (Chapter 8).

MAJOR ISSUES FOR COAL PRODUCTION

This study identifies the major technical, environmental, business, and social issues that confront the coal sector. These issues will need to be addressed as the quantity and geographic distribution of coal supply and demand shifts over time. To meet future demand, the coal production industry will increasingly have to focus on opening new mines, rather than relying, as in the past, primarily on expanding capacity at existing mines. That means attention must be paid to the long lead times typically required to develop new mines to the point where they are producing, the uncertainties associated with both geological and market conditions, and the large capital sums needed to develop new resources. All of these factors contribute to uncertainty and create a risky environment for investment in coal production capacity. This study identifies several key issues that will confront the industry in expanding production to meet projected U.S. coal demand to the year 2030:

- There is a fundamental need to develop, test, and adopt new, environmentally responsible technologies for mining and processing coal.
- Workforce shortages at all levels and in all segments of the coal sector are a major challenge for the industry.
- Coal mining continues to lack broad social acceptance at local, regional, and national levels.

The study also identified two other areas where progress is needed:

- Readily and publicly available data on the major upstream factors covered in this report are inadequate for timely decision-making.
- Cultivating a "beyond compliance" culture within the coal industry and relevant government agencies would foster greater cooperation in addressing upstream issues and promote public trust.

The central findings and recommendations of this study are summarized below.

1. Information Challenges

There is a fundamental need for better and timelier data related to all aspects of the coal sector. The need for publicly accessible and reliable information recurs as a common theme throughout this report. At present, the information needed to support sound decision-making regarding different aspects of coal production—including scientific data and information on the industry's current performance—is not readily available. Researchers for this study found that data on coal reserves, the effectiveness of current or proposed environmental or health and safety regulatory programs, the demographics of current and future labor pools, and other such issues were either difficult to obtain or simply not available. In today's information-based society, access to data and other substantive knowledge are critical for decision-makers in the public and private sector. Therefore, government and industry must work with other stakeholders to ensure that information is collected, disseminated, and analyzed in a useful way.

2. Technology Needs

There is a need to develop and adopt better technologies in all facets of the upstream cycle. Government and the private sector have reduced their R&D investments in recent years, slowing the development of improved technologies for mining and processing coal. Government, industry, and academic and private research institutions must work together to address the need for more R&D. These efforts should include increased support for relevant graduate level and Ph.D. programs in the nation's academic institutions.

The Report Committee recommends a three-pronged approach. First, research efforts must shift to a greater emphasis on revolutionary advances rather than, as is common in industrial research, primarily pursuing evolutionary changes in existing product lines and strategies. Ground-breaking research is often best accomplished by academia, with the support of industry and government. Second, the particular challenges facing the U.S. coal industry, such as the need to mine increasingly thinner coal seams while addressing domestic environmental and health and safety concerns, will require public investment in domestic R&D efforts led by U.S.-based government, industry, and academic institutions and less reliance on "imported" R&D from other nations. Third, the coal industry should draw on technology innovations developed in related disciplines and areas of industrial research, such as automation, robotics, communications, and geosensing.

3. Improving Performance

There is a fundamental need to change the culture of the entire coal sector to one that focuses on "beyond compliance" approaches to dealing with regulations and public trust. Specifically, the industry should voluntarily adopt practices that go beyond minimum standards. At the same time, government agencies must also be accountable and should work on developing up-to-date, science-based regulations and improving technology transfer. In addition, government agencies should support a "beyond compliance" approach by providing more technical and compliance assistance and staying actively involved with local, state, and corporate entities to ensure that all stakeholders have access to accurate and up-to-date information on environmental and health and safety issues.

The application of more sophisticated risk management approaches by both industry and regulators holds promise for enabling improved environmental and health and safety performance. This could ultimately lead to greater societal acceptance of coal production and utilization. Companies noted for taking a beyond compliance approach to mine health and safety issues have enjoyed better reputations with the workforce and the public. In addition, promoting a safety culture as the top priority of senior management and setting correspondingly ambitious corporate goals can have positive impacts throughout the organization and communities of interest.

4. Economic and Business Challenges

The coal mining sector must address economic uncertainty, avoid supply interruptions, and promote production stability. Coal producers, coal users, and, given coal's importance in the electricity supply mix, the public more broadly, have a vested interest in ensuring an uninterrupted and stable coal supply. To achieve this goal, three areas need increased attention.

First, short-term investment and business practices, which have led to boom and bust cycles in the past, must be avoided. Longer-term considerations also must be addressed, including long lead times for acquiring reserves and obtaining necessary permits, changing workforce needs, and requirements for specialized equipment. In addition, the larger infrastructure issues pertaining to coal and energy transportation must be resolved.

Second, uncertainty about laws and regulations pertaining to health and safety and the environment, public acceptance of coal production and utilization facilities, and future climate policy make it difficult to invest large sums of capital in developing new resources or replacing equipment. The successful development and commercial-scale deployment of carbon capture and storage technology, for instance, would have profound implications for the industry's prospects in a policy environment designed to constrain carbon emissions. The coal community should take a critical look at this and other sources of uncertainty and take a proactive role in helping to find solutions.

Third, policy clarity regarding the role of coal in the nation's domestic energy portfolio is needed to alleviate business uncertainty that tends to discourage private and public investment in coal mining.

5. Workforce Crisis

If the coal mining sector is to remain viable, it must address a potentially significant shortfall in the workforce at all levels. As members of the Baby Boom Generation retire, the coal mining sector will increasingly need to compete with other businesses and industries for new workers. Labor shortages could present a significant problem if demand for coal increases in the future, and could potentially affect all types of jobs in the coal production sector, from mineworkers, to suppliers and service providers, to educational and training institutions, to government agencies. Shifting opportunities and demands in the labor force, from entry-level miners, to management and professional positions, will have consequences for productivity, safety, demand for training, and corporate structure and culture.

The workforce requirements projected in this study, while possibly more conservative than other estimates, suggest that more than 64,000 new workers will be needed to enable the industry to supply projected demand to 2030. Moreover, this figure represents an overall total—as such it does not reflect the serious deficit in workers qualified for managerial, professional, and academic positions that, according to most estimates, is expected to reach crisis proportions in a few years.

High-level efforts by several coal companies to change the corporate culture to emphasize safety while also nurturing workforce development represents a positive step toward addressing these workforce challenges. Further progress toward adopting workplace "best practices" that result in lower turnover and greater job satisfaction is needed. Such efforts must address needs that are particular to the sector, such as recruiting workers who require relocation to coal production sites.

6. Education and Training Needs

Education and training resources are not in place to ensure an adequate supply of professionals and workers and their continued development within the industry and broad coal community. Government and industry should support new and expanded training and education initiatives to address employee development and maintain sufficient expertise to maintain the performance level of the sector. Globally and nationally, there is a severe shortage of students enrolled in the engineering and scientific disciplines related to coal mining. Major challenges exist in undergraduate recruitment and enrollment, support for graduate students and programs, and development of new faculty. Mining-related disciplines in higher education, particularly at the Ph.D. level, must be reinforced and supported by the coal industry and government. In addition, technical training at regional training centers, vocational schools, and community colleges should be expanded and enhanced. Companies, unions, private training vendors, federal and state agencies, and institutions should work together on this effort.

7. Societal Acceptability

It is imperative to address the societal acceptability of coal mining and utilization. The coal industry—including both segments of the industry involved in coal production and utilization—faces real and perceived challenges in societal acceptance. For coal to remain a viable part of the domestic energy supply mix, the entire coal sector needs to work collaboratively to disseminate factual information about the availability, importance, and impacts of coal production and use. A skeptical public must be assured that the coal industry is sufficiently regulated and provides a net contribution to society. At the same time, the industry must provide opportunities for local communities and people affected by mining operations to provide input, express concerns, and work with coal producers in a cooperative, good faith manner to resolve issues. To that end, the coal industry must foster proactive dialogue, transparency in its operations and activities, and public participation.

In addition to these broad findings and recommendations, this study offers detailed conclusions and recommendations in six major areas. Chapter conclusions are summarized below.

Coal Resources and Reserves (Chapter 2)

The nation's coal resource base or endowment is very large. In broad terms, the magnitude of the resource base is relatively well understood—the locations of all major coal basins are known and it is not expected that large, new coal fields will be discovered in the conterminous United States. State and federal agencies have collected a large body of data concerning the quantity and quality of coal basins over the past century, but only a small fraction of the resource base has been sufficiently characterized to be classified as economically recoverable under current conditions (this definition distinguishes "reserves" from "resources"). The Report Committee recommends several initiatives to improve the state of knowledge concerning coal resources and reserves in the United States.

Reassess the demonstrated reserve base (DRB) and economically recoverable reserves (ERR). The U.S. Energy Information Administration (EIA) began a modest effort to update information about the DRB in the 1990s, but it has since been discontinued and EIA has not allocated funds or personnel resources to this effort for several years. The EIA has been responsible for DRB assessment since 1977 and remains the logical agency to continue updating this information. Because of the importance of the DRB, other federal agencies could be given the task if EIA is not able to resume work in this area.

Expand "coal availability" and "coal recoverability" assessment programs. Existing programs can assess economically recoverable resources (reserves) at a pre-feasibility level of detail. These investigations should, however, be expanded—with the aid of state geological agencies—to provide information on a national scale.

Make resource and reserve data readily accessible. All data used by federal, state, or other public entities to assess resources and reserves should be maintained in databases that are readily accessible to everyone. These data can be used to update the DRB and ERR and can serve as the basis for nationwide assessments of domestic coal reserves. Database development should include several elements, including identifying new coal parameters, incorporating GIS technologies, and procuring computers capable of analyzing large amounts of data. A federal agency such as the U.S. Geological Survey will need to oversee and coordinate this effort with other federal and state agencies, and this will require funding.

Assess the option of expanding company disclosure of reserves. Information on coal reserves obtained by means of questionnaires developed by EIA and the National Mining Association (NMA) is relatively easy to collect and, likely, fairly accurate. Efforts should be made to expand this source of information and to test the willingness of mining companies to be more forthcoming and more detailed in the information they provide.

Mining Technology and Resource Optimization (Chapter 3)

The specific technologies used in coal extraction directly impact productivity, health and safety, and environmental performance of upstream coal production. These issues and challenges not only have the potential to interrupt production at existing mines and slow the development of new resources, they often also have negative impacts on permitting lead times, mine production and productivity, and cost performance. Mining extraction and resource optimization is dependent, therefore, on the continuous technological development of equipment, systems, and process at the nations coal mines. The following recommendations address issues related to mining technology and resource optimization.

Reduce the uncertainties associated with mining conditions. Accurately predicting mining conditions is essential for productive and safe mine operations. As existing mines are expanded or new mines are opened, some of them in virgin areas, the importance of intense and detailed exploration to assess resource characteristics and mining conditions cannot be over emphasized. New applications of remote-sensing and in-seam geophysical exploration techniques for this purpose should be developed.

Develop new mining equipment and mining technologies. New technological developments have the potential to improve both underground and surface coal mining, including longwall mining and continuous mining. These improvements may increase productivity, enhance health and safety for mineworkers, and reduce adverse environmental impacts. Mining companies, equipment manufacturers, academic institutions, and private research groups should pool their resources to advance these technologies, and government programs should bring additional resources to bear on the development of new technologies and processes.

Address changing mining conditions. Changes in the physical mining environment, such as changes in the depth and thickness of the coal, will pose technical challenges and may lead to adverse mining conditions such as increased gas, heat, and ground stress problems. Use of existing or new equipment not specifically designed for in these changed physical conditions can also give rise to new hazards. Finally, the transition to a less-experienced workforce can bring risks. In this context it will be important to develop innovative technologies, including new equipment and processes, that can help mitigate these risks and be responsive to new laws and regulations.

Develop energy complexes. The coal industry is well aware that it may be necessary in the future to exploit coal resources, particularly in the Appalachian and Interior regions of the country, that are less attractive and harder to mine. These resources are likely to be smaller, thinner, and deeper; of inferior quality; and located farther from transportation and other infrastructure facilities. To improve the economics of accessing these resources, it may be necessary to capitalize on synergies that can result from integrating coal production, processing, and utilization facilities at the same site.

Promote engagement with local communities. The mining industry today must clearly understand that local communities and people who are affected by a mining operation must be engaged at a much higher level and through a process based on respect, transparency, and dialogue among all stakeholders. This dialogue is an important component in the selection of extraction technologies and approaches. The coal mining sector must create opportunities and seek out engagement with communities so as to achieve the desired outcome—ensuring that local community concerns and aspirations are important elements of mining planning, development, and post-mining land use.

Coal Preparation (Chapter 4)

The expected steady decline in the quality of U.S. coal reserves will necessitate technology improvements to process feed coals with increasingly difficult washing characteristics. This may involve both incremental enhancements to existing processes as well as revolutionary advances that result in more efficient, less costly, and more environmentally attractive technology options. Coping with lower reserve quality is likely to be especially challenging for western coal operations, because coals in this region have traditionally not required preparation other than size reduction. Increasingly stringent customer demands coupled with an overburdened railway infrastructure will pressure these operations to improve quality via the application of new coal processing technologies. In addition, several environmental issues represent significant challenges to expanded U.S. coal preparation facilities. Although these impediments vary from state to state, the most significant challenge facing the industry is the management of coal wastes.

The following recommendations address these issues.

Establish a national coal washability database. Detailed data related to the cleaning characteristics of much of the nation's coal resources do not currently exist or are not readily accessible. Therefore, it would be useful to develop a detailed database of information about coal washability that fully defines the cleanability of different U.S. coals. This would allow for a more accurate accounting of the existing reserve base and would inform efforts to develop effective and realistic policies for the optimum utilization of the nation's coal resources.

Provide support for new and improved technologies for upgrading coal quality. Government and industry commitments to cost-shared support of basic and applied R&D programs in areas related to coal preparation are urgently needed. Specific technical areas that require additional R&D support include fine particle cleaning, fine particle dewatering, dry separation processes, advanced instrumentation, low-rank coal upgrading, particle reconstitution, and waste disposal and handling.

Address environmental issues associated with waste disposal. Environmental impacts associated with the disposal of wastes generated during the coal preparation process continue to be a source of concern for communities in the vicinity of coal processing facilities. Therefore, continued support is recommended for environmental studies designed to quantify the long-term and complex effects of preparation operations on human health and the environment. In addition, new technologies should be developed for remining and reprocessing valuable coal contained in waste impoundments.

Health and Safety Issues (Chapter 5)

The U.S. mining industry has made significant progress over time in improving mine health and safety by developing and incorporating major advances in mining technology, equipment, processes, and procedures. Increased attention to mine planning and engineering, mining operations, worker selection and training, and safety equipment and practices—all aided by more effective laws and regulations—have made mines safer than ever before. Notwithstanding this impressive progress, however, illnesses, injuries, deaths, and disasters continue to occur. Efforts to continue identifying and reducing the root causes of mine health and safety risks should be accelerated. Management must play an active role by developing and implementing a zero tolerance approach to accident prevention. Accident prevention programs should combine insights gained through research on the "science of safety," including recent work in the area of human-machine interaction, with a "culture of safety" that seeks to influence human reactions in the workplace.

Specific recommendations in this area are summarized below.

Enhance and accelerate recruitment and induction strategies for new workers into coal mining. Experience has repeatedly shown that outstanding engineering controls and a knowledgeable, well-trained workforce are the two prime requisites for safe mining operations. Given the impending critical shortage of qualified personnel at all levels, there is an immediate need to recruit and train qualified workers for the industry. New workers must not only be recruited in sufficient numbers, they must gain the skills needed to ensure a safe, healthy, and productive work environment. Future miners will be required to have multidisciplinary and critical thinking skills to work effectively and safely in an industry that is increasingly mechanized and reliant on larger-scale equipment.

Enhance the application of systems safety methods for safety evaluation of mining systems. The fact that mining injuries, illnesses, deaths, and disasters continue to occur suggests that the root causes of these incidents have not been fully addressed. The result is that hazards in the system can remain undetected and may manifest at a later time, possibly with disastrous consequences. Proactive approaches that examine systems critically for either component and/or systemic weaknesses, using tools and techniques from risk and reliability analyses and techniques, are needed.

Evaluate and develop more effective systems for management and control of the safety functions in organizations. The coal-producing industry increasingly recognizes the importance of organizational factors, including the goals, objectives, and means of managing safety, that are in place at different firms to enhance mine health and safety performance. Introducing modern safety management techniques in coal mining requires a detailed evaluation of current best practices in other industries and applying those practices, where possible, to the mining environment.

Expand the funding and scope of mine health and safety research. To make substantial and sustained progress in mine health and safety, vibrant research initiatives involving government, industry, universities, and manufacturers are needed. Since 1995, government funding for mining health and safety research has declined. Though Congress has occasionally funded specific projects, there is a need to increase health and safety R&D more broadly and on a more permanent basis.

Environmental Protection, Practices, and Standards (Chapter 6)

Significant progress has been made over the last 30 years in implementing changes in coal mining practices that protect the public, environment, and natural resources while substantially expanding coal production. Practices such as "beyond compliance stewardship" are becoming accepted in coal companies, and have resulted in improvements in environmental planning, reclamation, and revegetation practices. Post-mining improvements at surface coal mines are providing greater opportunities for wildlife, landowners, communities, and industry. Further advances in this area will lead to better land, air, and water stewardship, and reduce societal and other impediments to continued production of coal for the nation's energy needs. The environmental impacts that need to be addressed at different sites vary depending on resource quality, quantity, and distribution; geologic integrity; mining methods; climatic and biological factors; and proximity of cultural and historic landmarks. For coal production increases to keep pace with demand, more attention will need to be focused on a number of environmental issues, including: drainage waters; reclamation practices; air quality concerns, including fugitive dust and methane; potential disturbances to hydrologic systems; ground subsidence; broader habitat displacement; and waste management at mines and preparation plants.

The following are specific recommendations for continued progress in addressing the upstream environmental impacts of coal use.

Reduce impacts on water resources and quality. The coal industry, working in conjunction with federal and state regulatory agencies and research organizations, must develop better science-based technologies for modeling hydrologic changes and address water quality concerns, including those related to sedimentation, acid mine drainage (AMD), and the impact of trace elements that occur both during and after mining.

Address prominent regional environmental problems. The industry's approach to high-profile environmental issues in each of the nation's three major coal-producing regions has the potential to define its environmental performance and strongly influence the public's perceptions about, and overall acceptance of, mining operations. Mountaintop mining and valley fills in Appalachia may be limited in the future because they are highly controversial with the public. Air quality issues, especially related to fugitive dust and methane release, are of major concern throughout the United States, but have become increasingly important in the Western region. At the same time, greater coordination is needed to protect threatened and endangered species from the adverse effects of coal mining operations, particularly in the Interior and Appalachian regions of the country.

Implement an effective and transparent community engagement process. The coal industry must adopt effective and transparent processes to engage local communities, emphasize the conservation of biodiversity, and implement integrated approaches to post-mining land-use planning that involve all stakeholders. Environmental concerns must be addressed and various parties must work together to ensure that there is a better understanding of environmental issues and challenges associated with all phases of coal mining operations.

Enhance reclamation planning and performance measures. Despite the tremendous progress made in surface mine reclamation, there is growing public concern that efforts to restore land and return it to other uses after mining are not occurring in a timely manner. The status of reclamation efforts, often gathered from bond release information, is an inadequate measure of the extent of actual field work or of whether restoration has been successful. Industry, federal agencies, and state regulatory agencies must develop reasonable deadlines for reclamation and establishment of post-mining land uses.

Develop science-based and technologically feasible regulations and practices. Environmental concerns, public attention, and local issues will influence how and to what extent coal production can be expanded in different regions. Federal and state regulatory agencies, working with industry and communities, must develop science-based regulations that include technically feasible guidelines and best practices to effectively address environmental concerns and encourage adoption of new technologies and approaches that minimize impacts.

Improve the permitting process on federal lands. About 40 percent of the nation's coal production is from mines located on federal lands and this share is projected to increase in the future. The federal government, in consultation with local communities and industry, should consider restructuring federal coal leasing and permitting programs to eliminate duplication and overlapping requirements.

Encourage additional funding to support research and workforce development. Increased funding is needed to support research efforts at federal and state agencies, universities, and other research organizations aimed at addressing the environmental impacts of past, existing, and future mining operations. Increased funding will also be required to sustain personnel levels at federal and state regulatory agencies and to support the development and use of environmentally responsible technologies.

The Workforce Challenge (Chapter 7)

The coal mining sector will face significant workforce challenges between now and 2030. Given retirements and potential growth in demand for coal, over 64,000 workers will need to be recruited—and these estimates do not include managerial and professional positions. Labor shortages are likely to impact all types of jobs in all areas of the coal mining sector, from coal producers to the coal community at large, including suppliers and service providers, educational and training institutions, and government agencies.

The following recommendations address issues of workforce recruitment, retention, and career-long development in the coal sector at large.

Create a new pool of workers for the coal mining industry. Developing a pool of potential workers at all levels will require actions by coal producers, coal suppliers, state and federal governments, and educational and training institutions. Companies must develop, or reinforce, corporate philosophies and cultures that promote the development of employees, offering competitive salary and benefit packages and providing a rewarding work environment to enhance recruitment, retention, and development.

Integrate the impacts of a massive labor swing into human resources and operations strategies. A major labor transition could have significant impacts on worker productivity, health, and safety, and even on social and cultural environments in the workplace and in mining communities. Developing and supporting innovative, accelerated training programs for all levels of employees will be necessary if the sector as a whole is to achieve its workforce objectives and successfully integrate large numbers of new workers.

Strengthen mining-related disciplines at higher-education institutions. Globally and nationally, there is a severe educational crisis in the engineering and scientific disciplines that relate to coal mining. Major problems include undergraduate recruitment and enrollment, support for graduate students and programs, and faculty development and promotion in these fields. Mining-related disciplines in higher-education institutions must be reinforced and supported by the broader coal sector.

Expand training institutions and resources on a regional basis. To ensure an adequate supply of skilled employees, enhanced and expanded training centers and facilities will be required. Companies, unions, private training vendors, federal and state agencies, and institutions should work together on this effort, which must involve community colleges and vocational schools and must make use of new technologies such as virtual reality, advanced simulation, and distance learning.

Overcome perception problems of the coal mining sector. The coal mining sector needs to overcome perception issues and public mistrust to become an employer of choice. The coal community must address its public image by promoting active community engagement, fostering pride in coal-related disciplines, and committing to the career-long development of current and future employees. Image improvement should be a major goal for the entire coal sector.

CONCLUSION

Coal will continue to play an important role in the U.S energy portfolio, at least until 2030, which is the time frame of this study. It is therefore critical to address the challenges and the need for improvement in the upstream aspects of the coal fuel cycle. There are also important issues of safety and security with regard to meeting the nation's energy demands from domestic sources, including coal, that are beyond the scope of this study and therefore are not addressed in this report. An overarching theme of this study is the need for greater cooperative efforts by coal producers, coal suppliers and equipment manufacturers, government agencies, academic institutions, and other nongovernmental organizations to examine system-wide needs and impacts, as well as economic contributions and benefits. A comprehensive life-cycle analysis should include factors associated with coal extraction, processing, transportation, and utilization. Worker health and safety issues, positive and negative environmental impacts, and contributions to the public wellbeing should also be fully assessed so that policymakers can make informed decisions regarding the role of coal in meeting the nation's future energy needs.

Chapter 1 Introduction

1. SUMMARY

In June 2007, the National Commission on Energy Policy commissioned a comprehensive review of the major upstream issues associated with coal production. The central focus of the study was to address issues important to ensuring a coal production system consistent with the nation's long-term energy and environmental goals and objectives through 2030. The Virginia Center of Coal and Energy Research (VCCER) of Virginia Tech, contracted to conduct this study, established a committee of experts (the Report Committee) to complete this report, which reviews upstream issues, identifies problems, discusses progress and strengths, and recommends areas of improvement.

Several recent studies have addressed the role of coal as a major component of the future energy supply (NCC, 2006a; MIT, 2007; NRC, 2007a; EIA, 2008). In fact, projected coal production in 2030, under the latest reference scenarios in the Energy Information Administration's (EIA) Annual Energy Outlook (AEO), is 1.6 billion tons as compared to the current production of 1.16 billion tons (EIA, 2008). These studies have highlighted the importance of coal in the U.S. energy portfolio, even under a carbon-constrained framework. Although this assumption may be challenged, it is beyond the scope of this study to debate overall national energy policy or to address issues surrounding coal utilization and carbon capture and storage. It should be noted that the studies referenced above have been concerned mainly with downstream issues associated with coal production and use (see Box 1.1), or have addressed basic infrastructure challenges; little attention has been devoted to upstream issues associated with coal production.

BOX 1.1 CHARACTERIZATION OF "UPSTREAM" VS. "DOWNSTREAM"

It is common to identify components of the coal system as upstream and downstream because activities and players associated with these two streams can be distinct. Using mining as a frame of reference, downstream components are processing for product improvement, transportation to markets, and utilization at the markets. Upstream components are basically exploration and resource definition, mining, and processing. Exploration, mining, and processing are often physically closely associated with each other, whereas utilization can occur at locations far from these operations. It is also important to consider the output of the utilization component, which is energy (such as electricity, oil, and gas) that must be transported to consumers.

This study focuses on six primary components of the upstream coal production process that could influence the ability of the U.S. coal industry to meet projected production over the next few decades: coal resources and reserves; mining technology and resource optimization; coal preparation; health and safety issues; environmental protection, practices, and standards; and workforce issues. Chapters 2 to 7 of this report cover these topics and provide a state-of-the-art review; conclusions in each chapter identify issues and recommendations aimed at potential improvements. Valuable input for framing these issues was received from industry leaders, government agency personnel, academics, other experts in the field, and interested citizens.

Though this study focuses on upstream issues, downstream concerns can also influence the upstream cycle, and hence, those impacts have not been ignored. A good example is the downstream impacts of coal combustion and utilization, including waste disposal, which impact upstream components such as coal reserves, mining and processing technologies, operations, productivity, and environmental performance and practices.

2. COAL IN THE U.S. ENERGY SUPPLY

Fossil fuels such as coal, petroleum, and natural gas have been central in supplying reliable, low-cost energy in the United States for more than a century. Today, they account for almost 80 percent of the nation's primary energy production and 85 percent of total energy consumption (Figure 1.1). Total primary U.S. energy production in 2006 was 71.03 quadrillion British thermal units (Btu), with coal accounting for 23.79 quadrillion Btu, about 33 percent of all sources of U.S. energy production. Other major energy fuels are natural gas (27 percent), petroleum (18 percent), and nuclear power (12 percent). Remaining sources of energy such as hydropower, biomass, and other renewable energy sources account for 7.16 quadrillion Btu, or about 10 percent of the U.S. energy production.

The U.S. coal industry is the second largest in the world (behind only China), producing over 1.16 billion tons of coal from lignite, bituminous, subbituminous, and anthracite sources in 2006. Coal accounts for about 23 percent of total energy consumption in the United States. An important fact that goes along with the above production distribution is the domestic energy reserve structure of coal, oil, and natural gas. According to AEO (EIA, 2006a, 2006b), as of January 2006, the United States possesses approximately two, three, and 27 percent of the world's natural gas, oil, and coal resources, respectively—193 trillion cubic feet of natural gas, 21.4 billion barrels of oil, and 271 billion tons of coal. The domestic coal resource base is extensive, representing over 94 percent of proven U.S. fossil energy reserves (DOE, 1993). There are considerable uncertainties in these numbers. Further, the numbers may be updated and revised as a result of changes in reserve estimation methodologies, improvements in extraction and processing technologies, cost of production, and price of competing fuels, among other factors. It is important to emphasize that, under all scenarios, coal supplies are projected to be sufficient for domestic energy needs for the foreseeable future, whereas natural gas and oil supplies will need to be supplemented with substantial foreign imports. Although the United States imports significant amounts of oil and gas, coal is a net export commodity for the U.S. economy.

The United States has the largest reported coal reserves of any country in the world, which are widely distributed across the nation (EIA, 2006a, 2006b, 2006c, 2006d). Electricity generation consumes 92 percent of U.S. coal production; coal accounts for over 50 percent of U.S. electricity generation. As advanced clean coal technology use increases and as the technology for conversion of coal to liquid, gas, and other more convenient forms of energy are developed, the role of coal in the future energy supply could dramatically increase. The extensive U.S. coal reserves, therefore, have the potential to reduce imports of oil and gas and provide greater security for the nation's energy supply.

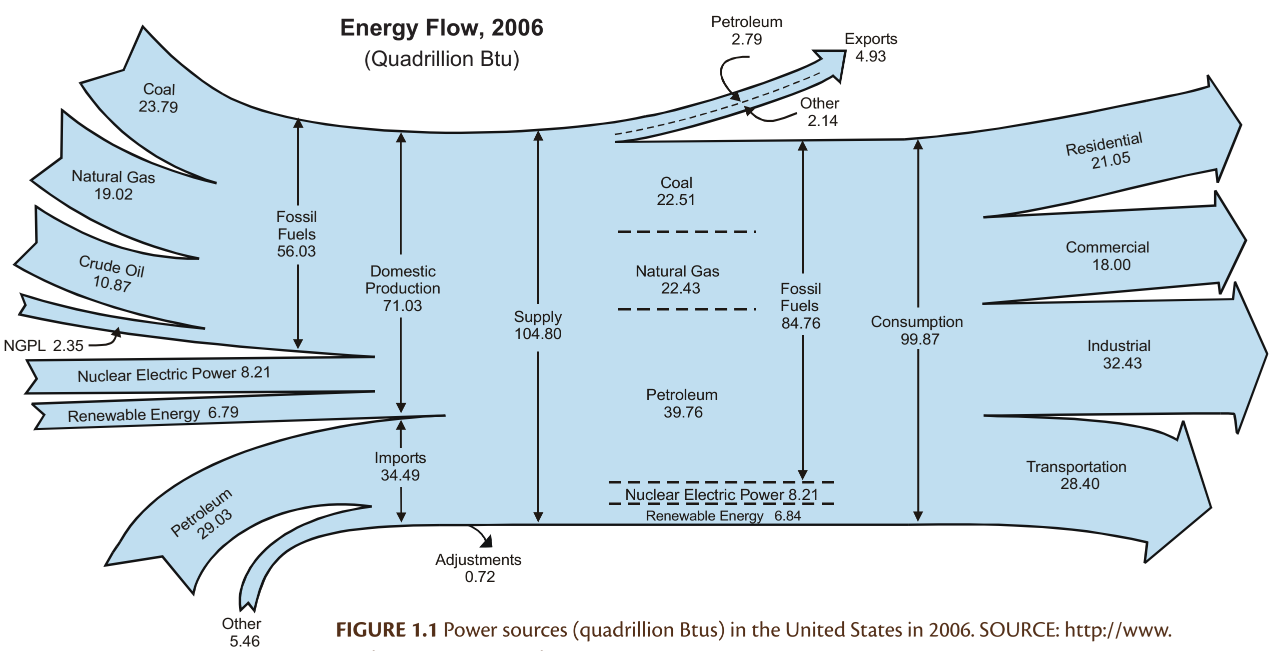


FIGURE 1.1 Power sources (quadrillion Btus) in the United States in 2006. SOURCE: http://www.eia.doe.gov/emeu/aer/diagram1.jpg.

3. HISTORICAL OVERVIEW

References to coal mining in the United States date back to the 1680s, with the first coal mines developed around 1750 at Midlothian, near Richmond, Virginia (Eavenson, 1935). In 1822, about 54,000 tons were produced and, by 1828, production had grown to over 100,000 tons. Early industrial development of the United States was powered by coal, mostly from mines east of the Mississippi. By 1850, a thriving coal mining industry had developed, with anthracite mining in northeastern Pennsylvania and bituminous coal mining in the eastern states of Pennsylvania, Illinois, Ohio, West Virginia, Virginia, and Alabama. By 1900, coal had become the leading energy source for the nation (Figure 1.2), displacing the use of wood as a fuel. The industrial activity of coal mining spanned even more states in the east and west, producing over 50 million tons of anthracite and over 200 million tons of bituminous coal. Eavenson (1935) stated that, "the use of coal everywhere has been largely a matter of transportation, and other fuel supplies, oil and natural gas, compete with the development of coal," which continue to be important factors associated with the coal industry today.

Figure 1.3 shows coal production in the United States from 1890 to 2005. The Depression temporarily setback coal production in the 1930s, as did the loss of the railroad market in the 1950s. Since the 1960s, however, coal production has steadily increased. An overview of the coal industry from 1970 to 2005 can be found in Bonskowski et al. (2006).

In the early 1950s, coal markets included industrial, residential, commercial, metallurgical coke ovens, electric power, and transportation, each accounting for five to 25 percent of total consumption. From the end of World War II to 1960, coal use for rail and water transportation and for space heating declined. The contribution of coal to electricity generation increased in the early 1960s, a trend that has continued to this day. According to AEO (EIA, 2008), in the reference case (Box 1.2), coal-to-liquid (CTL) production is projected to become the second largest coal use in 2030, although this forecast is more speculative given the carbon impacts of CTL technologies.

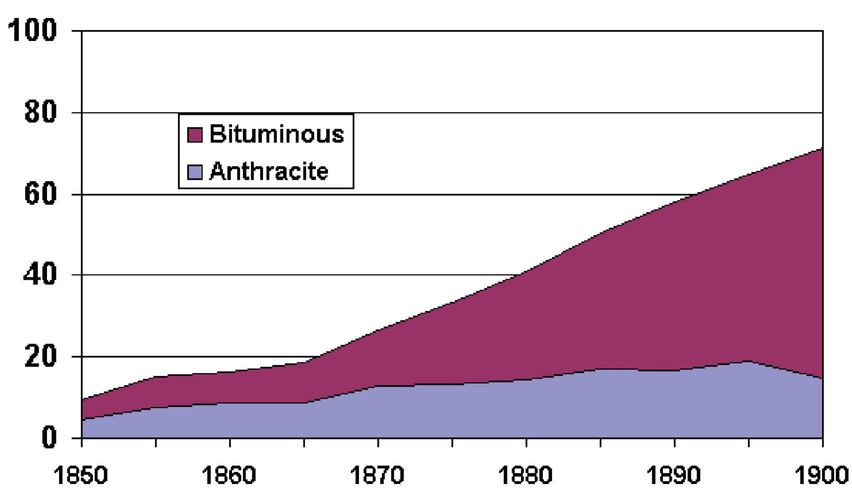


FIGURE 1.2 Coal as a percentage of U.S. energy consumption, 1850–1900. SOURCE: Schurr and Netschert, 1960.

Health, safety, and environmental regulations of the sixties and seventies, the oil embargo of 1973, and labor unrest and contract settlements all influenced coal industry development throughout the last three decades. Some of these matters had short-term effects while other had longer-term impacts. The influence of factors such as ease of mining and coal utilization, mining conditions, mining technology, health and safety and environmental laws, mining costs, and competing fuels led to dramatic shifts in production from underground mining to surface mining, from east of Mississippi to west of Mississippi, and from bituminous to subbituminous coals. The coal industry today, as compared to the industry thirty years ago, has fewer mines (by almost one-third) and active miners (by almost half), and produces almost twice as much coal (NRC, 2007b).

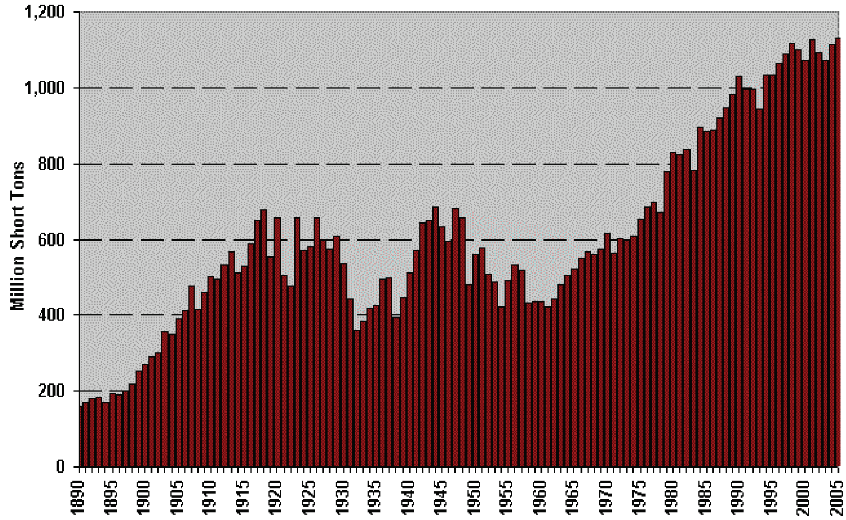
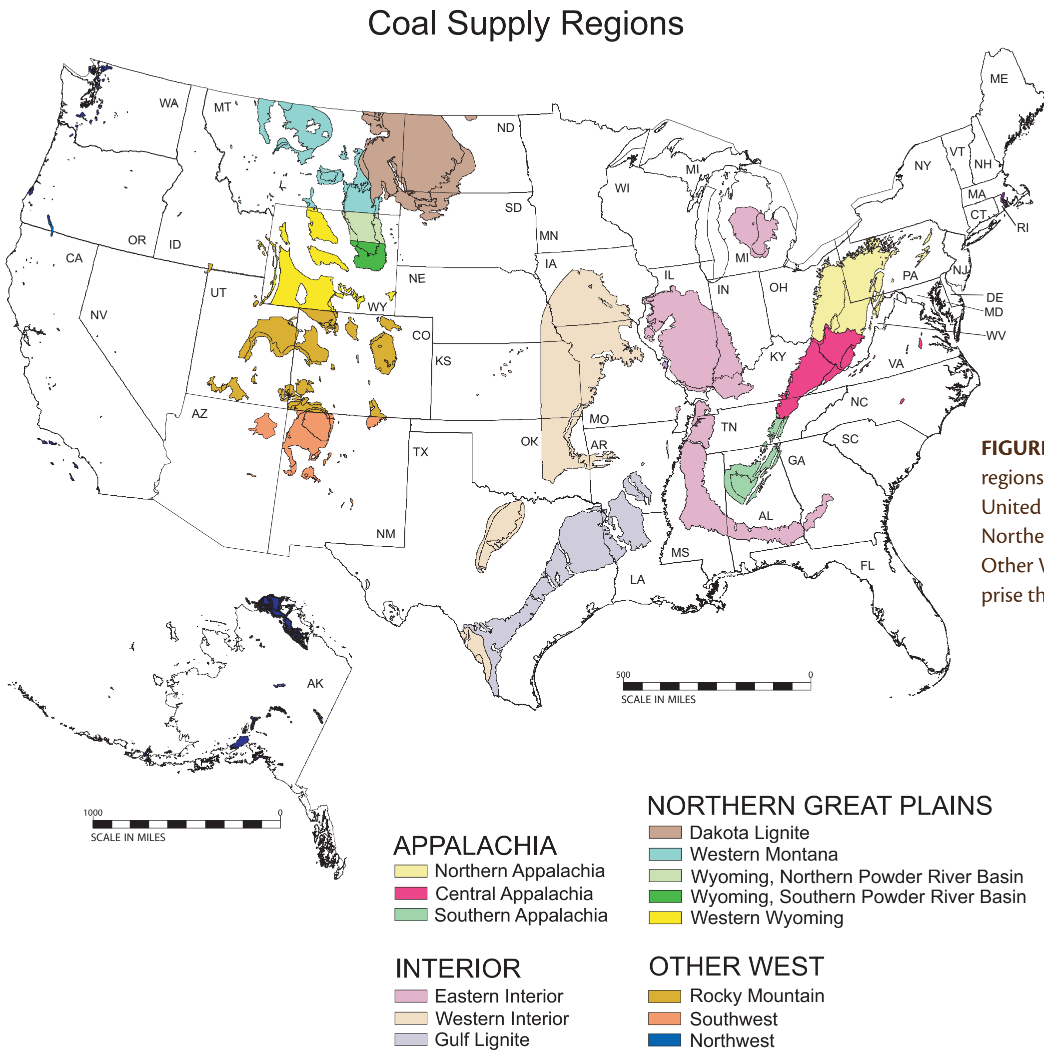


FIGURE 1.3 U.S. coal production, 1890–2005. SOURCE: (http://www.eia.doe.gov/cneaf/coal/page/coal_production_review.pdf).

In terms of coal production, the country is typically split into three primary coal regions: the Appalachian region, the Interior region, and the Western region, with several subregions (i.e., coalfields), as shown in Figure 1.4. Because in some cases the same state may belong to different statewide or regional collections, there may be discrepancies in data based on particular divisions of the regions. Occasionally, it is useful and common to describe coal production in the country as if it were simply east and west of the Mississippi River.

BOX 1.2 THE ANNUAL ENERGY OUTLOOK (http://www.eia.doe.gov/oiaf/aeo/index.html)

The U.S. Energy Information Administration (EIA), a branch of the Department of Energy, develops a range of scenarios related to energy use in the United States. These are published in annual volumes as the *Annual Energy Outlook* (AEO). According to EIA, the projections are not statements of what will happen, but of what might happen given the assumptions and methodologies used. The projections are business-as-usual trend forecasts, given known technology, technological, and demographic trends, and current laws and regulations. Projections by EIA include a policy-neutral reference case that can be used to analyze policy initiatives. EIA does not propose, advocate, or speculate on future legislative and regulatory changes. All current laws are assumed to hold; however, the impacts of emerging regulatory changes, when defined, are reflected in the scenarios. The AEO is based on the National Energy Modeling System. Because energy markets are complex, models are simplified representations of energy production and consumption, regulations, and producer and consumer behavior. Projections are highly dependent on the data, methodologies, model structures, and assumptions used in their development. Scenarios described in the AEO recognize that many events that shape energy markets are random and cannot be anticipated, including severe weather, political disruptions, strikes, and technological breakthroughs. In addition, future developments in technology, demographics, and resources cannot be foreseen with any degree of precision. Therefore, key uncertainties are addressed through alternative cases.



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting

FIGURE 1.4 Coal-producing regions and subregions of the United States. Note that the Northern Great Plains and Other West categories comprise the Western coal region.

4. FUTURE DEMAND FOR COAL

Projections of future demand for coal are based on a number of assumptions, among the most important of which are economic growth, the cost of coal as compared to the cost of competing fuels, the rates at which coal mining and coal utilization technologies are likely to emerge, and the impact of policy measures related to controlling greenhouse gas emissions. Depending on assumptions concerning growth rates (e.g., high or low, rapid or slow), these projections are likely to differ. For example, the National Research Council (NRC) reports that, based on different assumptions about carbon policy, estimates of projected coal energy use in 2030 in the United States range from 70 percent above to 50 percent below the 2004 level, from about 1.8 billion tons to 540 million tons (NRC, 2007a).

According to AEO scenarios (EIA, 2006a, 2007a, 2008), coal production growth by the year 2030 is projected to range between 1.6 billion tons (2008 estimate) and 1.8 billion tons (2007 estimate). Nearly two-thirds of this production is estimated to occur in western states. Changes in the predictions are the result of assumptions concerning, among other things, growth in electricity demand and share of coal-fired generation. CTL production assumes increasing importance, with AEO projecting 157 million tons of coal (2.4 quadrillion Btu) slated for CTL use in 2030. The NCC (1995) study projects that several factors, including new electricity generation, CTL plants, and coal-to-gas plants could increase demand for coal, adding up to 1.3 billion tons of new coal production per year by 2025.

Projections for future coal production also depend on assumptions made about the import and export of coal. The United States has not been a major player in importing or exporting coal; imports and exports account for only a small part of coal production or use in the United States (NRC, 2007a), but coal exports have increased in the past few years and are expected to continue to do so. Specifically, coal exports increased from 49 million tons in 2006 to 59 million tons in 2007, and the United States will export seven or eight percent of its coal production in 2008, up from about five percent in 2007 (Krauss, 2008).

Exports have a pronounced impact on pricing, at least in the short term. The largest increase in global consumer prices was in the coking coal sector, which represents the primary use for coal exported from the United States. The limited availability and tight specifications needed for coal to produce coke has contributed to price increases for coal used specifically for this purpose. High international prices for exported metallurgical coal throughout 2007 and 2008 also affected both metallurgical and steam coal prices in the U.S. market.

Under all scenarios and projections, a large fraction of the increase in coal production (over 60 percent) is slated to come from the Western region, particularly the Powder River Basin (PRB). Appalachian production is projected to remain static because of reserve depletion, and production from the Interior region is expected to increase slightly from current levels because of better reserve conditions and improved technology for utilizing coals with higher sulfur content.

The major limitation of these recent coal projection studies is the inability to accurately predict future economic conditions and policy directions. Scenarios that assume high economic activity, growth in energy consumption, high oil and gas prices, and no major policy shifts concerning carbon capture result in higher projections; scenarios with opposite assumptions result in lower projections. Assumptions about imports and exports of coal are also important in determining projections for domestic coal production and projecting future coal prices. Because future projections are often based on recent history, projections made during periods of rapid growth in the economy tend to overestimate production, while those made during periods of relatively slow growth are likely to underestimate production. Moreover, longer projection periods rely on more assumptions, resulting in more uncertainty. Clearly, the infrastructure development needed to support downstream operations such as transportation and power plant construction must also be realized and implemented as planned for production forecasts to be reasonable.

5. COAL SYSTEM COMPONENTS

Taking a systems approach to analyzing the main issues involved in coal production, as this study does, requires characterizing the coal system components. There are a number of ways in which a system can be defined. The NRC (2007a) defined and developed a coal fuel cycle as an organizing framework to address the scope of the "Research and Development to Support National Energy Policy" associated with coal. The coal fuel cycle consists of mass flows of coal from reserves to subsequent stages of mining and processing, transport, and use.

For purposes of this study, coal system components are exploration (from the federal or state viewpoint), reserve definition (from a mining company viewpoint), mine development, extraction, processing, transportation, and utilization (Figure 1.5). Reserve definition, mine development, extraction, and processing are usually performed by one operating entity, the mining company. Therefore, these four components are aggregated into one major component. Because there are sufficient differences between mining and post-mining processing of raw coal for product improvement, and because more processing may be needed in the future to produce different feedstocks for different end uses (such as electricity generation, CTL, and coal-to-gas), processing should be a distinct component of the coal system. Transportation, utilization, and the development and transmission of energy are the final stages of the cycle. Coal system components that transcend the entire system are health and safety, environmental, community, and personnel considerations.

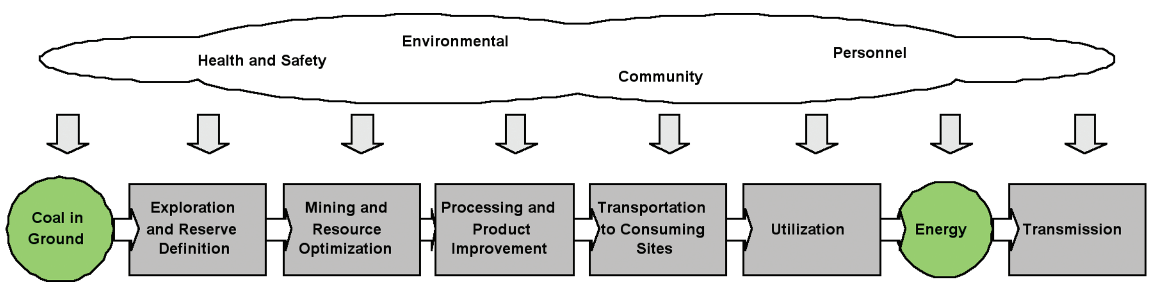


FIGURE 1.5 Coal system components.

6. COAL PRODUCTION UNCERTAINTIES

There are several important factors specific to the mining and marketing of coal as a commodity. First, most coal is now sold on somewhat shorter-term contracts than in earlier years. Unless there are dramatic revisions in prices, these contracts will continue to be renewed with adjustments for changing economic conditions. There is always opportunity to sell production in spot markets, though the quantities are likely to be small. Second, coal reserves are widespread, and in many cases, coal of marketable quality can be produced from raw coals close to the consumer site, which offers a competitive advantage. The source of the competitive advantage of coal over other fuels is its heat content and price. A reserve is usually tied to a secure market before a mine can be planned, permitted, and brought into production.

A main reason for not mining a coal reserve is competition from other reserves due to marketplace conditions. A mine cannot be opened under the assumption that a market for the mined coal will evolve. In fact, as stated by a coal industry CEO, "any expansion of production capacity must meet a number of criteria:

- More than 60 percent of the output should be under contract before proceeding with major capital commitments;
- These new contracts cannot cannibalize existing business;
- The projects are expected to generate internal rates of return that exceed 20 percent; and
- We can do the project with internally generated funds.

These criteria reflect our determination to add capacity only when the market signals its need for coal through contract commitments as well as our determination to maintain a healthy balance sheet as we grow" (Harvey, 2006).

Several issues become apparent when considering opportunities for increasing coal production. Although there was some excess production capacity in the coal industry in the past, increases in coal demand in recent years have been accommodated mainly with mine expansions (rather than new mine openings) and consolidation of mining companies. However, increases in production to 2030 will require development of new mines and, thus, a market commitment to buy the increased coal produced. The ability to (1) supply coal of desired quality to the market, (2) transport the coal from the mine to market, and (3) achieve competitive prices for both consumers and producers are critical considerations. Some of these assumptions may be challenged in view of transportation infrastructure capacity issues and escalating production costs, among other factors.

In summary, issues associated with coal utilization, coal transportation, and coal price are important downstream factors that can also impact upstream production levels from coal reserves. The redistribution of coal production among the Appalachian, Interior, and Western regions in the last three decades has, to a large extent, resulted from the ability of PRB coal operations to compete effectively with reserves in the other regions.

Uncertainty concerning the commitment to coal utilization for future energy needs can negatively impact decisions to open new mines in a timely manner. An NRC (2007a) report asserts that, "The context for any assessment of future coal production is inextricably linked with the development of a national carbon emissions policy. Potential constraints on greenhouse gas (especially CO_2) emissions and the technical and economic feasibility of CO_2 control measures are the dominant issues affecting the outlook for the future of coal use over the next 25 years and beyond." The report also states that, "potential regulatory requirements to further reduce emissions of NOx, SO_2, mercury, and particulate matter in the future are not expected to significantly limit the overall use of coal in the next several decades. However, future emission control requirements for these regulated air pollutants could result in changed preferences for particular types of coal."

At present, U.S. policy on CO_2 control is still evolving. Because of uncertainty about the outcome, efforts to develop new coal mines are often hindered. In addition, there are the other uncertainties concerning developments in transportation and human resources. Finally, there is a need to ensure that society in general and local mining communities in particular are supportive of the development of the coal sector. Mining companies would be in a better position to interact with the communities and assess the needs of the communities prior to, during, and after mining if uncertainty on decisions about opening new mines was reduced. The long lead times necessary to bring a reserve to a marketable stage—five to 15 years depending on how new mines are permitted—are discouraging to investors. If uncertainties persist concerning coal utilization, then it will be more difficult to encourage investment in opening new mines.

7. THE ROLE OF COAL TRANSPORTATION

Coal transportation is not the subject of a specific chapter in this report because it has been well documented and presented in a number of recent studies (NCC, 2006; NRC, 2007a). This omission is not to reduce its importance. Transportation is a vital link within the coal distribution system and a major component of the coal cycle; its impact is well recognized in various chapters of this report. As noted by the NRC (2007a), "growth in coal use depends on having sufficient capacity to deliver increasing amounts of coal reliably and at reasonable prices. Conversely, insufficient capacity, insufficient confidence in reliable delivery, or excessive transportation prices could reduce or eliminate growth in coal use." Depending on the study or model used, transportation has been considered either an upstream or a downstream issue based on how the system functions for the specific purpose of describing components of the coal cycle.

Coal transportation encompasses a network of more than 600 coal-burning power plant sites in the nation and a number of export terminal facilities, and is discussed in two reports (NCC, 2006; NRC, 2007a) that also address R&D needs of the sector. Gulf Coast lignite is generally transported over very short distances to mine mouth power plants. The Appalachian and Interior regions' coals are typically transported over longer distances. PRB coal may travel from fewer than 100 miles to over 1,500 miles before reaching its final user (NCC, 2006).

Recent coal statistics indicate that approximately 58 percent of coal is transported by rail; 17 percent by water; 10 percent by trucks; 12 percent by multiple transportation modes (primarily rail and barge); and the remaining three percent by conveyor systems at mine mouth plants (NCC, 2006; NRC, 2007a). The rail transportation network and distribution system for 2002 is depicted in Figure 1.6. In 2004, more than 85 percent of coal shipments were delivered to consumers either by rail (684 million tons), truck (129 million tons), or water (98 million tons), based only on final destination (i.e., coal delivered), ignoring the significant transloading requirements (almost one-third of all coal delivered) along the transportation chain (NCC, 2006).

Transportation networks have an inherent fragility and instability common to complex networks. As noted in the NRC (2007a) report, "The complex and dynamic interactions between societal and environmental factors—as well as the intrinsic dynamics of a system that operates close to its capacity—result in the potential for small-scale issues to become large-scale disruptions." In addition, adverse weather can cause localized line outages that can, in turn, adversely affect an entire rail network or other transportation mode. Furthermore, such disruptions have not only national but also international ramifications. For example, transportation and weather disruptions were major contributing factors to the doubling of global coal prices from July 2007 to March 2008 (Medine, 2008); other factors included demand growth outpacing supply growth, the weak U.S. dollar, and increased freight rates. The most spectacular disruption occurred in Australia in 2007 and 2008, severely affecting the ability of Australian producers to meet contracts. Weather-related transportation delays resulted in congestion at ports and infrastructure problems (mainly in rail). In addition to the high export price, the Australian disruption had significant effects in the United States, including an increase in exports of metallurgical coal and even some redirection of high-quality coal from the domestic steam market to international markets. This disruption primarily benefited eastern U.S. coal producers.

In summary, projected coal production needs can only be achieved if sufficient and reliable transport capacity is available to deliver the increased amounts of coal at reasonable prices. Rail transportation is the dominant factor in the transportation chain and, as noted in the NRC (2007a) report, the capacity, reliability, and price of rail transportation, "depend largely on the supply and demand for rail transportation, as well as on prevailing business practices, the investment climate, and the nature of regulatory oversight of the railroad industry."

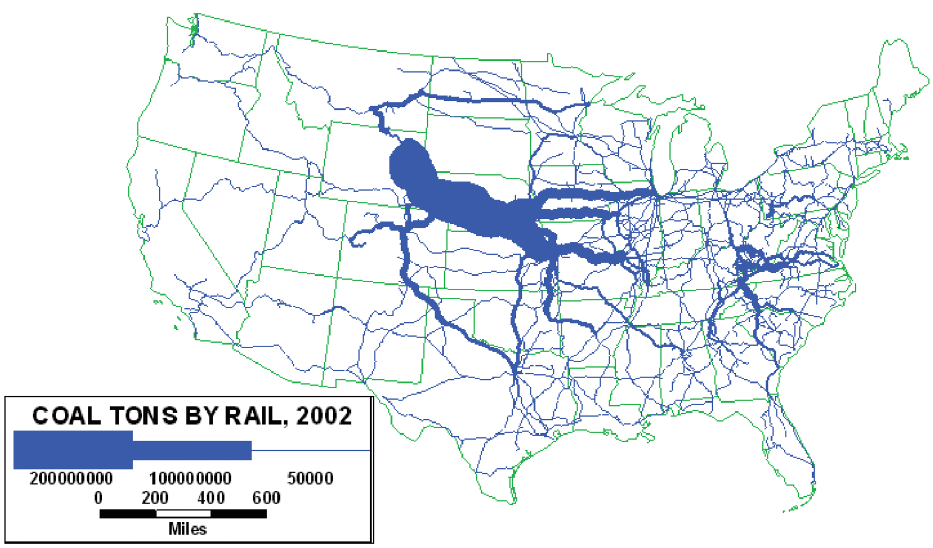


FIGURE 1.6 Schematic showing coal tonnage transported by rail in 2002 throughout the 48 conterminous states. SOURCE: Bruce Peterson, Center for Transportation Analysis, Oak Ridge National Laboratory, submitted for the NRC (2007a) report.

8. SOCIETAL ISSUES AND COAL MINING ACCEPTANCE

Societal issues impact all phases of coal production and utilization, and are discussed in many of the chapters of this report. Like all other sources of energy, coal production and utilization affect the environment in a number of ways, impacting society and the communities where coal is produced and used. As a result, the development and deployment of the best upstream technologies and practices and the wider acceptance and utilization of downstream clean coal and carbon management technologies could have a significant impact on societal and community attitudes towards coal and coal utilization.

According to a recent industry-wide stakeholder survey (ICMM, 2008), the most serious issues facing the mining industry in the next few years are environmental concerns and social and community acceptance. Coal is not an exception and, therefore, it is important that the industry, acting individually as independent coal producers and collectively on an industry-wide basis, create opportunities for engagement of all stakeholders and local communities.

The upstream coal cycle has visible benefits and adverse impacts at all levels, from individuals to communities to the nation as a whole, but it is the local citizens and communities that are, and should be, the focus of engagement. This point is highlighted in the NRC (2007a) report, where it is noted that a number of socio-economic issues exist in some older mining districts that reflect unique historical issues of coal mining and coal mine development as a land use. The report also lists impacts and benefits, and highlights the importance of developing sustainable communities (Box 1.3).

Community and stakeholder engagement is not a new concept; however, the focus of community engagement has shifted into the arena of sustainable development and corporate social responsibility (Department of Industry, Tourism, and

BOX 1.3 COMMUNITY IMPACTS (NRC, 2007a)

The impacts of mining on the safety and general welfare of coal communities can include mine drainage, mine fires, waste piles, ground movements (subsidence), and local hydrology. An additional concern in new mining districts, such as those in the West, is that the rapid development of sparsely populated areas will produce a sharply increased demand for infrastructure and community facilities that may be very difficult to satisfy or may be cost prohibitive. Beneficial impacts are realized during the productive life of a coal mining operation, and great progress has been made over the years in minimizing adverse impacts. Maintaining a healthy community following mine closure requires deliberate planning to develop new opportunities for the community. The key to establishing sustainable communities is for both industry and community participants to cooperate in developing guidelines, practices, and reporting mechanisms that promote sustainable development (NRC, 1996). The development and adoption of these procedures would benefit from active research programs involving case studies of positive post-mining community development.

Resources, 2006). Community engagement represents a continuum of activities (Figure 1.7). At the beginning of the spectrum, community engagement is very basic—simply providing information. As the level of engagement increases, the process moves forward to direct methods of stakeholder-driven interactions aimed at involvement and collaboration. The final stage of empowerment provides for engagement that extends to the community's future of post-mining land use after mine closure (Department of Industry, Tourism, and Resources, 2006).

The coal industry, along with the rest of the mining sector, has traditionally addressed community engagement from a compliance and legal framework, and has focused on information and consultation via media releases, newsletters, websites, public meetings, and discussions groups. The mining industry today clearly understands that local communities and local people affected by a mining operation must be engaged at a much higher level and in a process based on respect and dialogue. The desired outcome is to ensure that local community concerns and community aspirations are major components of mining planning, development, and post-mining land use. In essence, the industry must transition from an information sharing, crisis, and defensive mentality to one that promotes proactive dialogue, transparency, and participation.

The demand for all mineral resources, in fact for all raw materials, is growing at an unprecedented rate. For coal, the demand is expected to grow, not only in the United States, but across the world. Therefore, it is imperative for individual companies and the coal mining sector at large to respond collectively by developing institutional capacity and planning. Management leadership must establish higher performance standards and actively pursue engagement with all communities of interest to ensure that coal mining is conducted in a responsible, sustainable manner.

FIGURE 1.7 Public participation spectrum. SOURCE: International Association of Public Participation, IAP2, www.iap2.org.au/.

9. ALTERNATIVES TO TRADITIONAL COAL MINING TECHNIQUES

There is considerable interest in developing alternatives to traditional mechanical methods for mining coal. Alternatives include in situ gasification, hydraulic mining techniques, and chemical communition, all of which are in various stages of development. For instance, hydraulic methods for fracturing and transporting coal, or in situ gasification, has been practiced or tested in many parts of the world for some time.

There is particular interest about in situ gasification. In simple terms, gasification is a chemical process for converting a solid or liquid fuel into a combustible gas. A gasifier differs from a combustor in that the amount of air or oxygen available inside the gasifier is carefully controlled so that only a relatively small portion of the fuel burns completely. This "partial oxidation" process provides the heat. Rather than burning, most of the carbon-containing feedstock is chemically disaggregated by the gasifier's heat and pressure, setting into motion chemical reactions that produce "syngas." Syngas is primarily hydrogen, carbon monoxide, and other gaseous constituents, the exact composition of which varies depending upon the gasifier and type of feedstock (http://www.fossil.energy.gov/programs/powersystems/gasification/howgasificationworks.htm).

Underground coal gasification (UCG) "involves the passage of air through a burning coal seam to produce a hot, combustible gas, which is brought to the surface for use" (Noble, 1959). Gas is produced and extracted through wells drilled into the coal seam in order to inject air or oxygen to combust the coal in situ, and to extract the coal gas to the surface for further processing, transport, and utilization (Figure 1.8). The process relies on the natural permeability of a coal seam to transmit gases to and from the combustion zone, or on enhanced permeability created through reversed combustion, an in-seam channel, or hydrofracturing (Burton et al., 2007). Though simple in principle, the industrial application of in situ gasification is extremely complex.

UCG has been tried in many countries, particularly in the former Soviet Union, for nearly 60 years. In the United States, extensive trials have been conducted by the former Bureau of Mines, the present Department of Energy, and some energy companies. Proponents of UCG claim that

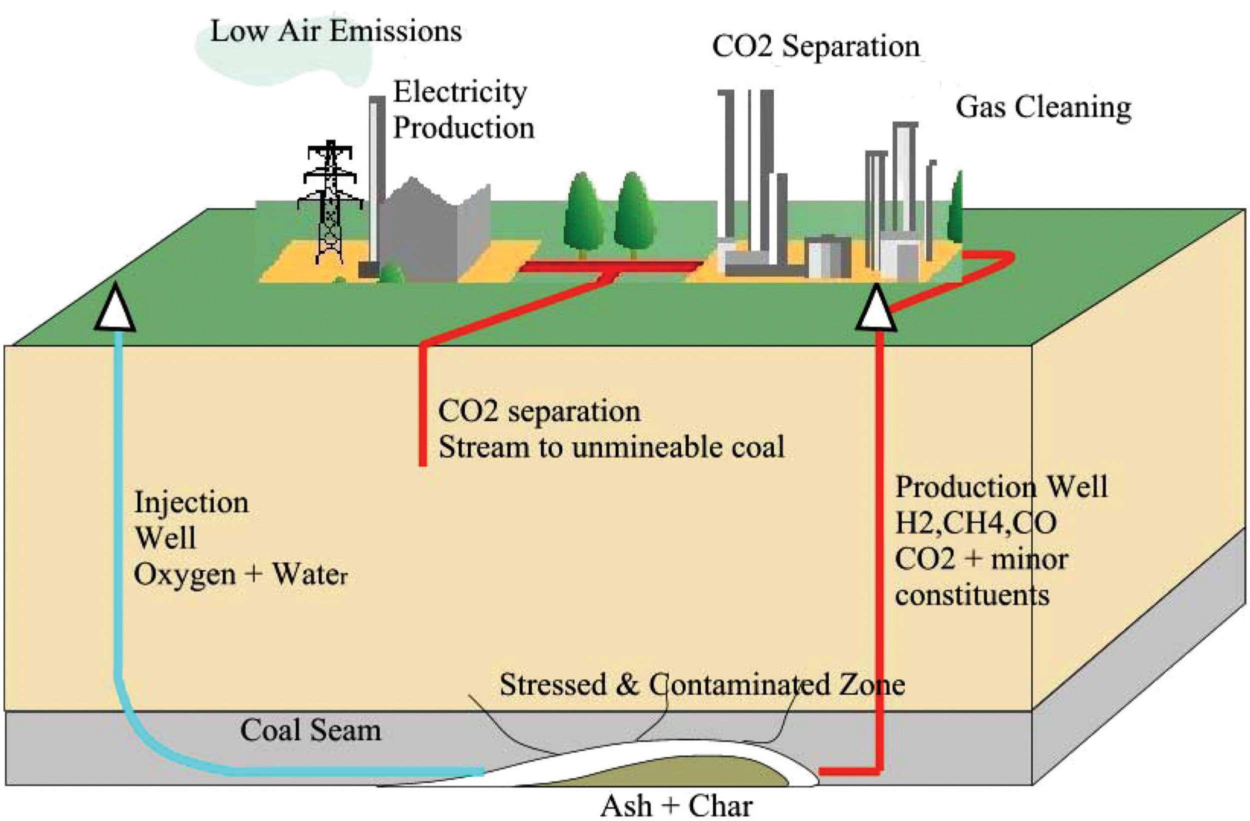


FIGURE 1.8 Schematic of the components of the UCG process collocated with electricity generation. SOURCE: UCG Engineering, Ltd., 2006.

its advantages are potentially enormous, including reduction or elimination of underground mining, improvements in health and safety, exploitation of resources that would be economically or technically unmineable, increased use of the abundant coal resources of the United States, and decreased dependence on imports. Although a number of environmental issues associated with conventional coal mining, processing, and utilization may be reduced by UCG, other environmental concerns such as aquifer disruption or contamination, subsidence, and fire propagation must be addressed. Current high costs of natural gas and imported oil are also factors that make it desirable to take a renewed look at the economics of UCG.

A recent draft report on UCG by Burton et al. (2007) discusses the rationale for reexamination of the potential benefits of UCG and provides an extensive review and presentation of techniques, results from trials and operations around the world, and scientific and technical gaps that need to be addressed. The report calls for U.S. development of an accelerated research program that "could lever substantially off of existing knowledge, planned commercial tests, and advances in engineering and earth science simulations." The report specifically recommends that the United States "undertake a plan to evaluate advanced simulation opportunities, critical laboratory components, and current and potential sites for field work, especially in monitoring and process control."

There is considerable interest in finding alternatives to conventional methods of underground coal mining. There are also formidable technical and economic challenges that make the prospects of widespread application of these technologies unlikely in the short term.

10. THE STUDY AND REPORT

10.1 Scope of the Study

The assumption that coal will remain an important energy resource in any U.S. energy supply scenario was an important factor in determining the scope of this study. The promise of advancements in technology to address environmental concerns, most importantly regarding carbon capture and sequestration, is important for this assumption, as are advancements in technology pertaining to the future utilization of coal.

This study provides a state-of-the-art review of six major areas of upstream coal production, each of which could affect the ability of the U.S. coal industry to meet production demands that have been projected to 2030. These areas include coal resources and reserves (Chapter 2); mining technology and resource optimization (Chapter 3); coal preparation (Chapter 4), health and safety issues (Chapter 5), environmental protection, practices, and standards (Chapter 6); and workforce challenges (Chapter 7). In addition, each chapter identifies important issues and offers recommendations for meeting future production needs given these challenges. This study also includes a chapter that presents overarching themes and recommendations (Chapter 8). Industry leaders, government agencies, academics, interested citizens, and others provided valuable input for identifying and framing these issues.

10.2 The Study Process

In June 2007, at the behest of the National Commission on Energy Policy, VCCER contracted to conduct this study, establishing a committee of experts for its execution, as listed in Appendix A. As part of the study, a dedicated website was created to compile the considerable background information that was available to the committee and to provide public information on the report status and committee meetings (http://www.energy.vt.edu/ncepstudy/). The Report Committee attended two major kickoff meetings, one in Washington, D.C., and the other in Denver, Colorado, where members heard from experts on issues that confront today's industry and those that are likely to become important for the future in the areas of exploration, extraction, coal processing, health and safety, environment, and human resources. At each of these two locations, an open question and answer session was held with stakeholders to discuss the scope of the study and receive their input. Details from the two open forums are posted on the study website, along with the formal presentations; the agendas for the meetings are shown in Boxes 1.4 and 1.5.

The entire study team, including the Committee, staff, and the National Commission on Energy Policy liaisons, subsequently met several times in Washington, D.C., and once in Charleston, West Virginia. The team had the opportunity to participate in a comprehensive visit to a major mining complex in West Virginia, including a visit to an underground and a surface mine, and to a state-of-the-art coal preparation facility.

BOX 1.4 WASHINGTON, D.C., KICKOFF MEETING

OPENING REMARKS: Corporate Strategy
- Michael Quillen, Chairman and CEO, Alpha Natural Resources

ROUND TABLE DISCUSSION 1: Health and Safety
- Jack A. Holt, Senior Vice President-Safety, CONSOL Energy
- Robert McAtee, Vice President of Safety and Human Resources, United Coal Company
- Randall J. Harris, Engineering Advisor to the Director, West Virginia Office of Miners' Health Safety and Training

ROUND TABLE DISCUSSION 2: Environment
- Mark R. Yingling, Vice President, Environmental and Engineering, Peabody Energy
- Rusty Ashcraft, Manager of Environmental Affairs and Permitting, Alliance Coal
- Scott Roberts, Deputy Secretary for Mineral Resource Management, Pennsylvania Department of Environmental Protection

OPEN SESSION: Input from Stakeholders
- Welcome and Remarks
- Committee Presentation of Report Chapters and Stakeholders Discussion

BOX 1.5 DENVER KICKOFF MEETING

OPENING REMARKS: Corporate Strategy
Colin Marshall, President & CEO, Rio Tinto Energy America

ROUND TABLE DISCUSSION 1: Resources and Coal Preparation
Tim Rohrbacher, Mining Engineer, USGS
Jeffrey Quick, Coal Group , Utah Geological Survey
Kip Alderman, President, Advanced Coal Technology
Peter Bethell, Director of Coal Preparation, Arch Coal

ROUND TABLE DISCUSSION 2: Mining Extraction and Manpower
John Rusnak, VP of Geology, Peabody Energy
Phil Hansen, Commercial Manager, Caterpillar Global Mining
Kim McCarter, Chair, Mining Engineering, University of Utah
Rebecca Boam, HR Team Leader, BHP Billiton, New Mexico Coal

OPEN SESSION: Input from Stakeholders
Welcome and Remarks
Committee Presentation on Report Chapters and Discussion

10.3 Contribution of the Study and Report

All realistic projections, under various scenarios, predict that coal will be a major contributor to the U.S. energy mix for the term of this study and beyond. In introducing bipartisan federal legislation on carbon capture and storage, Congressman Rick Boucher (D-Va.) stressed that coal is the most abundant energy source in the United States, stating further, "Given our large coal reserves, its lower cost in comparison with other fuels, and the inadequate availability of fuel alternatives, preservation of the ability of electric utilities to continue coal use is essential" (Boucher, 2008). The Report Committee concurs with this view, and acknowledges the National Commission on Energy Policy for appreciating the vital role of upstream coal production issues and the fact that these have largely been ignored in previous studies. The support from the Commission facilitated an extensive analysis of the upstream problems, prospects, and needs for meeting coal projections to the year 2030.

Finally, this report reflects the comments and suggestions of the Report Committee—a team of experts with diverse perspectives and technical expertise in the topics discussed. In essence, this report provides not only a critical review of the important upstream issues of coal production, but also allows for a thorough state-of-the-art examination of each topic. As such, this report should be useful to policymakers, interested and concerned citizens, and academics as a comprehensive reference guide to the basic upstream issues of coal production and as a textbook in the classroom.

Chapter 2 Coal Resources and Reserves

1. SUMMARY

Accurate estimates of total coal reserves are needed by the federal government to formulate a national energy policy, as well as an energy foreign policy. State and local governments factor coal reserve data into decisions concerning taxation, environmental protection, institution and infrastructure development, and energy conservation. Those involved in industries dependent on coal, including mining companies, suppliers of mining equipment and services, transportation companies (e.g., truck, rail, barge), power producers, transmission companies and others, all make business decisions based on their analyses of the future of the industry and the location and availability of a sufficient quantity and, often specific quality, of coal. Estimates of total coal resources in the United States have been published for nearly 100 years, and all have been large, in trillions of tons. These data are of little value for supporting policy decisions about coal usage. Subsets of the total coal endowment, such as the Demonstrated Reserve Base (DRB) and Estimated Recoverable Reserves (ERR), are more useful, but neither are true "reserves," and they are out of date, limited in scope, and incomplete. Updating and completing them would be valuable in supporting policy and business decisions such as those listed above.

Knowledge of true "reserves" (i.e., coal that can be economically produced) is important for making policy decisions. Only recently have advances in handling large databases (e.g., through geographical information systems, or GIS) allowed for improved assessment of reserves by federal and state agencies; Coal Recoverability and Coal Assessment are two programs making such assessments. These programs offer detailed information appropriate for government agencies, but these programs should be broadened and expanded to include additional coal-producing areas.

Coal companies report reserves at operating mines on questionnaires to specified government agencies and some also report their total reserve holdings to the National Mining Association (NMA). The values reported are consistent from year to year and are also consistent with reserve information reported elsewhere. Reserves that are reported represent much of the coal that will be produced in the coming decades. This data collection should be expanded and coordinated and coal companies should be encouraged to be more forthcoming with information about the nature of their reserves.

Coal in the United States has been used primarily for combustion in steam boilers for the generation of heat and electricity, and secondarily for the production of coke for use in manufacturing steel. These uses will continue, but coal use in new technologies such as gasification and liquefaction is expected to increase according to most forecasts. As this evolution occurs, there will be a demand for data concerning potential coal reserves with specific properties. These properties may be very different for each new coal-processing method. Because it is not possible to know precisely which properties will be relevant, national and regional databases should be developed and maintained that would permit rapid response to any and all questions concerning location, coal quantity, and coal quality.

2. INTRODUCTION

2.1 Resources and Reserves: Terminology

"Coal resources" are the total endowment of coal in the ground, limited only by depth and some minimum thickness of the coal bed. Coals above the rank of lignite are included in resource estimates if they are less than 6,000 feet deep and all surface mined coals are to be included if they are less than 500 feet deep. Anthracite and bituminous coal seams greater than 14 inches thick and subbituminous coal and lignite greater than 30 inches thick are classified as resources (Wood et al., 1983).

"Coal reserves" are the economically minable subset of the resources; a very small percentage of the total resources are or will ever become reserves.

2.2 Distinguishing Resources and Reserves

A decade following the seminal paper by Vince McKelvey (1972), a publication by the U.S. Geological Survey (USGS) included a glossary that listed 31 distinct terms that had "reserves" or "resources" as part of the term being defined (Wood et al., 1983). A simple distinction between

BOX 2.1 DEFINITIONS

Better methods for estimating the magnitude of potential mineral resources are needed to provide the knowledge that should guide the design of many key public policies.

This statement was the subtitle of the article entitled "Mineral Resource Estimates and Public Policy," by V.E. McKelvey, then director of the USGS, in the *American Scientist* in 1972 (McKelvey, 1972). That paper, which had originally been presented at Harvard University, was the impetus for renewed efforts by the USBM and the USGS to come to grips with the variety of terms and methodologies then in use regarding energy and mineral deposits. By the end of the 1970s, the two federal agencies had agreed on the terms and methods that would be used in future coal resource classification systems. They published a series of papers that summarized the consensus of the representatives of the two federal agencies and, at the time, seemed to define resources and reserves in succinct and clear language (Averitt, 1975; USGS, 1976, 1980; Wood et al., 1983). In their most concise forms, the definitions are:

COAL RESOURCES: "Total quantity of coal in the ground within specified limits of bed thickness and overburden thickness" (Averitt, 1975)

COAL RESERVES: "That portion of the Identified Coal Resource that can be economically mined at the time of determination" (USGS, 1976)

resources and reserves, as had been originally proposed, did not suffice, but adjectives such as hypothetical, inferred, marginal, measured, restricted, and indicated were deemed necessary in order to calculate, classify, and discuss coal resources. Researchers at the USGS were charged with reporting "resources" and the researchers at the United States Bureau of Mines (USBM) had responsibility for determining "reserves," but the boundaries between the two were blurred from the beginning. Many of the adjective-modified terms were introduced by those charged with doing the assessments, often geologists who believed that geologic interpretation and knowledge are necessary for a proper resource assessment. However, as noted by McCabe (1998, p. 2113), "For nongeologists, however, there understandably is little or no interest in how the geologists have done the assessment, and there is an assumption that the methodology is scientifically sound. The only question that most nongeologists will ask of an assessment is: How much is there and where is it?" Unfortunately, oversimplifying the reporting of resources and reserves does not allow for informed use of the available information, imperfect as it might be.

2.3 Value of Resources and Reserves

Benefits of accurate information concerning resources and reserves of energy sources, including coal—a significant contributor to the world's energy mix—are many. The lack of accurate information can be economically and politically catastrophic. Results of energy assessments are factored into decisions concerning foreign policy, a nation's internal energy policy, investments in energy research and development, national land use, taxation levels, environmental protection, energy conservation, human health, institution and infrastructure development, and investment strategies.

The types of decisions listed are made not only by the federal government, but are also by state, regional, and local governments and private industry. Knowledge of resources and reserves and their relative abundances and perceived future costs, financial and environmental, may also effect decisions of the average citizen. Decisions concerning expenditures on energy-saving devices, energy-efficient homes, electric vehicles, and which national policies to support, are strongly influenced by one's belief about whether there is an inexhaustible supply of energy (including coal) or whether that energy resource is soon to be exhausted.

2.4 Historical Perspective: Coal Resources of the United States

The first considered estimate of the total original coal resources of the United States was prepared in 1909 by M.R. Campbell and E.W. Parker of the USGS and published with successive minor revisions several times between 1909 and 1929 (Averitt, 1975). These early estimates of total coal resources considered the area underlain by coal and coal thickness—with minimum thicknesses of 14 inches for bituminous and anthracite coals, 24 inches for lignite, and 36 inches for subbituminous coals. Thickness and area covered resulted in "acre feet" of coal. A value of 1,770 tons per acre-foot was used for all ranks of coal for the calculation of tons of coal in the ground. The 1909 estimate of coal resources included coal to a depth of 3,000 feet. Subsequent revisions to these estimates by Campbell added an estimate for coal with overburden of 3,000 to 6,000 feet (Campbell, 1913, 1917, 1929). The estimates for original coal resources in the ground in Campbell's series of reports range from 3.7 trillion tons to 4.2 trillion tons.

The most recent attempt at estimating the total coal resources of the entire United States was published by the USGS more than 30 years ago (Averitt, 1975). This resource analysis identified coal resources by state, classified resources by rank, and was made possible by post-World War II programs of geologic mapping and exploration by federal and, most importantly, by state geological surveys (or equivalent agencies). This extensive resource estimate classified resources by a variety of factors, including reliability categories ("identified," including "measured," "indicated," and "inferred," and "hypothetical"), rank of the coal, thickness of overburden, and thickness of coal beds. Averitt (1975) estimated the total coal resources of the United States at 3,968 billion tons and was the first to include coal resources in Alaska in the national estimate. All previous estimates were for the conterminous United States.

Inasmuch as Averitt was able to classify coal resources based on reliability categories, he was also able to calculate the "reserve base" of the United States. The reserve base is a selected portion of the identified resources deemed to be suitable for mining, in this instance by 1974 methods. Averitt (1975) reported that the coal reserve base of the United States in 1974 was 434 billion tons, based on data obtained from the USBM (1974).

Figure 2.1 shows the total coal resource estimates for the United States from 1909 to 1974. The values for the resources are surprisingly similar although there are reasons to think that they would have changed over the intervening 65 years. The amounts of data and the extent of geologic information increased appreciably over that time period, and the estimates by Campbell and Parker (1909), Campbell (1913, 1922, 1929), and Buch et al. (1947) were for the conterminous United States, whereas Averitt (1975) also included Alaska.

There has not been an attempt at a complete, nationwide assessment of coal resources since that done by Averitt (1975). However, the USGS conducted an assessment, initiated in 1995, of the top-producing coal beds and coal zones in the five major coal-producing regions: the Appalachian Basin, Gulf Coast, Illinois Basin, Colorado Plateau, and northern Rocky Mountains and Great Plains. These regions produced approximately 93 percent of the coal in the United States at the time of the study (Ruppert et al., 2002). The USGS study attempted to target those coals that are expected to supply the bulk of coal production for the next several decades and was much more rigorous than previous attempts at assessing resources. The most significant advancement in methodology used by the USGS in the recent national coal resource assessment was that all data were entered in digital form and were analyzed by means of a GIS. More than 1.6 trillion tons of resources were identified in over 60 assessed coal beds and coal zones in the United States.

Averitt (1975) included coal in Alaska in the assessment of coal resources of the United States as of January 1974, but the estimate for Alaska was only 265 billion tons. The more recent USGS study referred to above (Ruppert et al., 2002) did not include Alaskan coal. However, the fact that Alaska is generously endowed with coal resources is well known; for example, Stricker (1991) estimated that the resources of Cretaceous coal strata on the North Slope were 3.9 trillion tons and, most recently, Flores et al. (2003) estimated 5.5 trillion tons of coal resources in the entire state. The coal resources of Alaska are nearly 1.4 times the estimated 4 trillion tons of coal resources in the conterminous 48 states.

Information on total coal resources is frequently referred to relative to the total energy endowment of the United States, often to support a political position. The extremely large values that geologists have estimated for almost 100 years suggest that there are likely large tracts of minable coal in several U.S. regions (Figure 2.2). Intuitively, one can readily believe that a resource measured in the trillions of tons and produced at a little more than one billion tons per year can sustain the industry for some time to come. Beyond these general observations, total coal resource estimates of the nation, a state, or a coal basin are by themselves not of great value. However, data on total coal resources are necessary to more accurately determine coal reserves, and the more comprehensive, complete, and detailed the resource data become, the better the reserves can be determined.

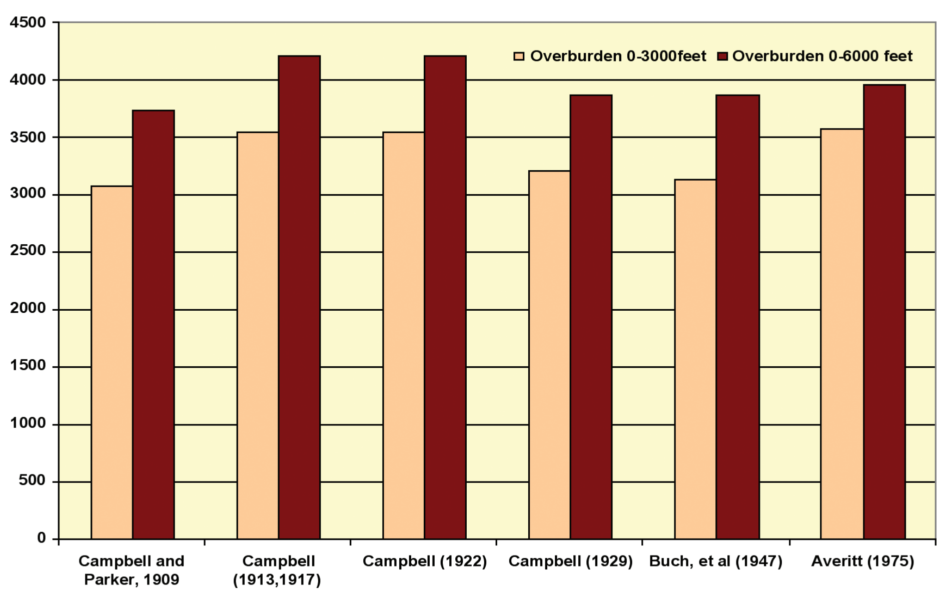


FIGURE 2.1 Coal resource estimates of the conterminous United States 1909–1947 and of the entire United States as of 1974. SOURCE: Modified by H. Gluskoter from data table p. 49 and data p. 1 in Averitt 1975.

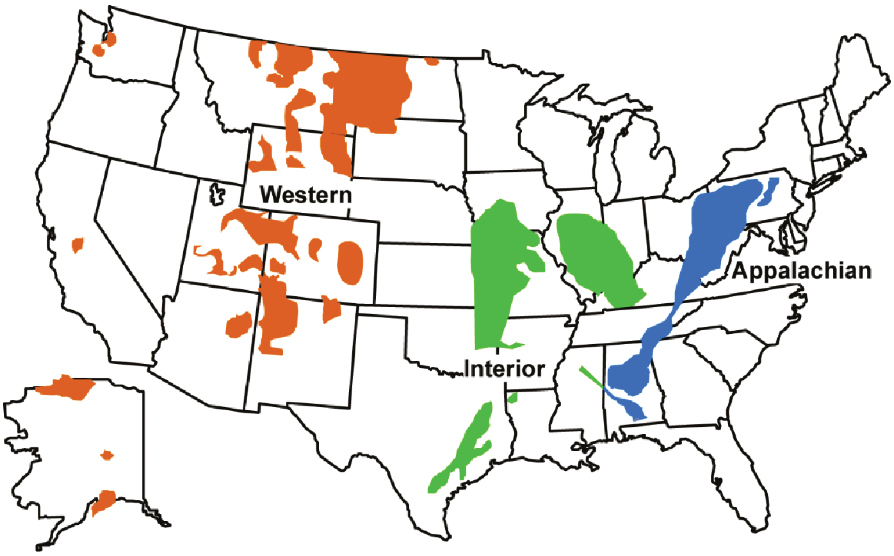


FIGURE 2.2 Coal fields of the United States. SOURCE: National Research Council, 2007a (after EIA, 2005).

2.5 From Resources to Reserves: Classification Systems

Figure 2.3 graphically depicts the coal resource and reserve classification system, developed by the USGS and USBM, which provides the basis for the most commonly used systems today. This figure, also commonly referred to as the "McKelvey Box" or "McKelvey Diagram," defines resources and reserves based on their degree of geologic assurance or reliability (horizontal axis) and the degree of economic feasibility (vertical axis). The geologic reliability categories are based on distance from actual data points; the most reliable are "measured" resources, within one-fourth mile of a data point. "Indicated" resources are within three-quarters of a mile and "inferred" resources are within three miles of a measured data point. These three categories are considered "Identified Resources," and the remaining resources (Hypothetical and Speculative) are "Undiscovered Resources."

It can be effectively argued that a one-size-fits-all classification system for geologic reliability of coal beds nationwide does not take into consideration the variation in geological conditions of coal deposits from basin to basin. For example, the relatively flat-lying and continuous beds of the Eastern Interior Basin (Illinois Basin) can be extrapolated with greater confidence than the more discontinuous beds of Central Appalachia and, as a result, the "measured" category in the Eastern Interior Basin could possibly be expanded. However, the system does provide consistency, a desired attribute.

The box in the upper left corner of the McKelvey diagram (Figure 2.3), defined by the intersection

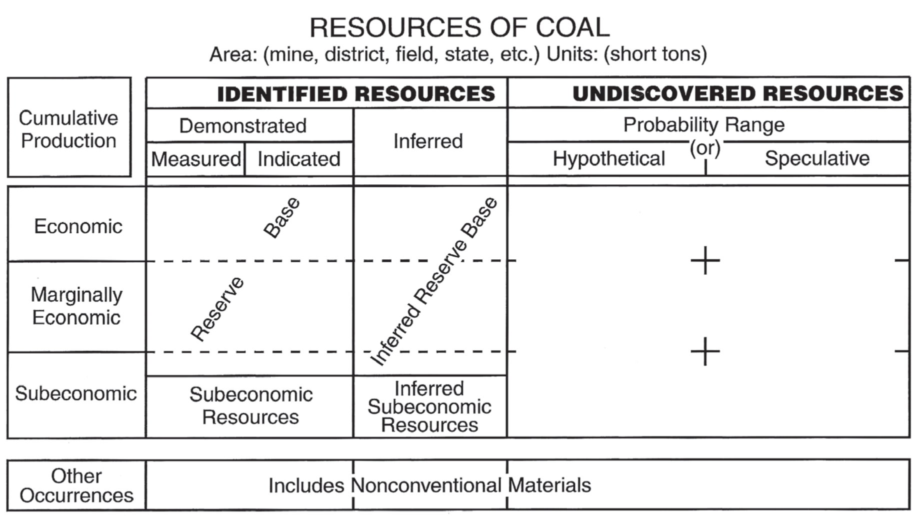


FIGURE 2.3 Format and classification of coal resources and reserves. SOURCE: Wood et al., 1983, p. 4.

of "Demonstrated Resources" on the horizontal axis and "Economic" on the vertical axis, represents reserves. Only those resources that meet the strict definition of reserves in this system of coal classification are included in that box. They are measured and indicated geological resources and they are "economic."

Problems with geological reliability, the horizontal axis of the McKelvey diagram, are minor compared to the difficulty of defining the vertical or "economic" axis. Wood et al. (1983, p. 9) recognized many of the elements comprising an economic assessment: "A critical analysis resulting in a judgment of the economic nature, significance, status, quantity, quality, market, demand, supply, costs, transportation, cash flow, capital, and processing of the coal resources of a mine, area, district, field, basin, region, province, state, or nation."

Perhaps the most widely recognized method of graphically depicting coal reserves and resources is that used by the Energy Information Administration (EIA, 1999), and is reproduced in Figure 2.4, with the notes accompanying the original figure. The EIA report states that the data represented in the triangular diagram are "interrelated conceptually, but cannot be maintained uniformly" (EIA, 1999). The entire triangle, including all shaded segments, represents the total coal resources in the United States as reported by Averitt (1975). Data reliability increases from the base of the triangle toward the apex. At the top of the triangle are reserves at active mines reported by mining companies to the EIA. This is an independent data set and is not calculated from the resources represented in the triangle.

The USBM originally developed the DRB in 1974 and it became the responsibility of EIA in 1977 at the time of the establishment of the Department of Energy (DOE). Originally, DRB resource data were used in the EIA coal-supply models, but

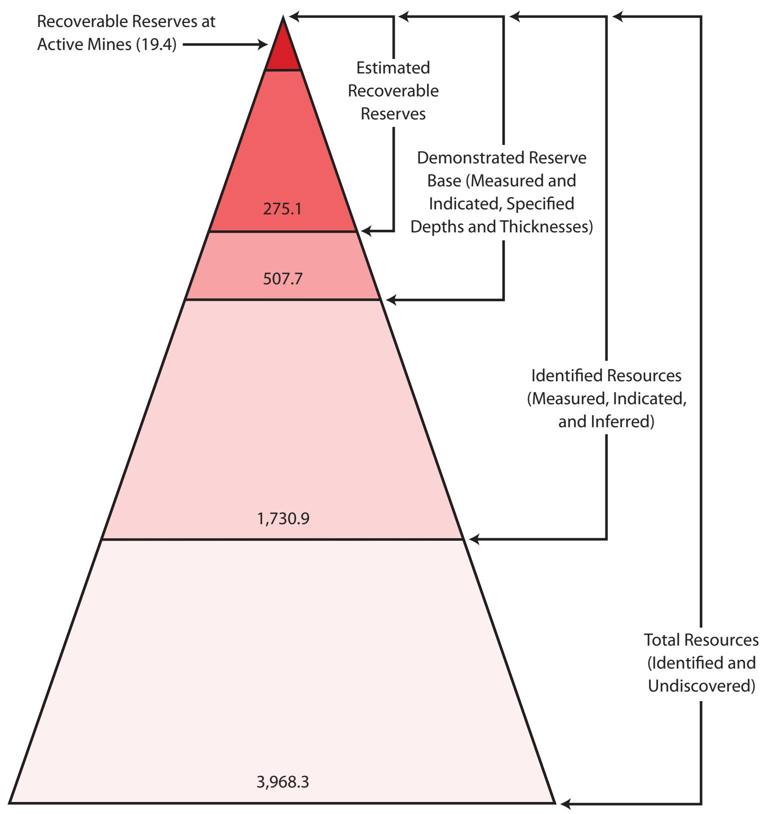


FIGURE 2.4 Delineation of U.S. coal resources and reserves. Notes: Resources and reserves data are in billion short tons. Darker shading in the diagram corresponds to greater relative data reliability. The estimated recoverable reserves depicted near the top of the diagram assume that the 19 billion short tons of recoverable reserves at active mines reported by mine operators to the Energy Information Administration (EIA) are part of the same body of resource data. This diagram portrays the theoretical relationships of data magnitude and reliability among coal resource data. All numbers are subject to revision with changes in knowledge of coal resource data. The DRB estimate was compiled by the EIA as of January 1, 1997. Estimated recoverable reserves were compiled in EIA's Coal Reserves Data Base (CRDB) program. Recoverable reserves at active mines were reported in EIA's Coal Industry Annual, 1996. Identified resources and total resources are estimates as of January 1, 1974, compiled and published by the USGS in *Coal Resources of the United States*, January 1, 1974. SOURCE: Slightly modified from EIA, 1999.

the current coal module of the National Energy Modeling System does not take into consideration data on coal reserves. DRB estimates have changed little in the past decade, from 507.7 billion tons in 1997 to 492.7 billion tons in 2006 (EIA, 2006b).

The EIA triangular diagram also indicates the ERR. The ERR is a subset of the DRB, reduced by accessibility factors (generally estimated by state) and recoverability factors (estimated losses in mining). The net result is that, for the entire country, the ERR is only 54 percent of the DRB, or 266 billion tons (EIA, 2006b), down from the estimated 275.1 billion tons in 1997. The difference is the coal that has been produced during the intervening nine years.

The numerical values in Figure 2.4 are in billions of tons and are reported to as many as five significant figures. This level of detail is an artifact of the addition of many smaller values to comprise the whole, and connotes a sense of accuracy that is not warranted. For example, the geological data on "measured" coal resources are those with the greatest degree of confidence because the data points are closely spaced. Averitt (1997, p. 26) commented on the accuracy of "measured resources" by stating, "The points of observation and measurement are so closely spaced and the thickness and extent of the coal beds so closely defined, that the computed tonnage is judged to be accurate within 20 percent of the true tonnage." Measured coal resources, the very best known segment of the entire coal resource database, make up 15 percent of the identified resources and only 6.5 percent of the total resources. All the remaining resources would be expected to have error bars around them that are well in excess of the 20 percent suggested for measured resources. However, even if all the coal resource data were as "accurate" as the measured resources, total resources should be reported to no more than two significant figures: 4.0 trillion tons, with a range of 3.2 to 5.0 trillion tons. The values for the various classes of resources and reserves presented on the triangular diagram are estimates and do not have the accuracy or precision often attributed to them.

The ERR is the basis for the all too often quoted figure that the United States has a 250-year supply of coal. EIA (2006b) most recently reported an ERR of 266 billion tons and the coal production in the United States for 2006 was 1.16 billion tons. When presented with these two numbers, individuals appear compelled to divide the larger number by the smaller one. The result is correct arithmetically, but of no real value with regard to making business or policy decisions because the premises that initiated the calculation are faulty. The future use of coal will not be at the current rate, and the resource base used in the calculation is only an estimate of what might be recoverable. Sufficiently detailed assessments of the resources and rigorous economic analyses have not been used in arriving at those numbers. Much more information is needed before it will be possible to give a time frame for future coal use.

Recently, an analysis of research and development needs to support energy policy conducted by the National Research Council (NRC) suggested that there was probably sufficient minable coal to meet the nation's needs for more than 100 years at current production levels, but that it was not possible to confirm that there is a sufficient supply of coal for the next 250 years (NRC, 2007a). The NRC study observed, "A combination of increased rates of production and more detailed reserve analyses that take into account location, quality, recoverability, and transportation issues may substantially reduce the estimated number of years of supply" (NRC, 2007a, p. 55). The NRC report then states that these factors are not currently known.

The DRB and the ERR have been extensively criticized as being out of date, underestimating the nation's true coal potential, and based on faulty assumptions (Southern States Energy Board, 2006). As part of the research for their report, the Southern States Energy Board sent questionnaires to coal geologists at state geological agencies in all 33 states reported by the EIA to have coal resources. Nineteen states responded and 13 indicated that the DRB, as currently reported by EIA, was understated. One state indicated the DRB was representative and two states thought the EIA estimate was too high (Southern States Energy Board, 2006).

The only comprehensive attempt at estimating the coal reserves of the entire world is conducted by the World Energy Council (WEC) on a triennial basis and is published in the Survey of Energy Resources (WEC, 2004). The WEC collects data on coal reserves from each country by questionnaire, and the ERR is the value reported for the United States. Even with the deficiencies in the ERR that have been mentioned, the value is clearly defined and has been consistently reported. Reserve estimates reported by other developed countries, especially those that produce significant amounts of coal, are likely of equal, but not greater, validity. Data reported by developing and still-to-be-developed countries tend to vary from survey to survey and are likely to be less precise. The state of knowledge concerning coal reserves and resources in the United States is greater than just the estimates included in the current ERR, with significant amounts of additional data in the reports of state and federal agencies.

2.6 Recent Studies that Address Coal Reserves and Resources

The most widely quoted projections of future coal use in the United States are those provided in the *Annual Energy Outlook*, published annually by the EIA. The 2008 *Annual Energy Outlook* (EIA, 2008) projects that coal usage will increase from 1.16 billion tons produced in 2006 to 1.60 billion tons in 2030. This projection is EIA's "reference case," which is a best estimate of a business-as-usual scenario: "…the reference case assumes that current policies affecting the energy sector remain unchanged throughout the projection period. Some possible policy changes—notably, the adoption of policies to limit or reduce greenhouse gas emissions—could change the reference case projections significantly" (EIA, 2007b).

Projections of increased coal consumption in the United States (and also in the world) have helped to stimulate interest in the problems and opportunities that increased coal production and coal use might present. Boxes 2.2, 2.3, and 2.4 summarize three comprehensive reports on various aspects of the future use of coal, all of which were published in 2006 or 2007.

Although resources and reserves of liquid fossil fuels (petroleum and natural gas) are often compared to coal resources and reserves, it is difficult to draw meaningful parallels. Much of the petroleum and gas reserves are "undiscovered" whereas the more significant coal resources are "identified." As noted by McCabe (1998, p. 2118), "Most of the undiscovered resources identified in the oil and gas assessments probably will play a role in the U.S. energy production over the next 50 yr, whereas the vast majority of the coal resources clearly will not." This is because it is much easier to economically elevate resources of oil and gas to reserves than to do the same for coal.

The press, the U.S. government, and, therefore, the general public place much more emphasis on oil and gas reserves than on coal reserves. This emphasis is likely the result of the perceived importance of the liquid fossil fuels to society in general. Energy consumption in the United States from oil and gas is three times as much as the energy consumed by burning coal.

BOX 2.2 NATIONAL COAL COUNCIL REPORT

Coal: America's Energy Future is a publication of the National Coal Council (NCC, 2006a, 2006b). NCC is a private, nonprofit, advisory body. Its members are appointed by the Secretary of Energy and provide guidance and recommendations as requested by the Secretary. Referring to the Demonstrated Reserve Base figures from the EIA, the NCC report concludes, "Coal's annual production of over 1.1 billion tons can be more than doubled to 2.4 billion tons. This increase of 1.3 billion tons is possible because our coal reserves are vast" (NCC, 2006a, p. 2). The entire report of the NCC is in two volumes, contains more than 200 pages of material, and primarily addresses future coal uses, such as coal-to-liquids, coal-to-gas, coal to produce ethanol, and coal-to-hydrogen. The section of the report that discusses coal reserves is titled, "Delineate U.S. Coal Reserves and Transportation Constraints as Part of an Effort to Maximize U.S. Coal Production" (NCC, 2006a, p. 95).

BOX 2.3 MIT REPORT

An interdisciplinary study conducted by the Massachusetts Institute of Technology (MIT), *The Future of Coal*, was published in 2007. The purpose of the study was to "examine the role of coal in a world where constraints on carbon emissions are adopted to mitigate global warming" (MIT, 2007, p. vii). This study quotes the estimates of U.S. reserves that are published by EIA (2006b) and does not appear to consider reserves as a factor in the economic scenarios used to model future energy use. Even with global carbon constraints, the MIT study projects a 20 to 60 percent increase in world coal use above the 2005 level (MIT, 2007, p. 95). The authors of the MIT report believe coal use will increase under any foreseeable scenario because coal is cheap and abundant (MIT, 2007, p. ix).

BOX 2.4 NATIONAL RESEARCH COUNCIL REPORT

The National Research Council report, *Coal Research and Development to Support National Energy Policy* (NRC, 2007a), attempted to define future coal-related research and development needs (primarily of the federal government) to accommodate an increase in coal consumption over the next 25 years. This report takes a much more critical look at the current state of U.S. coal reserve and resource estimates than the two previously mentioned reports, and concludes, "Because there are no statistical measures to reflect the uncertainty of the nation's estimated recoverable reserves, future policy will continue to be developed in the absence of accurate estimates until more detailed reserve analyses—which take into account the full suite of geographical, geological, economic, legal, and environmental characteristics—are completed" (NRC, 2007a, p. 49).

The dollar value of the energy from coal is less than five percent of the total expended on fossil fuels; the bulk of the cost is for oil (72 percent) and natural gas (24 percent). An example of this emphasis is that the USGS allocates approximately eight times as much money in funding oil and gas resource investigations ($16.8 million) than it does in funding coal resource investigations ($2.2 million) (USGS, 2008).

3. MAJOR FACTOR: THE NEED FOR INFORMATION ON COAL RESERVES

The recent study by the NRC recommended a study of the nation's recoverable coal reserves, as follows: "A coordinated federal-state-industry initiative to determine the magnitude and characteristics of the nation's recoverable coal reserves, using modern mapping, coal characterization, and database technologies, should be instituted with the goal of providing policymakers with a comprehensive accounting of national coal reserves within 10 years" (NRC, 2007a). Similarly, a reassessment of the nation's technically and economically recoverable coal was also recommended by the National Coal Council (NCC) in a report to the Department of Energy (NCC, 2006a, p. 99) stating that, "It is appropriate for the U.S. Department of Energy to perform or commission a new estimate of the DRB and its recoverable fraction…While in-place resources are important to understand and form a basis for further policy studies, policy decisions, and land and resource management activities, it is also important to understand what portion of those resources are technically and economically recoverable." The recommendation of the NCC for additional study of the nation's coal reserves follows their assertion that, "Coal's annual production of over 1.1 billion tons can be more than doubled to 2.4 billion tons," over a period of several decades (NCC, 2006a, p. 2). Southern States Energy Board (2006) suggested a completely new approach to coal resource estimation that deals with probabilities (as is done in assessing oil and gas reserves).

The studies by the NRC (2007a) and the NCC (2006a) recognize that knowing that the United States has a vast coal resource (national endowment) is not sufficient in itself and that only a small percentage of those resources can be currently mined economically. It is also unlikely that much of the coal will ever be mined and used. Answers to two questions are needed to make the desired policy and business decisions concerning coal resources and reserves. First, which of the coals identified as resources are reserves under current economic and regulatory conditions? Still more difficult, but extremely important, which of the resources are most likely to become reserves during the next several decades, the period during which coal consumption is projected to increase significantly?

The nation's coal resources are vast, as has been recognized for over a hundred years. Additional data concerning coal deposits are continually being collected by federal and state agencies and industry. Previously undiscovered coal beds of sufficient thickness at acceptable depths were identified by mapping and added to total coal resources. The absolute amount of resources can, therefore, be expected to increase as further geologic studies are done in regions that contain coal-bearing strata. However, the NRC and MIT groups that recently investigated the status of coal did not suggest that coal resources require further study; rather they state that coal reserves are of primary interest. The principal difficulty of defining coal reserves for policy purposes and for meeting future coal demands is the temporal nature of reserves compared to the time-stable nature of the bulk of the resources. Reserves are economic under current conditions and as those conditions—technological, environmental, regulatory, and business—change quickly with time, a small percentage of resources may become reserves and some previously defined reserves could revert to being resources. Accurate assessment of reserves is the desired end product, but it can only be achieved if the underlying coal resource data are accurate and complete.

4. STUDY APPROACH

4.1 Traditional Coal Data Input for Resource Assessments

Averitt (1975) classified coal resources by rank (lignite, subbituminous, bituminous, and anthracite); by coal grade, or quality (sulfur and ash content); by reliability of estimates (distance from a known data point); by overburden thickness; and by thickness of coal beds. The results of the assessment were reported by state, with Kentucky divided into eastern and western basins. The USBM (1974) defined a subset of the total resources from the same data set used by Averitt, which they termed the "demonstrated reserve base," or simply, "reserve base." This subset of resources included coals with higher degrees of reliability (measured and indicated), at relatively shallow depths (up to 120-foot overburden for lignite and 1,000-foot overburden for bituminous coal and anthracite), and in beds thicker than 60 inches for subbituminous coal and lignite and 28 inches for bituminous coal and anthracite.

EIA assumed responsibility for the DRB in 1977 when the DOE was established. The DRB underwent some revisions and updates during the following two decades (EIA, 1989, 1993, 1996, 1999). However, much of the basic data remained unchanged from that used by the USBM in the original 1974 study. In the past few years, EIA has not been funded to update or revise the DRB and has only adjusted the reserve numbers by subtracting annual coal production from the previous year's DRB. The total coal resources, the DRB, and its progeny, the ERR, are widely quoted and, for many, including those responsible for making policy, are considered to be much more accurate estimates than the methodology warrants. More precise estimates of the DRB and the ERR would be of value in setting energy policy at the national level, and also of great value in determining minable reserves.

4.2 Available Coal Data

Since gathering the data used in the assessments reported by the USGS (Averitt, 1975) and the EIA (1999), a revolution in data acquisition, storage, and analyses has taken place. Averitt (1975, p. 31) reported that only three of the reporting states—Illinois, Oklahoma, and Kentucky (only for the eastern coal field)—used computers to read individual punch cards to calculate coal resources. All of the remaining states used strictly analog methods and calculated resources manually.

An unfortunate characteristic of coal data is that they most often represent coal that has been mined, not coal that remains to be mined. The coals most likely to be described, collected, and analyzed are those in operating mines, and soon after the sample is taken the area is mined through and remaining coal in the vicinity is mined out. Coal can often be identified in surface exposures, such as natural outcrops and road cuts, but then it is generally too altered by weathering to be worth the trouble of analyzing chemically. Coals recovered from drill holes in areas that have not yet been mined are more desirable. However, these samples are relatively expensive to obtain and therefore represent the source of an all too small percentage of the available coal data.

Currently, there is a large volume of coal information available in digital form in state and federal agencies. The bulk of these data are in the hands of the state geological agencies in the coal-producing states. These agencies often have "geological survey" in their name, but not always. The Virginia Division of Mineral Resources and The Texas Bureau of Economic Geology are two examples of geological surveys by other names. The size of some of these data sets is large; examples include a record set of stratigraphic information greater than 50,000 from drill holes and outcrops available from the Illinois State Geological Survey (ISGS, 2007), and a record set greater than 25,000 of thickness of coals in Kentucky, available from the Kentucky Geological Survey (2007a).

The National Coal Resources Data System (NCRDS) was originally developed as a response to the energy crisis of the mid 1970s. It is an ambitious program that has created, in cooperation with many state geological surveys, a comprehensive national coal information database, containing information on the quality as well as the quantity of the U.S. domestic coal resources (Bragg et al., 1997). There are more than 32,000 records in the NCRDS database. More than 7,400 of those represent full coal bed samples have been chemically analyzed in detail, and are included in a subset called "COALQUAL." COALQUAL contains detailed geographic and stratigraphic data as well as results of chemical analyses of the samples, including major, minor, and trace element analyses. These data sets are searchable online at the USGS website (http://energy.er.usgs.gov/coalres.htm). Although these numbers may appear to be large, 7,400 chemically analyzed samples cannot adequately characterize the large number of potentially minable coals in the many coal-producing states. The COALQUAL samples also suffer from having been collected over a long time periods, from what are now mostly mined-out coal deposits.

Resources and reserves are assessments of coal in the ground, and the preferred data sets used to determine resources are "raw coal," that is, coal as it exists before being mined and prior to preparation or "washing." However, at times, there is valuable information to be gleaned from analyses of coal samples delivered to power plants. Power plants of at least 50 megawatts capacity report operating data monthly to the Federal Energy Regulatory Commission (FERC). Companies report, on FERC Form 423, county of origin, mine or operator, tonnage received, calorific value, sulfur, and ash. FERC does not distinguish between washed and raw coal.

Occasionally, other data sets become available. In 1999 the EPA conducted a study of mercury emissions from power plants that included collecting a large amount of coal data by means of an official Information Collection Request (ICR). Coal data, including mercury content, chlorine content, moisture, ash, sulfur, and calorific value of delivered coals were collected from 1,140 coal-fired utility generating units and made available to the public. These data, coupled with data from a subsequent ICR on emissions from the power plants, have been a valuable source of information and have been used to interpret mercury content of coal reserves.

4.3 Proprietary Sources of Coal Reserve Information

Mining companies collect large amounts of data on the quantity and quality of the coal reserves that they are mining or intend to mine in the near future. Other than the information that they are required to report to the federal government on reserves at operating mines or that they report to their stockholders, company data are proprietary and are not likely to be made available to the general public or to state agencies. Regulations regarding drill hole data vary on a state-by-state basis. When companies are required to submit reports on drilling to a state agency, the data may be considered confidential or, as in the case of Wyoming, where drill hole data are publicly available, the coal bed methane drilling data have provided a welcome windfall. The well logs for tens of thousands of coal bed methane drill holes are currently available from the State of Wyoming, and information on depth to the coal beds and the thickness of the coal can be determined from those logs. On occasion, when private companies do cooperate in conducting research with state agencies, the data are generally only released in summary or aggregate form.

Independent mining consulting firms produce local resource and reserve studies for specific clients and/or publish regional coal reserve studies for sale. Because of the high cost of these reports, they are generally not available to the state and federal agencies reporting on coal resources and reserves.

4.4 Compiling and Analyzing Coal Resource Information and Assessing Reserves

Large amounts of data on coal, such as those listed above, are available. But these data sets are in many different formats and at many disparate locations, with a large number of individual "owners"—federal, state, and private. Acquiring, reformatting, and manipulating the data to create a coherent series of files so that they can all be queried simultaneously is complicated and time consuming. Although all the manipulations are of digital data, the effort requires a large amount of time by personnel trained in database management, GIS, coal geology, and mining engineering. An assessment of the nation's coal reserves is feasible, but it would require an investment of resources, both of personnel and money, well in excess of the modest efforts currently being made by U.S. government and state agencies.

5. ANALYZING COAL RESOURCES AND RESERVES

5.1 Coal Quantity and Geographic Location

Averitt (1975) reported coal resources that were determined, for the most part, by painstakingly aggregating coal volumes from coal maps. Most of the estimates were calculated manually with only the assistance of a calculator or adding machine and, perhaps, a planimeter. The most significant contribution to the art and science of resource and reserve analyses made in recent years has come from the use of modern, GIS-based data management systems. These systems allow for large amounts of data to be manipulated rapidly and also have the great advantage of being reproducible and updateable as new data become available (NRC, 2007a). Prior to the development of these dynamic GIS systems, resource analyses were static and the values could only be updated by a complete repetition of a laborious, time-consuming, and manpower-intensive study.

Modern methods for analyses of resources collect similar types of data and import them into a GIS for manipulation. Basic data include linear and polygonal data consisting of coal-bed outcrops, areas that have been mined, and restrictions to mining; and point-source data on coal-bed thickness (or top and bottom elevation). These data are combined with USGS digital elevation models (DEMs) that represent the land topography. Subsurface coal-bed elevations are subtracted from DEM elevations to determine coal depth and thickness of overburden between the coal bed and the surface (Carter et al., 2001). The compiled data are imported into a GIS for manipulation and for calculating coal resources. The validity of subsequent analyses of coal resources and reserves depends on the accuracy of the location of individual coal data points in three-dimensional space—longitude, latitude, and elevation—and the accuracy of the coal bed's stratigraphic correlation.

5.2 Coal Ownership

Coal in the ground in the United States may be owned by individuals or organizations, federal or state governments, or Native Americans. The potentially most complicated of these forms of land ownerships is that which was originally owned by private individuals as a "fee simple estate," where the surface and mineral rights were held in common. Through inheritance, the land and mineral rights may have subsequently passed through many hands and may have been subdivided among a number of heirs. In many instances, mineral rights were separated from the surface ownership, or "severed" and sold. These mineral rights also may have changed ownership many times since being acquired. Ascertaining coal ownership on private lands generally requires detailed investigation of local government records (deeds and leases). Keeping track of individual coal ownership on private lands is currently beyond the capability of national and most statewide databases.

Digital databases of coal on federal lands and tribal lands are available and maps can readily be constructed. Figure 2.5 shows the tribal and federal lands on a national scale (conterminous United States only). Approximately 60 percent of the area underlain by coal-bearing rocks in the conterminous United States is under federal surface (Biewick, 1997). In 2000, there were more than 287 thousand acres of federal lands leased for coal production and 411 million tons of coal produced from federal coal leases. Coal produced on federal lands accounted for 38 percent of the

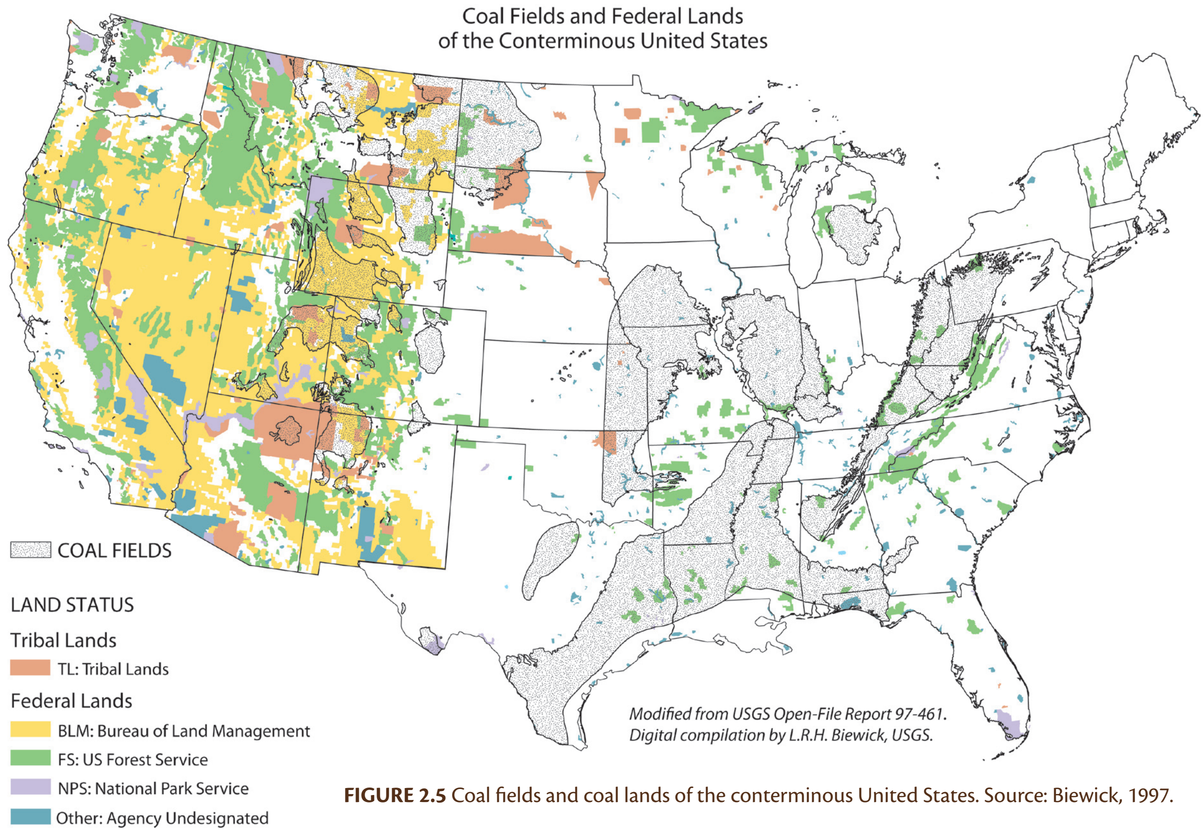


FIGURE 2.5 Coal fields and coal lands of the conterminous United States. Source: Biewick, 1997.

total U.S. production in 2000. Another 28 million tons, or 2.6 percent of the total U.S. production, was from American Indian Leases (EIA, 2000, data table 13). Data on coal resources and coal production on state lands are most likely to be found in the individual states, with the quality of the data and the detail of the information varying from state to state.

5.3 Integrating Coal Rank and Coal Quality Information in Defining Coal Reserves

5.3.1 COAL HETEROGENEITY

When discussing coal resources, especially on a regional or national scale, there is a tendency to speak of coals as if they were relatively homogeneous and that one coal must be very much like another. That is certainly not the case; coals are extremely heterogeneous and may be significantly different from source to source. These differences are exhibited geographically, from coal basin to coal basin and from state to state. A named coal bed or seam, such as the Herrin Coal of the Illinois Basin, may be very different from the immediately underlying Springfield Coal, and either of those coal beds may change character (e.g., relatively high sulfur to low sulfur) over distances of less than a mile. A single coal seam in an operating mine may vary in quality from one operating face to another, and because of those differences one section may be economic and the other may not meet the specifications of the sales contract. Coals also vary in both rank and quality. (Coal rank, also referred to as coal type, is a quality parameter in the broad sense, but is generally distinguished from other quality factors for descriptive purposes).

Coal rank and several coal quality parameters that are of concern at the present time are briefly discussed below. The reasons for the heightened interest in these parameters are varied and may be technological, environmental, and economic (which are not mutually exclusive). The topics discussed below are not all-inclusive and additional parameters may need to be added with changing conditions of coal use and as statutes and regulations related to coal combustion come into existence. Some, perhaps all, of the parameters discussed will be factors used in determining coal reserves in the next few decades.

5.3.2 COAL RANK

Coal rank is commonly recognized as ranging from lignite, the lowest rank, to anthracite, the highest rank. Lignite, subbituminous, and high-volatile bituminous coals are classified on the basis of heating value expressed as Btu/lb on a moist, mineral-matter-free basis, with medium-volatile bituminous, low-volatile bituminous, and anthracite coals classified on the basis of their fixed carbon content on a dry, mineral-matter-free basis (ASTM International, 2000). Heating value ranges from less than 7,000 Btu/lb in lignite to over 15,000 Btu/lb in low-volatile bituminous coals and in anthracites (Figure 2.6). To produce the same heating value, it would be necessary to burn approximately twice as much lignite as a low-volatile bituminous coal. The major difference between the two coals is their moisture content. It is much less costly per unit of carbon to transport higher-rank coals than to transport lower-rank coals, a factor that greatly influences which coals get to markets. Coal rank does not generally vary across a coal basin. When coal rank does change, it does so at a fairly regular rate, and therefore it has been common practice to subdivide and classify coal resources on the basis of rank (Averitt, 1975; EIA, 1999). Coal rank alone is not the determining factor in economic viability of a coal, as evidenced by the rapid increase of coal production of lower-rank western coals over the higher-rank coals east of the Mississippi during the past 35 years.

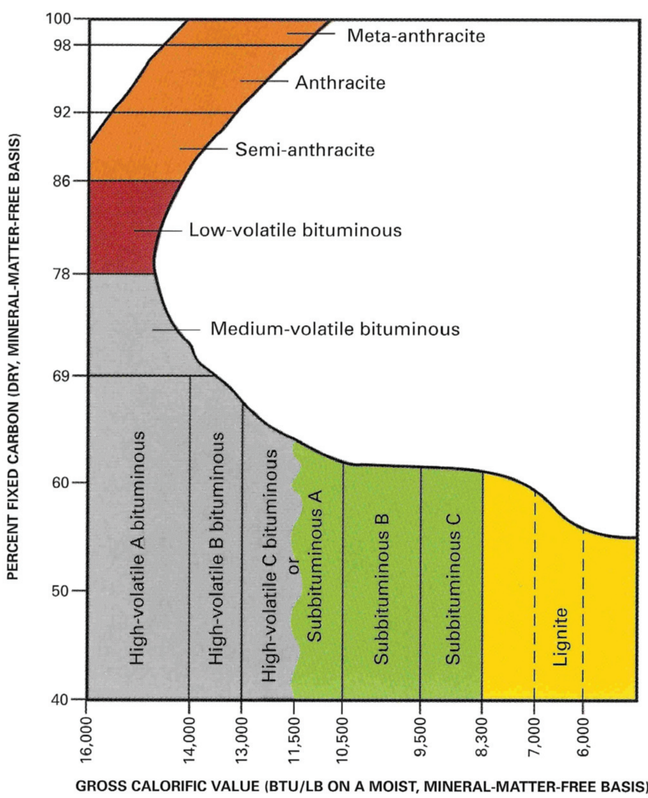


FIGURE 2.6 Diagram showing classification of coals by rank.
SOURCE: Schweinfurth, 2003, Figure 17.

5.3.3 SULFUR CONTENT OF COAL

Sulfur, an element necessary for sustenance of all living systems, occurs in all coals, is a major element with respect to concentration, and is reported as percent of the total composition. Sulfur content is highly variable, but as a general rule, coals of the western United States are low in sulfur, coals from Appalachia have moderate amounts of sulfur, and coals from central United States coal basins (Illinois Basin and Western Interior Basin) are relatively high in sulfur. The mean value for total sulfur in 488 samples collected in 1975 from around the United States and analyzed by the USGS was two percent (Swanson et al., 1976). That set of 488 samples is not a statistical sampling of all the coal in the United States, but it does represent a wide geographic distribution.

Sulfur occurs in coal in organic forms, sulfate minerals, and as sulfide minerals (pyrite and marcasite). The sulfur content is reported as total sulfur and as the component parts, organic sulfur, sulfate sulfur, and pyritic sulfur. Organic and pyritic sulfur are the dominant forms. The ratio of pyritic sulfur to organic sulfur also has a wide range of values. In a study of 474 coal samples from the Illinois Basin, there was approximately one and a half times as much pyritic sulfur as organic sulfur (Gluskoter and Simon, 1968). The ratio of pyritic sulfur to organic sulfur would be expected to be lower for coals that do not contain as much total sulfur as coals of the Illinois Basin.

It has long been recognized that sulfur in coal contributes to boiler fouling and associated problems of boiler tube corrosion, with specific sulfur limits on coals used for making metallurgical coke. However, the current level of interest in the environmental effects of sulfur in coal far surpasses the concerns related to technological problems.

In 1971, the Environmental Protection Agency (EPA) for the first time set enforceable air quality standards. The EPA established New Source Performance Standards (NSPS) that required coal-fired utility boilers built after mid 1971 to emit no more than 1.2 pounds of sulfur dioxide (SO_2) per million Btu of heat input. The EPA revised the NSPS in 1979, adding the requirement that SO_2 emissions be reduced from all new or modified boilers by at least 90 percent, unless that level of reduction would fall below 0.6 pounds per million Btu of input (EIA, 2007c). The 1990 changes to the Clean Air Act (Title IV of the Clean Air Act Amendments of 1990 – Public Law 101-549) set a permanent cap on the total amount of SO_2 that may be emitted by electric power plants nationwide. The EPA summarized the major effects of the act in the "Plain English Guide to the Clean Air Act," as follows: "The initial phase of EPA's Acid Rain Program went into effect in 1995. The law required the highest emitting units at 110 power plants in 21 Midwest, Appalachian, and northeastern states to reduce emissions of SO_2. The second phase of the program went into effect in 2000, further reducing SO_2 emissions from big coal-burning power plants. Some smaller plants were also included in the second phase of the program. Total SO_2 releases for the nation's power plants are permanently limited to the level set by the 1990 Clean Air Act—about 50 percent of the levels emitted in 1980" (EPA, 2007g).

The effects of regulating SO_2, as well as nitrogen oxides (NOx) and particulate matter (PM), have been widespread and of great impact on the coal-producing industry as well as on the electric utilities that consume coal. Future impacts can be expected, but exactly what form they will take is much more difficult to predict. The effect of emission regulations on production of western coals is discussed in section 5.4 below.

5.3.4 MERCURY IN COAL

Mercury (Hg) is a trace element in coal, occurring in quantities reported in fractions of parts per million (ppm) or mg/kg. The mean value for mercury in all 7,000 plus coals within COALQUAL (a subset of the USGS National Coal Resources Data System) is 0.17 ppm and the median value is 0.11 ppm (Tewalt et al., 2001). The EPA estimates that 75 tons of mercury are contained in the coals delivered to power plants each year and that two-thirds of the total is emitted to the air, resulting in about 50 tons being emitted annually (EPA, 2007c). The 25 tons, or one-third reduction, is achieved in the power plant boilers and through existing pollution-control devices, such as fabric filters and scrubbers. In 2005, EPA issued a "Clean Air Mercury Rule" to permanently cap and reduce mercury emissions from coal-fired power plants. The first phase of the regulations takes advantage of the "co-benefit" of regulations for reducing SO_2 and NOx emissions under EPA's Clean Air Interstate Rule and has a cap of 38 tons of mercury emissions per year. The second phase, targeted for 2018, would reduce the total elemental mercury emitted to the atmosphere to 15 tons per year, a reduction of nearly 70 percent from the current level (EPA, 2007a).

The status of the Clean Air Mercury Rule is in doubt. In February 2008, the D.C. Circuit Court rejected EPA's mercury rules, and unless the decision is reversed or circumvented by actions of the EPA, electricity-generating units will be required to meet strict "Maximum Achievable Control Technology" standards. In that case, no cap-and-trade program would be authorized. This action by the court could delay the effective date of national mercury emission standards for electrical generating units until as late as 2014, with additional legislation on mercury emissions also anticipated (Meltz and McCarthy, 2008).

Mercury, as it is directly emitted from power plants, is generally not considered to be harmful. However, mercury in the environment may be transformed to methylmercury, a phase in which it can enter into the food chain, accumulate in fish, and be consumed by humans. The EPA is especially concerned that developing fetuses are sensitive to the toxic effects of methylmercury, with the result that women of childbearing age are urged to avoid eating mercury-contaminated fish (EPA, 2007a).

5.3.5 CHLORINE IN COAL

Chlorine (Cl) is a common trace or minor element in coal and the range for most coals is approximately 50 to 2,000 ppm (Swaine, 1990). There are some exceptions with higher values reported, most notably in the Illinois Basin, where values above 6,000 ppm (0.6 percent) have been observed (Gluskoter and Rees, 1964). Conventional wisdom, based on experiences with high-chlorine coals in Great Britain, and ascribed to by some boiler operators in the United States, is that coals that are high in chlorine—above 0.2 or 0.3 percent (e.g., 2000 or 3000 ppm)—may cause problems of boiler fouling or corrosion in pulverized coal (PC) fired units. These guidelines could negatively impact the marketability of higher-chlorine coals from the Illinois Basin, including much of the deep-mined coal in the basin, because chlorine content tends to increase with coal depth (Gluskoter and Rees, 1964). However, there is controversy about whether the chlorine is responsible for boiler fouling or if other factors, such as alkali metals, sulfur, or boiler parameters, are responsible for the observed boiler corrosion problem (Chou, 1998).

A recent study by Quick et al. (2005) noted that the presence of chlorine in coal reduced the mercury emitted from coal-fired boilers with improvements occurring in all five emission-control technologies studied (Figure 2.7). The trend was most noteworthy with spray-dry adsorption with fabric filter (SDAS/FF) and cold-side electrostatic precipitator with wet-flue gas desulphurization (cESP/FGD). In these systems, mercury capture rapidly increased up to a concentration of 500 ppm chlorine and then only modestly increased above 1,000 ppm chlorine (Quick et al., 2005, p.59). The presence of modest amounts of chlorine may be beneficial when controlling mercury is a high priority.

5.3.6 RADIONUCLIDES IN COAL

The main sources of radioactivity in coal are uranium (U) and thorium (Th), with the concentration of these elements usually at trace element levels, ranging from 0.5 to 10 ppm (Swaine, 1990). Interest in radioactive sources in coal continues because of environmental concerns and also because a few coals have been mined as sources of uranium rather than for their heating value.

There is a controversy related to the radioactivity associated with power plants that suggests coal-fired plants emit higher radionuclide amounts than pressurized-water or boiling-water nuclear plants (McBride et al., 1978). The authors of the paper also state that their study did not assess the total radiological impacts of a coal versus a nuclear economy (McBride et al., 1978). It should be noted that radionuclides in coal are refractory and,

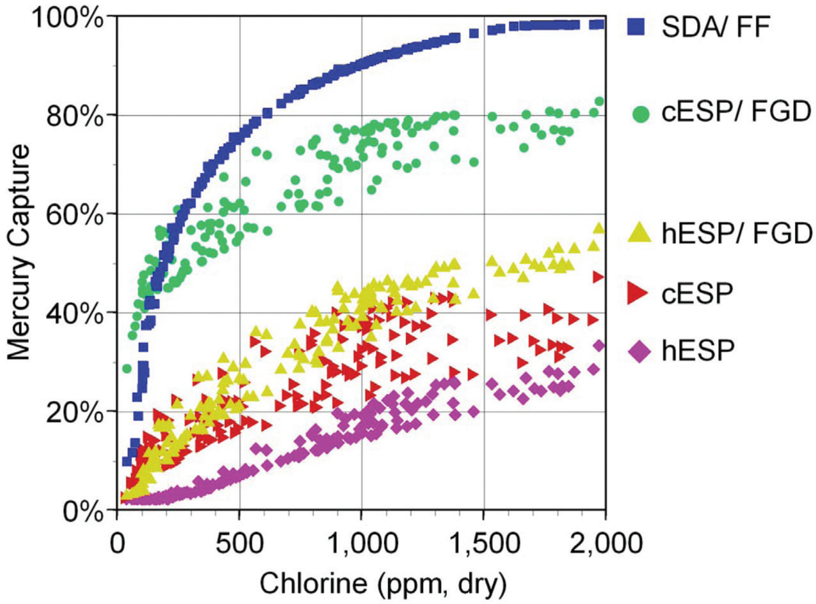


FIGURE 2.7 Mercury capture predicted for 162 U.S. counties increases with increasing coal chlorine for five existing control technologies. Mercury capture is the average result from three published equations for each emission control group (ICR 3 data, conventional pulverized coal units). Points correspond to average coal quality, 162 U.S. counties (ICR 2 data). Not shown are six U.S. counties where chlorine exceeds 2,000 ppm. SOURCE: Quick et al., 2005, Figure 26, p. 47.

therefore, remain in the coal ash and are not emitted in the stack gases. Styron et al. (1981) reported, "Essentially all of the nonvolatile radionuclides (uranium, radium, and thorium) from feed coal were accounted for in fly ash and bottom ash."

An exhaustive review of radioactivity in coal and a discussion of the potential environmental impacts, which some consider negligible and others consider significant, can be found in Swaine (1990, p. 192–195). Swaine concluded that there is general agreement that radioactivity from coal burning as well as from nuclear-power production is only a small fraction of background radiation and is below permissible limits. He also stated that it would be unwise to burn coal with more than 30 ppm uranium without checking the emissions and solid-waste products (Swaine, 1990, p. 195).

Interest in coal as an "ore" of uranium in the United States results from uraniferous lignites in southwestern North Dakota that were mined for their uranium content. Beginning in 1957 and continuing through 1962, uraniferous lignite was mined, some burned on the surface at the mine site, and the resulting ash was eventually shipped to uranium mills in South Dakota, Colorado, and New Mexico (Murphy, 2007). Uranium is thought to have been deposited in the host rock (lignite) by groundwater that had leached the radioactive element from reactive volcanic glasses. Mining for uranium was discontinued in 1967 after production of approximately 85,000 tons of ore. The State of North Dakota estimates that there is still a minable reserve of uranium in the form of uraniferous lignites in the southwestern corner of the state, although it represents less than one percent of the total U.S. reserve (Murphy, 2007).

5.3.7 CARBON IN COAL

Carbon (C) is the reason that coal is not just an interesting rock that tends to get one's hands dirty. Almost all of the energy obtained from coal is from the oxidation of the carbon, with only minor contributions of energy from oxidation of hydrogen (H) and sulfur (S). During coalification, the systematic changes in coal rank, from peat and lignite to bituminous coal and anthracite, there is a fairly regular increase in carbon content. Both chemical and physical changes take place during coalification. "Generally, overburden pressure should primarily affect the physical properties of coal (e.g., porosity), whereas temperature and duration of heating should primarily affect chemical composition (e.g., C, H, and O contents) and molecular structure of coal" (Damberger, 1991).

The carbon content of coal increases during coalification, primarily due to the loss of moisture and oxygen (Figure 2.8). On a dry, mineral-matter-free basis—that is, with the moisture content and the ash-forming ingredients mathematically removed from the analyses of the coal—peat contains 50 to 65 percent carbon and lignite contains 55 to 73 percent carbon. Carbon content then exhibits a fairly regular increase as coal rank progresses from subbituminous to bituminous to anthracite until values above 90 percent are reached (Damberger, 1991). Moisture in these highest-rank coals is often below one and a half percent and oxygen is below five percent.

Currently, there are no restrictions on carbon emissions from coal-fired power plants in the United States. There are bills designed to reduce carbon emissions that have been proposed in Congress and, although none of the legislation has yet become law, there is widespread anticipation that carbon will be regulated, in some fashion, within the near future. The expectation that there will be a "carbon-constrained world" was the impetus for the comprehensive report, *The Future of Coal*, published in 2007 by MIT. Another premise of the MIT study is that worldwide coal use will increase under any scenario, including when there are carbon-emissions restrictions, because coal is cheap and abundant (MIT, 2007, p. ix).

Carbon dioxide emissions from coal combustion vary systematically with coal rank. That is, during combustion, different coals produce different amounts of carbon dioxide per unit of heat value upon combustion (Quick and Glick, 2000). Figure 2.9 depicts the differences in pounds of carbon dioxide emitted per million Btu for coal of all ranks. The data plot is on a net calorific basis and is representative of the heating value of coal received by the boiler in a coal-fired power plant. High-volatile bituminous coals have lower rates of emissions of carbon dioxide than do coals both higher and lower in rank. Quick and Glick (2000, p. 803) observed that, "CO_2 emissions increased between 6 and 8% in instances where Midwestern U.S. power plants stopped burning local, high-sulfur bituminous coal and started burning low-sulfur, subbituminous C rank coal from western the U.S."

Figure 2.9 shows clearly defined differences in CO_2 emissions among the various coal ranks, but it also shows that there is significant spread around the best-fit line for coals of the same rank; that is, data points fall well above and below the net calorific value curve. The variation in maceral content of coals of the same rank may

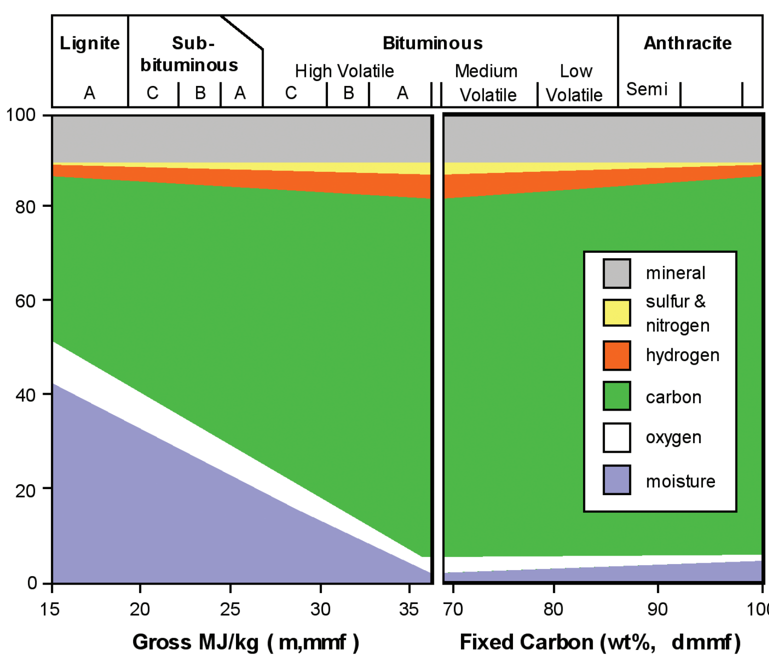


FIGURE 2.8 Variation of the composition of U.S. coal with ASTM apparent rank.
SOURCE: Quick and Glick, 2000.

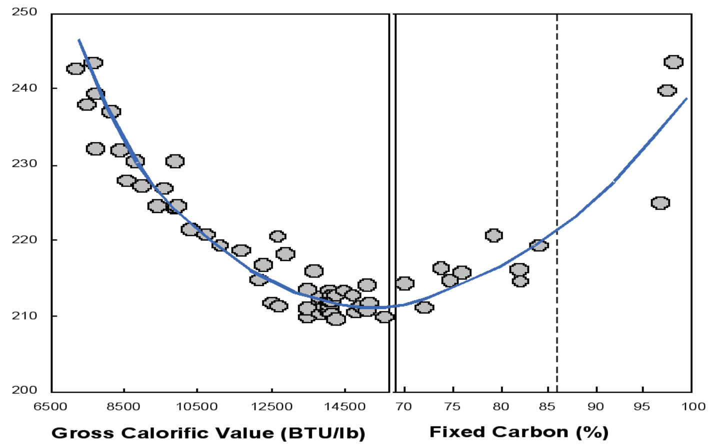


FIGURE 2.9 Variation of carbon emissions with ASTM International (2000) rank of U.S. coal. Rank is defined on gross Btu/lb calculated to a moist, mineral-matter-free basis for lower-rank coals and on fixed carbon on a dry, mineral-matter-free basis for higher-rank coals. That change takes place at 69 percent fixed carbon on the horizontal axis of the figure. SOURCE: Modified from Quick and Glick, 2000; Quick, personal communication, 2007.

explain some of that spread in emission of carbon dioxide. Macerals are to coal as minerals are to rocks. In the case of coals, they are the major organic building blocks and have differing physical and chemical characteristics. Quick and Glick (2000) observed that U.S. coals with relatively high concentrations of the maceral group inertinite have higher carbon emissions than predicted from ASTM rank parameters. In a study of Australian coals, Quick and Brill (2002) confirmed a positive correlation between inertinite abundance and carbon emissions for bituminous coals. The correlation was "modest" and they suggested that other factors besides inertinite content also influences carbon emissions. It is quite reasonable that inertinite would produce more carbon dioxide than the maceral "vitrinite" and that the maceral "liptinite" would produce less than either of the other two macerals. Inertinite is the most aromatic of these macerals and contains the greatest percentage of carbon; liptinite has the most hydrogen; and vitrinite is intermediate in both elements (Taylor et al., 1998). Quick and Brill (2002) concluded that rank-specific carbon emission parameters are provincial rather than global. That is, local variations in carbon emissions among several bituminous coals are as great as among bituminous coals that are widely separated geographically.

5.4 Coal Quality and the Production of Coal in Western United States

Figure 2.10 shows U.S. coal production from east and west of the Mississippi for 1950 to 2006 and predicted future production from those regions. Most of the rapid increase in western coal production has been from Wyoming (Figure 2.11). Coal production from the Powder River Basin (PRB) represents the overwhelming majority of coal produced in the state—in 2003, 97 percent of

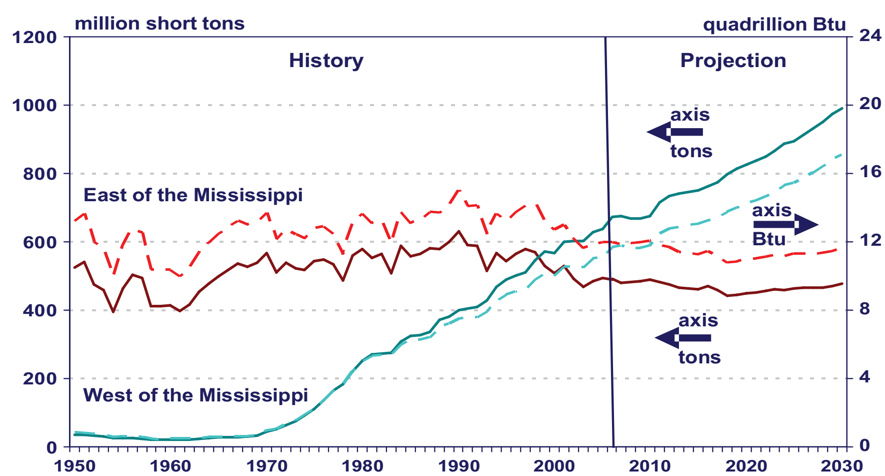


FIGURE 2.10 Coal production in the United States, 1950–2006 (with projections to 2030) east and west of the Mississippi River. Solid lines indicate coal production in tons and dotted lines represent production in quadrillion Btu. SOURCE: EIA, 2008, Figure 11.

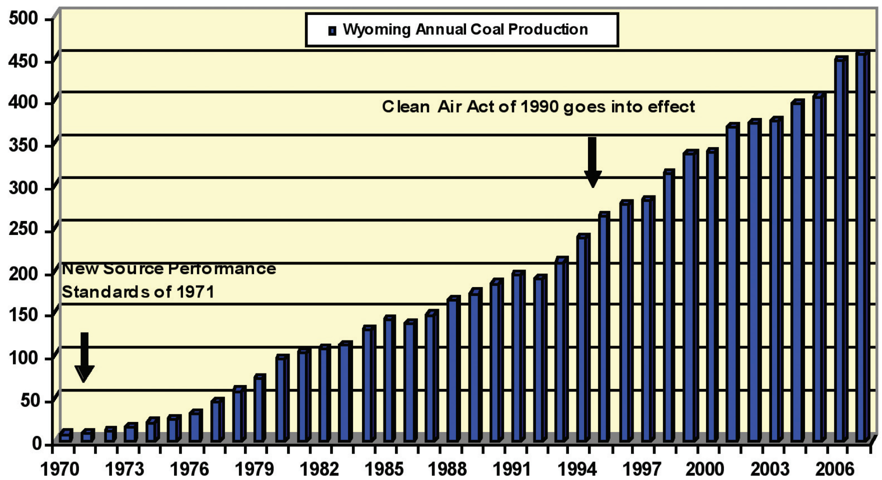


FIGURE 2.11 Wyoming coal production, 1970–2007. SOURCE: Data provided by Fred Freme, EIA.

Wyoming coal production was from the PRB (see http://smtc.uwyo.edu/coal/).

The shift to western coals, and to coals from the PRB specifically, resulted primarily from two of the three major air-quality legislative initiatives during the past half century. These initiatives, summarized in Box 2.5, created incentives for electric utilities to reduce sulfur emissions by burning coal that contained low amounts of sulfur.

The initial phase of the Clean Air Act, passed in 1990, went into effect in 1995 and required the highest-emitting units at 110 power plants in midwestern and eastern states to reduce emissions of sulfur dioxide. The second phase of the program went into effect in 2000, further reducing sulfur dioxide emissions from large coal-fired power plants (EPA, 2007g).

One of the ways the power companies met the requirements to reduce sulfur was to switch from higher sulfur eastern coals to lower sulfur western coals, and the largest, most economically accessible resource of low sulfur coal was in the PRB of

BOX 2.5 EPA AIR-QUALITY INITIATIVES

"The Environmental Protection Agency's New Source Performance Standards of 1971 set strict limits on emissions of sulfur dioxide from new electric power plants. These limits required new power plants either to burn coal with an average sulfur content of 1.2 pounds per million Btu's of heat output or to install expensive flue gas scrubbers. The 1971 Act is credited with causing many utilities—particularly in the Midwest—to switch from locally mined coal to low-sulfur coal from the Powder River Basin. In 1979, the Revised New Source Performance Standards changed the incentive structure established by the former standards, actually reducing companies' incentives to burn low-sulfur coal. The new regulations increased incentives for new plants to use scrubbers, reducing utilities' dependence on low-sulfur coal as a means of limiting sulfur dioxide emissions.

"Finally, the Clean Air Act Amendments of 1990 were intended to provide utilities with increased flexibility in meeting standards for sulfur dioxide output, including burning coal of moderate sulfur content along with low-sulfur coal, cleaning coal prior to burning it, and buying emissions allowances to make up the additional sulfur output" (McDermott, 1997).

Wyoming. These resources, although of lower rank than the eastern coals and at a greater distance to markets, were converted to reserves almost instantly by legislation of the federal government because of the coals' quality. They were low in sulfur and benefited from the very low cost of production (i.e., thick coal beds near the surface, large amounts of coal reserves, and large-scale mining).

5.5 Effect of Regulating Mercury Emissions on Coal Reserves

Regulations that limited the amount of sulfur that can be emitted from coal-fired power plants had a profound effect on the production of coal in the United States, establishing the PRB and its large resource of subbituminous coal as the most productive coal region in the nation. The Clean Air Mercury Rule, issued in 2005, calls for a significant reduction of mercury emissions from power plants, resulting in a reduction of 70 percent by 2018 (EPA, 2007g). The obvious issues are whether the controls on mercury will influence coal production and to what extent, and whether some regions will benefit from the regulations while others will be penalized.

There are regional differences in the mercury content in coal. The mean value for all coals in the United States is 0.17 ppm. Coals from northern Appalachia have the highest mercury content, averaging 0.24 ppm, and coals from Unita Basin of Utah have the lowest concentration of mercury, averaging 0.07 ppm (Tewalt et al., 2001). The concentration of mercury expressed on an equal-energy basis is more relevant than concentration in the coal, because it represents the input load of mercury to the power plant. Input load is usually expressed as pounds of mercury per trillion Btu. The variation in mercury loadings by coal-producing regions is shown in Figure 2.12.

The highest mercury input load values are calculated for the Gulf Coast lignites (27.0 lb Hg/trillion Btu) and they are more than four times greater than the lowest values (6.5 and 6.6 lbs Hg/trillion Btu) reported from the Green River and the Unita Basins. Coals from the Gulf Coast and the Green River and Unita Basins are very different in age and rank, but there are also significant variations in mercury loading among coals of similar rank and geologic age. Coals from northern Appalachia have twice the input load of coals from the Illinois Basin (15.7 lbs per trillion Btu versus 7.8 lbs per trillion Btu) and these regions both produce high volatile bituminous coals of Pennsylvanian age. Regional variations can provide a first estimate of as-shipped mercury concentration in coal.

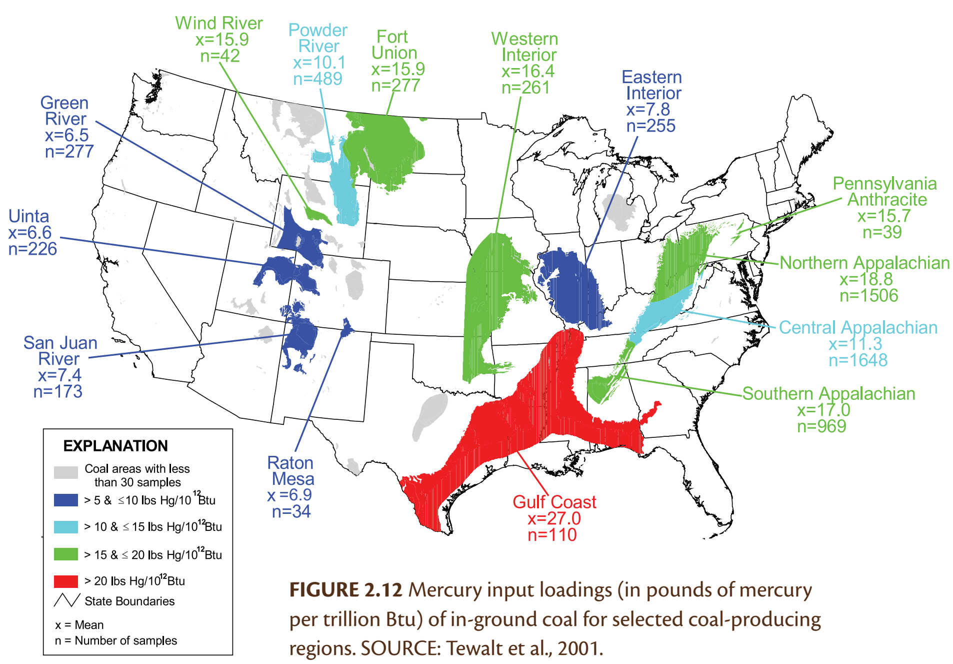


FIGURE 2.12 Mercury input loadings (in pounds of mercury per trillion Btu) of in-ground coal for selected coal-producing regions. SOURCE: Tewalt et al., 2001.

Quick et al. (2005) investigated mercury emissions from power plants. Using large data sets, they created a set of maps showing expected mercury emissions by origin of coal (by county) from pulverized coal-fired electric generating units with five different emission-control technologies: (1) hot-side electrostatic precipitator (hESP), (2) cold-side electrostatic precipitator (cESP), (3) hot-side electrostatic precipitator / wet flue-gas desulfurization (hESP/FGD), (4) cold-side electrostatic precipitator / wet flue-gas desulfurization (cESP/FGD), and (5) spray-dry adsorption/fabric filter (SDA/FF) emission controls. Identifying coals that work best with each control device is complicated, because mercury emissions vary by control technology used, and also with abundance of other elements in coal, such as chlorine and sulfur (Quick et al., 2005, and Figure 2.7).

The conclusions reported by Quick et al. (2005, p. 65) are all associated with coal quality:

- Selection of coal with low mercury content may be an effective control strategy for units equipped with hESP/FGD, cESP, or hESP controls, whereas selection of high-chlorine coal is indicated for units with cESP/FGD or SDA/FF controls.
- Blending to an optimum level between 500 and 1,000 ppm chlorine may be an effective mercury control strategy for units equipped with SDA/FF or cESP/FGD controls.
- Flue-gas sulfur may reduce mercury capture by carbon in fly ash.
- Coal washing or selective mining might be an effective mercury reduction strategy, especially for coals from the northern Appalachians or Gulf Coast.

Only limited attention has been given to selective mining for low-mercury coals. Observations that there is significant local and regional variability in mercury content, and that these differences would result in variations on mercury load factors to the boiler, suggest that selecting coals on the basis of their mercury content (as well as chlorine and sulfur) may be a viable strategy to limit mercury emissions.

5.6 Calculating Coal Resources

In 1986, the USGS conducted a pilot research project in cooperation with the Kentucky Geological Survey that was designed to develop a methodology for determining the quantity of coal resources available for mining within a specified area, which in this case was a single 7.5-minute geologic quadrangle (Eggleston et al., 1990). The methodology that was subsequently developed provided greater specificity for coal resource assessments when compared to traditional procedures that did not take into account many environmental and technological restrictions placed on coal mining. In addition to limitations of depth and thickness to coal mining, other restrictions that effectively limit mining were applied. Box 2.6 shows how the available coal was defined in this study.

Examples of land-use restrictions that have been applied in analyzing coal availability include power lines, pipelines, cemeteries, roads, railroads, towns, major streams, wetlands, oil and gas wells, alluvial valley floors, parks, and protected forests and wildlife (Carter et al., 2001). Technological and geologic restrictions include safety zones (buffers) around active or abandoned mines, coal beds that are considered too thin or deep to mine, multiple minable beds that are stratigraphically too close together for both to be mined safely, unstable roof or floor conditions, and other geologic factors such as washouts, faults, disturbed areas, and impurities in the coal (Carter et al., 2001).

Coal resource assessments of this type came to be referred to as “Coal Availability Studies”; by the year 2000, such studies were completed in more

BOX 2.6 DEFINITION OF AVAILABLE COAL

ORIGINAL COAL RESOURCES
–
COAL MINED AND COAL LOST IN MINING
=
REMAINING COAL RESOURCES
–
COAL RESTRICTED BY LAND-USE CONSIDERATIONS
–
COAL RESTRICTED BY TECHNOLOGICAL RESTRICTIONS
=
COAL RESOURCES AVAILABLE FOR DEVELOPMENT

than 100 selected 7.5-minute study areas in the Northern and Central Appalachian Basin coal regions, in the Illinois, Powder River, and San Juan Basins, and in several coal fields in the Unita and Green River Basins (Carter et al., 2001). The coal availability project was originally designed to study 1:24,000-scale, 7.5-minute quadrangles (50 to 60 square miles). With the extremely rapid advances in computer technology, coal-availability projects were expanded to include multiple coal beds in larger areas, some as large as several counties. For example, Overfield et al. (2004) investigated the Davis and Dekoven coals in eight counties in western Kentucky, and Korose et al. (2002) studied five different coal beds within the state of Illinois. The coal-availability technique has also been applied to a single coal bed that covers much of the state (e.g., Treworgy et al., 2000, for the Herrin coal in Illinois).

In 1990, researchers at the former USBM cooperatively joined the project and conducted the subsequent "Coal Recoverability Studies" to determine that part of the available coal resources that could be recovered economically (Rohrbacher et al., 1993). With the closure of the USBM in 1995, the coal recoverability project was transferred to the USGS. Coal recoverability takes, as a starting point, the results of the coal-availability analyses and determines the economically recoverable coal in the steps outlined in Box 2.7.

In these "Coal Recoverability Studies," GIS programs are used to lay out mine plans, and cost-analyses programs estimate the amounts of coal that will be economically recoverable at current mining costs and expected sales prices.

A total of 65 areas of varying size in 22 coal fields have been analyzed for coal recoverability.

BOX 2.7 DEFINITION OF ECONOMICALLY RECOVERABLE COAL

COAL RESOURCES AVAILABLE FOR DEVELOPMENT
–
FUTURE MINING AND WASHING LOSSES
=
RECOVERABLE COAL RESOURCES
restricted by
MINING COSTS AND SALES PRICES
=
ECONOMICALLY RECOVERABLE COAL RESOURCES (RESERVES)

Coal resources available for development range from eight to 89 percent of the identified (total) resources and from five to 25 percent are classified as economically recoverable coal resources, or reserves (T.J. Rohrbacher, USGS, *pers. comm.*, 2006).

The USGS reported on coal-availability and coal-recoverability studies of 32 individual 7.5-minute quadrangles in the northern Appalachian and central Appalachian coal fields (Carter et al., 2001). Results varied significantly from quadrangle to quadrangle, ranging from zero to 43 percent of the original resource that can currently be extracted at an expected profit—the definition of economically recoverable coal (Carter, et al., 2001). Economically recoverable resources average ten percent of the total resource in the Central Appalachian Basin and 14 percent in the Northern Appalachian Basin.

Because of the large amount of variability, results from an individual quadrangle should not be extrapolated to predict availability or recoverability at other sites. However, the averaged values from all 32 quadrangles provide insight into regional availability and recoverability in regions that have had a long history of coal mining. Figure 2.13 summarizes the results of 18 studies in central Appalachia and 14 studies in northern Appalachia.

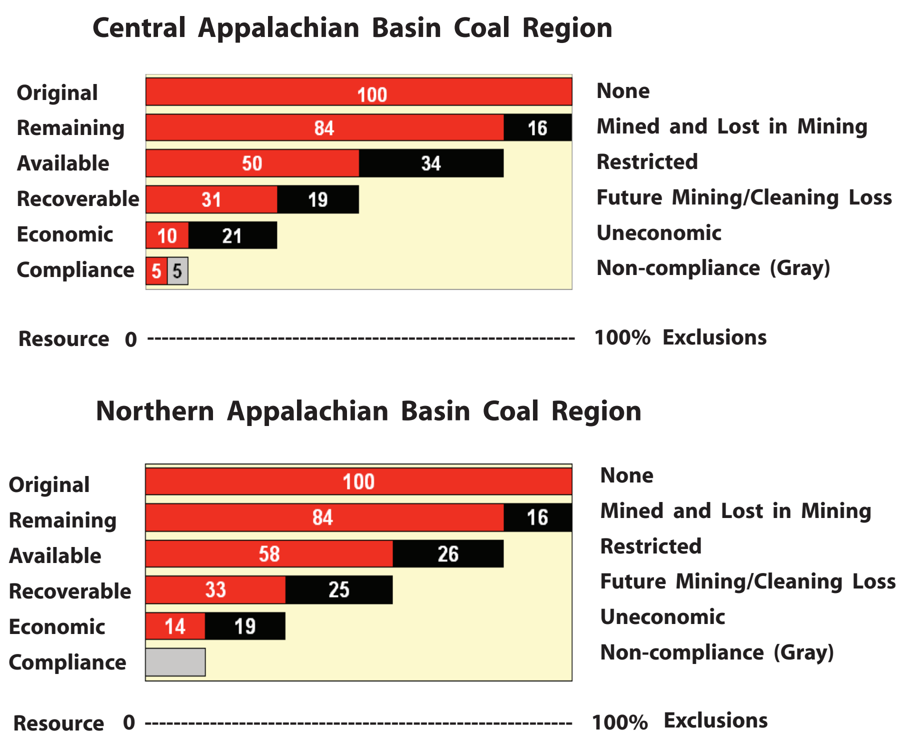


FIGURE 2.13 Bar charts summarizing the results of coal availability and coal recoverability studies conducted in the central and northern Appalachian coal fields. Compliance coals would meet the emission level compliance standard of 1.2 lbs sulfur dioxide per million Btu. Data from 18 coal availability studies and 15 coal recoverability studies in Central Appalachian Basin, and 14 coal availability studies and 10 coal recoverability studies in Northern Appalachian Basin. SOURCE: Carter et al., 2001.

Coal resource/reserve assessments at the USGS rely on input from a mine-type modeling program, MINEMODEL, and a mining economic analysis software program, COALVAL, originally developed at the USBM and further perfected at the USGS (Carter et al., 2001). COALVAL considers all costs associated with mining, depending on the mine model selected, and also includes a factor for discounted cash flow. The result of these analyses is a cost-curve graph (Figure 2.14), representing the amount of coal that can be produced at a defined cost (Rohrbacher, 2007); the amount of marketable coal at a given sales price can be determined from the cost curve. The methodology is intended to be interactive; users can enter whatever parameters they believe best represent the conditions in their area of interest. Recently, the economically recoverable coal-resource-assessment methodology of

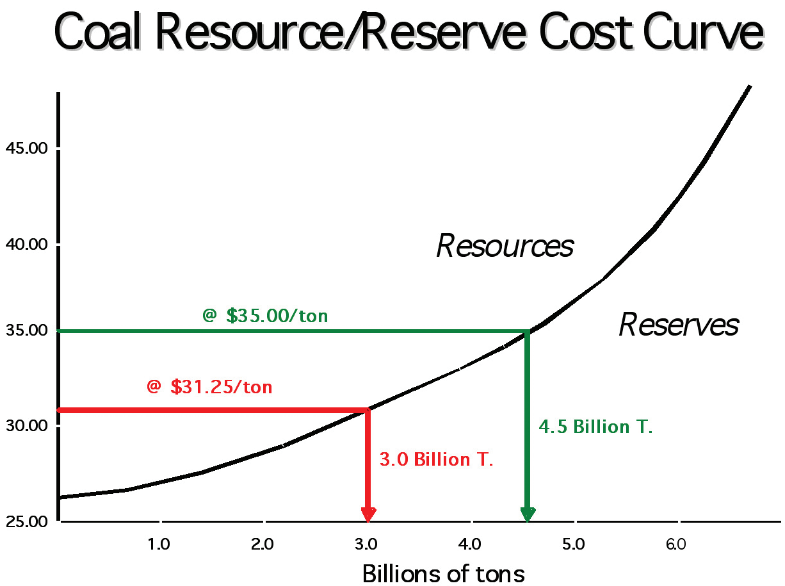


FIGURE 2.14 Coal reserve cost curve. The resource cost curve is derived from costing all of the resource tons available for mining within the study area. Given the sales price of $31.25/ton in January 2004 the coal reserve for all mining methods in the study area would be 3.0 billion tons. Using this cost curve, if the price of coal rose to $35.00/ton the coal reserve would increase to 4.5 billion tons. Although this cost curve will indicate the amount of reserves as the coal price increases or decreases it is important to note that as the market place, mining costs, and technology change the data used to create this cost curve will be adjusted, thus changing the slope on the curve. SOURCE: Modified from Rohrbacher, 2007, Figure 16, including text.

the USGS (including COALVAL) has been successfully peer reviewed (Rohrbacher et al., 2005).

The coal resource/reserves assessment program at the USGS, as it has evolved to date, is the most complete publicly available program for assessing economic reserves. Similar regional studies have been completed for coal companies and other clients by independent consulting firms, using their own proprietary methods. These studies are also sold on a proprietary basis and are not available to the general public.

The combined coal availability/coal recoverability analyses produced by the USGS have been considered to be equivalent to the results of a "pre-feasibility" study in the United Nations Framework Classification for Resources/Reserves (United Nations Economic and Social Council, 1997; Gluskoter, 2000). Pre-feasibility studies are not as rigorous as "feasibility studies," which are generally done on site-specific properties, involve detailed economic considerations, and are conducted by a mining company or by a consultant to a mining company. Results from feasibility studies are used in making business decisions such as opening or expanding a mine, and they are also expected to be "bankable" (one of the bases on which the company obtains financing). Feasibility studies are extremely detailed and generally well beyond the purview of federal or state agencies, which are concerned with areas larger than a single mine site. There is an exception, however, to this general case. The U.S. Bureau of Land Management (BLM) conducts detailed economic analyses of site-specific coal properties as one of several factors used to determine fair market value of a potential coal lease. The results of these fair market analyses are proprietary until a successful lease sale is concluded, after which some of the input data may be released (BLM, 2007).

5.7 Coal Reserves Reported by Coal Companies

The uppermost tip of the triangle representing all of the coal resources and reserves in the United States (Figure 2.4) is labeled "Recoverable Reserves at Active Mines." This information is obtained by the EIA from the coal companies via Form EIA-7A, entitled, "Coal Production Report." Coal companies with mines producing more than 10,000 tons per year are required to submit Form 7A annually and are asked to report information concerning the reserves at each mine. The companies are requested to state the "recoverable reserves," excluding coal left in place during mining, and to estimate the recovery percentage. The product of the two values is the total minable reserve at the mine. They are also asked to explain if the quantity of recoverable reserves increased or decreased by more than 40 percent from the last year's response. The numbers are aggregated by both state and mining method—as long as the aggregated data do not allow for identification of specific mines—and published in the *Annual Coal Report* (EIA, 2007a). The assumption is that the reported reserves will be mined by the same methods that are currently used to produce coal from the mine. The reserves are then tabulated by state; by size of mine; whether underground or surface; and if underground, by continuous, conventional, or longwall methods. (Chapter 3 describes each of these types of mines and mining techniques.) The total for recoverable reserves at operating mines reported in 2006 was 18.8 billion tons, only slightly less (by 500 million tons) than the amount reported in 1997. This value for recoverable reserves at operating mines is not the product of an independent analysis. Although it is a result of self-reporting by the companies and the submitted values are not often questioned, it is probably the most accurate of all the values on the resources triangle in Figure 2.4 and represents much of the coal that will be produced over the next twenty years.

Table 2.1 lists the recoverable reserves at producing mines. The data, however, are not geographically referenced (in a GIS) and are not individually reported by mine. The recoverable reserves at producing mines are reported individually for each mine on the EIA 7A form once per year; however, that data item is not publicly available. Further inferences cannot easily be drawn from the aggregated data. For example, it is not possible to estimate what percentage of the reported 588 million tons of recoverable reserves of surface minable coal in West Virginia (EIA, 2007a) that would likely be produced by mountaintop removal mining. A breakdown of surface mining reserves in central Appalachia by type is a figure that many would find interesting and could have important policy ramifications.

The NMA also requests that coal companies provide annual information on their holdings of coal reserves. The companies report total holdings of reserves, not just those at operating mines (although it is assumed that reserves at operating mines are included in the totals), and are listed in order from largest to smallest in the NMA report, *Coal Producer Survey* (Coleman, 2007). These values are the same, or nearly the same, as those reported by the mining companies on their websites and in corporate presentations, and match those reported to the Securities and Exchange Commission in various filings. In 2006, 41 companies reported a total of slightly more than 60 billion tons of coal reserves to the NMA (Table 2.2). The top seven companies reported more than 70 percent of the coal holdings. The 60 billion tons did not include coal under federal ownership that has been leased. Subtracting 19 billion tons of recoverable reserves at mines reported to EIA from the 60 billion tons reported to NMA results in an additional 41 billion tons of "reserves" currently owned by mining companies. These reserves are not identified as to location, rank, or any other parameter in the NMA report, but their magnitude suggests that much of the coal to be mined in the near future will be from these sources.

5.8 Reserves and Methods of Coal Use

5.8.1 TODAY'S COAL-FIRED POWER PLANTS

More than 92 percent of all the coal consumed in the United States is burned in electricity-generating power stations. The remainder is used in other industries for steam and heat, and in the manufacture of metallurgical coke (EIA, 2007a). Implicit in the preceding discussion of coal reserves and

TABLE 2.1 Recoverable reserves (millions of tons) at producing mines, 2006.

STATE	UNDERGROUND MINABLE COAL	SURFACE MINABLE COAL	TOTAL
Alabama	280	56	336
Alaska	N/A	W	W
Arizona	N/A	W	W
Arkansas	W	N/A	W
Colorado	W	W	335
Illinois	1,255	40	1,294
Indiana	249	135	384
Kansas	N/A	W	W
Kentucky Total	962	171	1,134
Eastern	554	149	703
Western	408	23	431
Louisiana	N/A	W	W
Maryland	W	W	28
Mississippi	N/A	W	W
Missouri	N/A	W	W
Montana	W	W	1,211
New Mexico	W	W	504
North Dakota	N/A	1,145	1,145
Ohio	192	99	291
Oklahoma	W	W	23
Pennsylvania Total	468	79	548
Anthracite	2	14	16
Bituminous	466	65	531
Tennessee	12	8	21
Texas	N/A	730	730
Utah	243	N/A	243
Virginia	223	51	273
Washington	N/A	W	W
West Virginia Total	1,206	588	1,793
Northern	252	32	284
Southern	954	556	1,510
Wyoming	W	W	7,890
U.S. TOTAL	**5,897**	**12,983**	**18,880**

NOTES: N/A = No data are reported. W = Data withheld to avoid disclosure
SOURCE: Modified from EIA, 2007a, Table 15.

resources is that the coal quality parameters of greatest interest are those that relate directly to coal use as a boiler fuel. The primary generating technique is pulverized coal combustion in steam boilers. The coal quality parameters of interest are calorific value (Btu/lb), sulfur, moisture, and ash, the latter because of ash fusion characteristics as well as the amount of ash in the feed coal. Many existing coal-based generating plants could, on average, operate another 30-plus years and many of the planned new generating units are coal-fired. Some of the new state-of-the-art units will be "supercritical" and "ultra-supercritical" and operate at higher temperatures and pressures and be more efficient than units currently in operation (MIT, 2007), but they will still burn pulverized coal, blown into the boiler. The coal characteristics that the power plant operators and their coal buyers will be evaluating in the future will primarily be those previously mentioned, although the tolerances may be less (more stringent) as the gas temperatures and pressures in the boilers increase.

Fluidized-bed combustion uses crushed, rather than powdered coal as a feed, with coal and coal char comprising less than five percent of the

TABLE 2.2 Major holders of U.S. coal reserves, top 25 corporate reserve holders.

RANK	COMPANY	TONS (BILLION SHORT TONS)
1.	Great Northern Properties Limited Partnership	20.000
2.	Peabody Energy Corporation	9.400
3.	CONSOL Energy Inc.	4.300
4.	Arch Coal, Inc.	2.900
5.	The North American Coal Corporation	2.300
6.	Massey Energy Company	2.300
7.	Natural Resource Partners L.P.	2.100
8.	Pocahontas Land Corporation (Norfolk Southern)	1.750
9.	Murray Energy Corporation	1.700
10.	Foundation Coal Corporation	1.635
11.	Rio Tinto America (Kennecott)	1.400
12.	Westmoreland Coal Company	1.200
13.	International Coal Group (ICG)	1.063
14.	Penn Virginia Resource Partners, LP	0.765
15.	TXU Mining Co.	0.718
16.	BNI Coal, LTD	0.650
17.	Alliance Resources Partners	0.634
18.	Kiewit Mining Group, Inc.	0.600
19.	Magnum Coal Company	0.600
20.	Kentucky River Properties LLC	0.570
21.	Alpha Natural Resources	0.548
22.	BHP Billiton	0.319
23.	Western Pocahontas Properties	0.300
24.	Black Hills Corporation	0.285
25.	Western Fuels Association, Inc.	0.273

SOURCE: Modified from NMA (Coleman, 2007, Table 5); 2006 data compiled from 2007 NMA survey of major producers.

mass of the bed (Kraemer et al., 2004). Generally, combustion takes place in a circulating fluid bed consisting of limestone, lime (calcined limestone), and coal and coal char. The particles are suspended in motion by combustion air that is blown in from below. Fluidized-bed units are not as large as some PC-fired boilers; the largest circulating fluidized bed in operation is 320 megawatts (MIT, 2007). The advantage of the fluidized-bed technique is that it has the ability to capture sulfur dioxide in situ and minimize the formation of nitrogen oxides. In addition, fluidized-bed combustion boilers are capable of burning a wide range of fuels, including bituminous coals, lignite, waste fuels, high-ash coals, petroleum coke, and biomass (MIT, 2007; Kraemer et al., 2004).

5.8.2 INTEGRATED GASIFICATION COMBINED CYCLE

Recent reports by the NCC (2006b), Kraemer et al. (2004), and MIT (2007) contain excellent summaries of the integrated gasification combined cycle (IGCC) technology. The following brief description of the process is a synthesis from those sources.

IGCC technology produces electricity by first gasifying coal to produce a syngas. The principal reactants are coal, oxygen, steam, carbon dioxide, and hydrogen, and the desired products are generally carbon monoxide, hydrogen, and methane. The syngas, after being cooled and cleaned, is burned in a gas turbine, which drives a generator. The hot exhaust from the gas turbine passes through a heat-recovery steam generator to raise steam to drive a second generator. Power is produced from both the gas and steam turbine-generators.

Four 275 to 300 megawatt coal-based demonstration plants have been built and are in commercial operation, two in the United States and two in Europe (MIT, 2007). Other IGCC units are in operation gasifying asphalt, refinery wastes, and petroleum coke (MIT, 2007). A total of 29 IGCC operations are summarized in tabular form in the NCC report (2006a, Table 1.10), but most do not generate electricity as their principal product.

The motivation for future development of IGCC is the potential for better environmental performance, easier capture of carbon dioxide for sequestration, and higher overall efficiency (MIT, 2007). The National Commission on Energy Policy (NCEP, 2004, p. 51) singled out IGCC as a potentially important advanced coal technology:

"Coal-based integrated gasification combined cycle (IGCC) technology, which—besides having lower pollutant emissions of all kinds—can open the door to economic carbon capture and storage, holds great promise for advancing national as well as global economic, environmental, and energy security goals. The future of coal and the success of greenhouse gas mitigation policies may well hinge to a large extent on whether this technology can be successfully commercialized and deployed over the next 20 years."

The current IGCC plants are oxygen-blown and have entrained-flow gasifiers. Other possible configurations are moving-bed, fluid-bed, and air-blown rather than oxygen-blown (MIT, 2007; NCC, 2006b). Because of the number of permutations that these conditions produce, it is difficult to do more than generalize about the effect of coal quality on IGCC technologies.

It is generally accepted that coal gasification can be applied to any kind of low-quality feedstock or any carbon-containing material (NCEP, 2004; MIT, 2007). However, reports have suggested that coal type and quality can have a larger effect on IGCC than on pulverized coal generation (MIT, 2007). "IGCC plants are proven to work very well with bituminous coal. It is important to recognize that different gasification techniques will likely be required for different types of coal, such as lignite and subbituminous" (Kraemer et al., 2004, p. 24). Coal quality and calorific value (rank) also have a greater impact on IGCC capital cost and generating efficiency than they have on the same factors in pulverized coal generation (shown in Figure 2.15). This may make it more difficult for low-rank, high-moisture coals to compete with bituminous coals in IGCC (especially slurry-fed gasifiers) than in PC plants (Kraemer et al., 2004; MIT, 2007). Ultimately, the total cost of electricity is most important in the choice of fuel, not only the capital cost and heat rate.

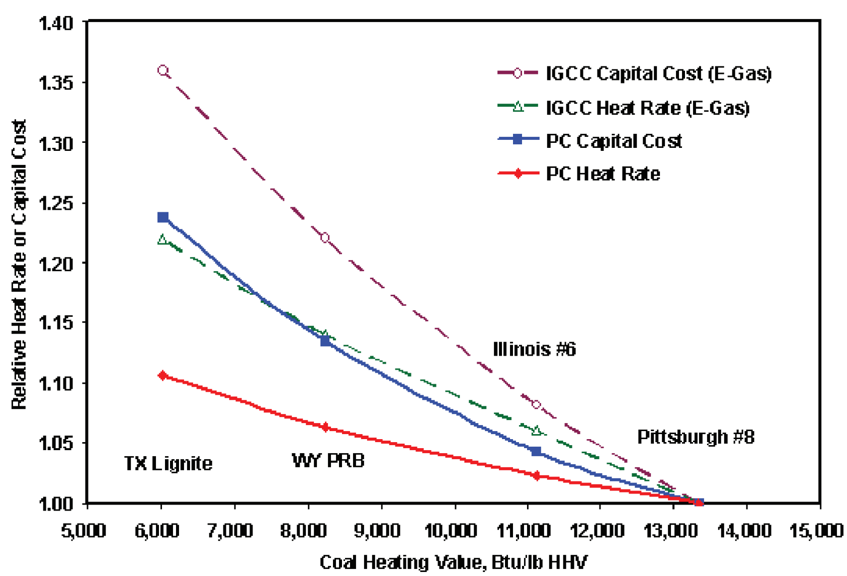


FIGURE 2.15 Effect of calorific value on heat rate and capital cost of IGCC and PC electricity generation. SOURCE: Kraemer et al., 2004.

5.8.3 COAL-TO-LIQUIDS

Several excellent reviews of processes that are termed "coal-to-liquids" (CTL), "coal liquefaction," or "coal to synthetic fuels and chemicals" have been published within the past few years (IEA, 2006; NCC, 2006; Southern States Energy Board, 2006; MIT, 2007). These recent studies contain detailed summaries of the technologies for converting coal to liquid fuels and discuss the commercial development of CTL. The brief description of CTL below is synthesized from those sources.

The two basic techniques that have been developed to produce liquid fuels and chemicals from coals are direct liquefaction and indirect liquefaction. In the direct liquefaction processes, coal is dissolved in a solvent at high temperature and pressure, producing a synthetic crude. This step is followed by catalyzed hydrocracking (refining) of the dissolved coal with hydrogen gas. Coal studies by Southern States Energy Board (2006) and MIT (2007) briefly describe the direct liquefaction process, but do not include the technique in their detailed modeling of liquefaction; rather, their analyses are limited to indirect liquefaction methods. MIT (2007, p. 153) provided two reasons for not including details on the direct approach. First, "the direct liquefaction route is very costly because of the severity of conditions and the cost of the capital equipment." Second, "The direct route generally produces low-quality liquid products that are expensive products that are expensive to upgrade and do not easily fit current product quality constraints." Further, the Southern States Energy Board (2006) assumes that all future CTL plants will use indirect liquefaction. The other studies listed above do give more attention to the direct coal liquefaction methods and reference the direct liquefaction facility currently under construction by the Shenhua Group in Inner Mongolia (IEA, 2006).

Indirect liquefaction of coal to produce liquids is a three-step process, beginning with coal gasification to produce synthesis gas (primarily a mixture of carbon monoxide and hydrogen), which is then purified to remove carbon dioxide and other contaminants. The second stage is conversion of the synthesis gas to liquids by means of the Fischer-Trospch (F-T) synthesis process. The final stage is upgrading the F-T product to the required final liquid products or chemicals. Indirect coal liquefaction is a mature technology, originally developed in Germany in 1923 and used by Germany to produce 17,000 barrels per day of liquid fuels from coal during World War II (NCC, 2006b). Sasol was created in 1950 with government assistance in South Africa and is currently operating the world's largest integrated coal-to-liquids and chemical manufacturing facility. Sasol now converts more than 40 million metric tonnes of coal per year to produce 160,000 barrels per day of crude oil equivalent (IEA, 2006). Several indirect coal liquefaction projects have been announced for development in China, and a number of projects are under consideration, although not yet under construction, in other countries, including eight in the United States (NCC, 2006).

Proponents of CTL argue that the technology would help achieve energy independence and replace imported oil with coal-derived liquids, and that it is economic at current world oil prices. CTL also has opponents. They point out that the lifecycle of synthetic fuel derived from coal produces large amounts of greenhouse gas (AAAS, 2007). MIT (2007, p.154) summarized the production and handling of carbon dioxide during indirect liquefaction as follows:

> *However, because of the need to heat the system to high temperatures, and because of process and system irreversibility and other inefficiencies, the amount of carbon dioxide (CO_2) formed is significantly larger. Thus, synthetic fuels derived*

from coal will produce a total of 2.5 to 3.5 times the amount of CO_2 produced by burning conventional hydrocarbons. Since this study is concerned with understanding how coal is best utilized in a carbon-constrained world, we must anticipate combining CCS [carbon capture and sequestration] with synfuels and chemicals production. Requiring CCS will make synfuels more expensive. On the other hand, CO_2 capture and separation is a required, integral part of the synfuels production process. It is also cheaper and easier because 'indirect' synthetic fuels production uses oxygen rather than air, and the cost of the air separation unit (ASU), CO_2 separation, and high operating pressure are 'sunk' costs of synfuels production process.

Replacing a small percentage of the 13 million barrels per day of liquid transportation fuels consumed in the United States would require a large amount of coal. To replace 10 percent of the transportation fuels with liquids from coal would require over $70 billion in capital investment and about 250 million tons of coal per year, an increase of more than 20 percent over current production (MIT, 2007). EIA's *Annual Energy Outlook* (2008) projects that 157 million tons of coal will be used to produce 2.4 quadrillion Btu of energy as CTL in 2030, and that CTL will be the second largest use of coal after electric power generation.

Coal gasification is the initial step in indirect coal liquefaction, as it is in IGCC; "conventional wisdom" is that, because of the gasification stage, indirect coal liquefaction can operate on nearly any coal feedstock (NCC, 2006b), and one can use virtually any carbon-containing material, including coal (Southern States Energy Board, 2006). The major coal feed to Sasol is subbituminous coal produced at Sasol mines. Models of hypothetical coal liquefaction facilities use input data that are intended to approximate average lignite, subbituminous, and bituminous coals (e.g., Southern States Energy Board, 2006).

Eastman Chemical Company is currently operating a chemicals-from-coal facility in Kingsport, Tennessee, that uses a Texaco coal gasifier to provide feed gas for production of acetyl chemicals. The plant has been in operation since 1983. Although the products from this plant are chemicals and not liquid fuels, the gasification stage is the same as that which could be used in an indirect coal-liquefaction facility. Eastman Chemical qualifies coals specifically for their Kingsport operation by means of an in-house slag viscosity test. Typical standard ash viscosity or melt-point tests were determined to be inadequate to fully predict behavior in their specific gasifier (Hrivnak, 2001). A continuous curve of viscosity versus temperature was produced that allowed selection of "better coals" that were also lower cost. Operation difficulties and shutdowns have been reduced by this means of coal selection (Hrivnak, 2001).

The Dakota Gasification Company's Great Plains Synfuels Plant in Beulah, North Dakota, although called a synfuels plant, is primarily a coal-to-synthetic gas (equivalent to natural gas) plant—the only such facility in the United States. It is generally referred to as the "Northern Great Plains Gasification Plant." The plant also produces anhydrous ammonia and ammonium sulfate for use as fertilizers, but these products are secondary to the more than 54 billion standard cubic feet of high Btu gas produced annually from more than six million tons of lignite (DOE, 2006c; Dakota Gasification Company, 2007). The Northern Great Plains Plant also separates carbon dioxide and delivers it through a 205-mile-long pipeline for use in enhanced oil recovery in the Weyburn Oil Field in Saskatchewan, Canada.

5.9 Underground Coal Gasification

Underground coal gasification (UCG) or in situ coal gasification, converts coal to a gas without having to mine the coal. UCG converts coal hydrocarbons into a synthesis gas at elevated temperatures and pressure. The synthesis gas, produced and extracted through wells, is similar to that produced in surface gasifiers, and can be used to create products such as electric power, chemical feedstocks, liquid fuels, hydrogen, and synthetic gas (Burton et al., in press). The process is not a new concept or technology, but is undergoing renewed interest and activity in the field (ECOAL, 2006). A workshop on UCG, sponsored by the DOE, Lawrence Livermore National Laboratory, India's Ministry of Coal, and Coal India, Ltd., was held in Kolkata, India, in 2007. The technical presentations at that meeting are available on the DOE website. Several articles summarizing the state of the technology have recently been published (ECOAL, 2006; Science and Technology Review, 2007). A report by Lawrence Livermore National Laboratory to DOE (Burton et al., in press) contains a current, comprehensive treatment of the UCG topic.

One of the purported advantages of UCG relative to underground mining or surface mining followed by gasification is that unminable coals (too deep, low grade, thin seams) are exploitable by UCG. If only coals that are not minable were to be considered for UCG, then "coal reserves" for this purpose would be an entirely different population of coals compared to those that could be mined. However, there is likely to be considerable overlap between resources of minable coals and the in-ground deposits selected for UCG. The proponents of the technique point out that, "UCG, compared to conventional mining combined with surface combustion, produces less greenhouse gas and has advantages for geologic carbon storage" (Burton et al., in press).

Worldwide UCG experience in the United States, Australia, and the former Soviet Union has generally been at depths less than 500 m (1640 ft), well within the range of minable coal beds. Many of these UCG sites were used for research purposes and were not intended to be developed as commercial projects. A few projects in Europe were at greater depths in coals less likely to be mined, up to 1200 m (3937 ft) (Burton et al., in press). Sawhney (2006) proposed that 200 to 400 m (656 to 1312 ft) is the prime target depth for underground coal gasification. Deep coal beds require higher injection and operating pressures, which increase cost, and also have higher drilling costs (Burton et al., in press). Coal-seam thickness is also an important factor in UCG. Thicker coals require fewer drill holes, which translates to lower cost. Some tests have encountered severe problems while attempting to gasify coal seams less than 2-m (6.6-ft) thick. Sawhney (2006) suggests beds to be gasified should exceed 2 m (6.6 ft) and Burton et al. (in press) note that best performance is in beds greater than 1.5 m (5 ft). Coal beds greater than 1.5 m (5 ft) thick are recoverable by underground mining methods and are included in assessments of resources for mining.

Lower-rank coals, such as lignite and subbituminous, appear to be easier to gasify in situ than coals of higher rank. Burton et al. (in press) suggest that lower-rank coals are preferable because they shrink upon heating, enhancing permeability and connectivity between wells, whereas bituminous coals tend to swell when heated. Once a site is proposed for UCG, the geology and hydrology of the coal bed and the surrounding strata must be characterized. This step requires drilling bore holes to test and sample the strata, a seismic survey (preferably three dimensional) of the whole area, and model of the area's hydrogeology (ECOAL, 2006). This level of study is comparable to a "feasibility" study for siting an underground mine, at the very least.

Traditional assessments of coal resources and reserves for surface and underground mining would include most of the potential sites for UCG that have been considered to date, but may not include areas of multiple thin seams, very deep coals, or lignite at depths greater than 500 feet. There are also coals that are not economically minable by conventional underground mining methods that may be reserves for UCG. One example is in Majuba, South Africa, where an underground mine that was abandoned because of an abundance of dolerite (igneous rock) dikes is now being investigated as a site for UCG (Ergoexergy, 2008).

5.10 Resources and Reserves for Developing Technologies

IGCC, CTL, and underground coal gasification are potential methods of getting energy from coal, all of which have been developed at least to pilot-scale testing and some to commercial operation. However, experiences with these processes are extremely limited compared to burning coal in steam boilers to produce electricity.

Major concerns in developing alternative methods of using coals have been the technologies themselves, not the specific fuel that will be the feedstock. For example, in the design stage for synfuels production, it is more important to decide whether to use direct or indirect methods, and if indirect methods are selected, which type of gasifier would best fit the conditions. The review articles referenced above suggest that the conversion methods are amenable to nearly all ranks of coal, although some ranks may be better than others. They model product output and costs using average values for lignite, subbituminous, and bituminous coals. The model is appropriate for coal conversion in the conceptualization or development stage. It is interesting to note that it does not appear to make much difference what hypothetical coal is burned in the model.

The combustion of coal in electricity-generating power stations also uses an extremely large range of coals (lignite through anthracite). Specifications for coals to be used in a specific coal-burning facility, however, may include heating value (Btu/lb), volatile matter, moisture, ash, sulfur, grindability (HGI), ash fusion temperatures, and ash chemistry (Fe, Cl, Na, Ca, Hg). The specifications that are of greatest concern to the operators of individual power stations are those that have been determined from their unique set of experiences.

If and when alternative methods of using coal come to fruition, the same degree of specificity for the feedstock can be anticipated, although the parameters that will be of concern are much harder to predict. For example, the Kingsport Plant of Eastman Chemical found it necessary to develop its own methods for testing slag viscosity of feed coals in order to select "better" coals for their process (Hrivnak, 2001). Eastman Chemical found it beneficial to select very-specific-quality coals, even though the gasifier used in their process can gasify a wide range of materials, including coal, heavy oil, petroleum coke, and refinery residue (Seabright et al., 2001).

6. CONCLUSIONS

The coal resources of the United States (the national coal endowment) are very large and the locations of all the major coal basins are known. It is not expected that large, new coal fields will be discovered in the conterminous United States. A large body of data has been collected concerning the quantity and quality of coals by state and federal agencies during the past century, but only a small fraction of the resources have been sufficiently characterized to be classified as reserves (coal that can be economically produced under current conditions). Coal resources are reported in trillions of tons and the annual consumption of coal in the United States is approximately 1.2 billion tons. These two factors suggest that the nation is not in immediate danger of exhausting its coal supply, but estimating just how long coal could be produced at any specific rate is difficult. ***Coal resource*** tonnages can not be rationally used to accurately calculate the number of years the nation could be supplied with coal, but if accurate national ***coal reserve*** data were available, estimates could then be made based on projections of future coal demands.

Coal companies annually report reserves at operating mines to the EIA and also report total holdings of reserves, including those at operating mines, to the NMA. Slightly more than 60 billion tons of coal reserves are currently reported in these surveys and additional reserves are on federal land not currently under lease. Much of the coal that will be produced in the time frame of recent EIA projections (to 2030) will be from these reported reserves, and the quantity is more than adequate to meet those needs.

Although the life span of coal use will go beyond 2030, the all too often quoted figure that the United States has a 250-year supply of coal cannot be supported by current data; much more detailed assessments of coal reserves are necessary before such projections can be made with any degree of confidence. The DRB and ERR resource categories are often quoted and widely used to support policy positions without regard to the inherent limitations of these categories. The major limitations are lack of precision of the data, incomplete data, and out-of-date information.

It makes a difference if there are 50, 100, or 150 years of coal reserves in the United States and the most forward-looking energy policy decisions should be made having factored such data into the analyses. However, there are many important questions concerning coal reserves that are not related to how long before the total quantity of coal reserves is exhausted. Local and regional governing bodies and business entities all make strategic decisions based on the quantity and quality of coals in a specific area, not in the nation as a whole. Investments in community infrastructure, such as whether to build roads and streets and additional schools, are all influenced by the prospect of future coal production or use in the region. Siting new mines, power plants, and transmission lines is strongly influenced by the location and quality of the coal reserves to be mined or consumed.

From the information, discussion, and analysis presented in this chapter, the following recommendations are appropriate.

- ***Reassess the DRB and ERR.*** The EIA began a modest effort updating the DRB in the 1990s, but it has been discontinued and EIA has not allocated funds or manpower (FTE) to the effort during the past few years. The EIA has been responsible for the DRB since 1977, and is the logical agency to continue updating the DRB. Other federal agencies could be given the task if EIA is not able to resume working on these resources. The assistance of state geological surveys or other state agencies as major contributors in updating the DRB and ERR is critical, regardless of which federal agency is involved. Much of the detailed information concerning coal geology and the coal mining industry in a specific state resides with the state geological surveys.

- ***Expand "coal availability" and "coal recoverability" assessment programs.*** These programs can now assess economically recoverable resources (reserves) at a pre-feasibility level of detail. These investigations, again with the aid of state geological agencies, should be expanded to provide information on a national scale. There is a reasonable expectation that once the coal reserve assessments have produced a large number of individual studies, it may be possible to identify shortcuts to the methods used that would permit an acceptable level of accuracy with less of an input of resources of time and people.

- ***Make resource and reserve data readily accessible.*** All data used by federal, state, or other public entity in assessing resources and reserves should be maintained in databases readily accessible to everyone. These data could then be applied to updating the DRB and ERR and serve as the basis for coal reserve studies nationwide. A user could retrieve information on coal resources and reserves by -entering physical and economic criteria. With the introduction of advanced technologies such as IGCC and CTL, it may become necessary to include additional coal parameters in the coal databases. Achieving this goal would require the application of modern geographic information systems, robust database systems, mining economics software programs, and computers capable of analyzing the large amount of data. Accessing all the necessary databases from a single point of entry into the system will require that a coordinating body be established and that funds are committed over an extended period of time in order to get all the necessary agencies involved. The USGS, with its history of cooperating with geological surveys in the many coal-producing states, appears to be the appropriate agency to lead this cooperative effort. In addition, a national assessment of coal resources and reserves will require cooperation among many federal as well as state agencies, a task that is not easily achieved.

- ***Assess the option of expanding company disclosure of reserves.*** Information on coal reserves obtained by means of questionnaires by EIA and the NMA is relatively easy to collect and, likely, fairly accurate. Additional efforts should be expended in this manner, testing the willingness of the mining companies to be more forthcoming and more detailed in the information they provide. Confidentiality could be maintained when and where it is necessary. This expanded effort could be coordinated by EIA as an extension of Form 7A, which is sent annually to mining companies.

Chapter 3 Mining Technology and Resource Optimization

1. SUMMARY

Coal occurs in sedimentary rock basins. There are over 2,000 such basins widely scattered around the world. As a result of several exploration programs, it has been estimated that there exists about 11 trillion tons of coal worldwide. As discussed in Chapter 2, the U.S. endowment is estimated to be about 4 trillion tons. Continued exploration of coal deposit characteristics for extraction leads to the definition of reserves—the quantity of the endowment that is economically mineable. The overall process of bringing a coal reserve to production is a complex process that may take anywhere from five to 15 years and is associated with substantial technical and business risks. Two essential requirements must be fulfilled before a reserve is developed: there are no unacceptable environmental or permitting risks and there is confirmation of an assured or contracted market for a substantial fraction of the planned mine production.

There is evidence that coal has been used from the earliest of times by several civilizations, including Chinese, Indians, Greeks, Romans, and American Indians. The traditional use of coal has been to generate heat. Coal is the basic energy source that powered the Industrial Revolution. Coal mining has progressed from scattered excavations of surface outcrops of coal seams in valleys and hills to a highly organized system of extraction from both near surface and deep deposits.

This chapter (1) presents an overview of the U.S. coal mining industry, (2) outlines the methods of coal mining in the United States, (3) briefly discusses the productivity, labor, health and safety, and environmental issues associated with coal extraction, (4) discusses emerging trends in the U.S. industry, (5) identifies major factors influencing production levels, and (6) provides suggestions and recommendations for addressing these factors.

2. OVERVIEW OF THE COAL MINING INDUSTRY

The U.S. coal industry is the second largest in the world, producing over 1.16 billion short tons of bituminous coal in 2006 and accounting for about 23 percent of total U.S. energy consumption. The electrical power generation sector consumes 92 percent of U.S. domestic coal production. Coal generates over half of the nation's electricity.

Coal occurs widely in the United States and is currently mined in 26 states, though Wyoming, West Virginia, Kentucky, and Pennsylvania account for nearly 750 million tons, or about 65 percent of annual production. On the basis of rank of coal, about 50 percent of the U.S. production is bituminous, over 40 percent is subbituminous, and nearly seven percent is lignite. There is a very small amount of anthracite production from northeastern Pennsylvania. Approximately 50 percent more subbituminous coal, or about twice as much lignite, on a tonnage basis is needed to produce the same amount of electricity generated by bituminous coal.

Coal production in the United States comes from underground and surface mines, from large and small mines, and from union and non-union mines. At present, surface mines account for 67 percent of the total production, and underground mines for the remaining 33 percent. The distribution of production in terms of coal regions is: Appalachian, 34 percent; Interior, 13 percent; and Western, 53 percent (see Figure 1.4 for coal regions in the United States). Production from mines west of the Mississippi is 58 percent, and from mines east of the Mississippi is 42 percent (Figure 2.10).

The shift of coal production from the eastern coalfields to the western United States is the most important development affecting the coal mining industry and coal markets in the last 30 years. The main reasons for this production shift from east to west are the thick beds of low-sulfur coal, low mining costs, and increasingly stringent restrictions on atmospheric emissions of sulfur dioxide at power plants. The development of railroads to transport western coal over long distances to power plants in the Midwest, South, and East greatly enabled the increase of the contribution of Wyoming's Powder River Basin (PRB) coal to the U.S. utility industry, from about 60 million tons in the early 1970s to almost 500 million tons today.

The heating values of different coals are quite variable. Therefore, it is usual to express coal production in terms of both heating value and tonnage. U.S. energy consumption in 2006 was 100 quadrillion British thermal units (Btu), with coal accounting for about 23 percent. The primary energy production in the United States in 2006 was just over 71 quadrillion Btu, with coal accounting for about 24 quadrillion Btu (1.16 billion tons). According to the Energy Information Administration (EIA, 2008), energy consumption will rise to nearly 124 quadrillion Btu by 2030, an increase of 24 percent over 2006. Coal will continue to be an important component of the U.S. energy mix.

Coal's contribution to the primary energy supply in 2030 is projected to be over 31 quadrillion Btu, a 30 percent increase over 2006 (Figure 3.1). In tonnage, this amounts to 1.61 billion tons, an increase of approximately 500 million tons over 2006 production. In general, a large fraction of the increased production (over 60 percent) is slated to come from the Western region (particularly the PRB). Appalachian production is predicted to remain flat due to depletion of reserves, and production from the Interior region is expected to increase from the current levels due to its better reserve situation vis-à-vis Appalachia and the improving technology for using coals with higher sulfur content. There are significant differences in the mining conditions and problems and practices in the three coal mining regions—Appalachian, Interior, and Western. The issues regarding coal reserves are important; however, equally important are the challenges of extraction of these reserves, emphasizing optimization of reserve use.

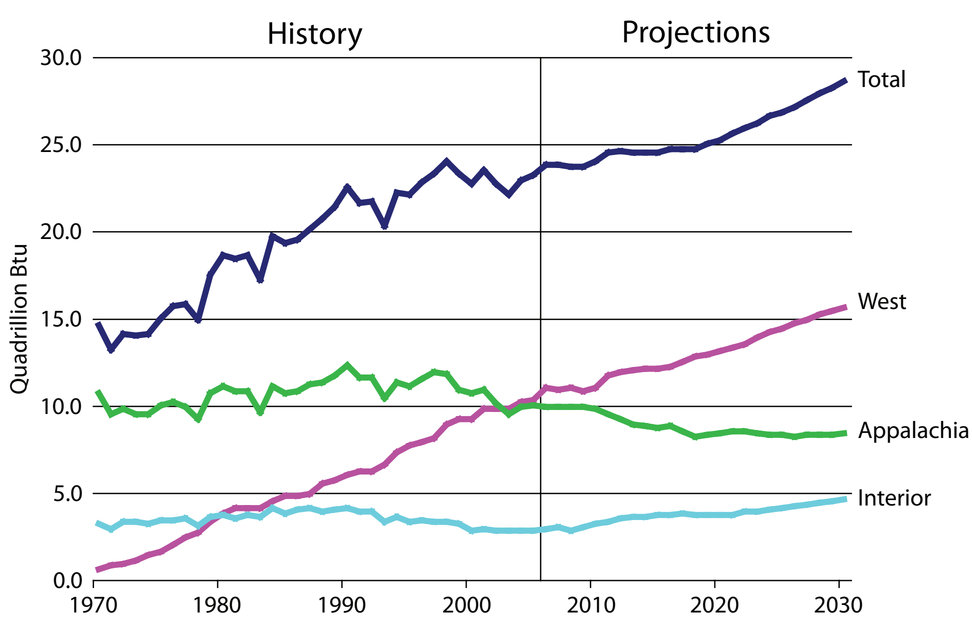


FIGURE 3.1 Historical and projected coal production by region, in quadrillion Btu.
SOURCE: EIA, 2008.

3. COAL MINING METHODS

The two major methods of mining coal are surface mining and underground mining (Figure 3.2). In surface mining, the soil and rock strata over the coal seam are first fragmented and removed, exposing the coal seam. After the coal seam is removed, the void in the ground is filled with broken rock strata and covered with soil. The soil is then graded and seeded in preparation for returning the mined land to productive post-mining land uses. Depending on local conditions and equipment used, there are several methods of surface mining, as discussed in Section 3.2.

Where surface mining of a coal seam is not feasible, underground mining of the seam can be attempted. In underground mining, the working environment is completely enclosed by the geologic medium, which consists of the coal seam and the overlying and underlying strata. First, the seam is accessed by suitable openings from the surface (drift, slope, or shaft, as shown in Figure 3.2). From these openings, a network of mine roadways is driven during the mine-development phase to prepare blocks of coal pillars that can be extracted in an orderly sequence. The infrastructure required for transporting miners, mining supplies, ventilating air, utilities (e.g., power, water drainage, and service water), and mined coal is important to ensure a safe and efficient operation. It is likely that about 20 to 45 percent of a coal seam may be extracted during the mine-development phase, also called "first mining." The extraction of the blocks of coal, often termed "second mining," has many variations. Even with the use of advanced underground extraction systems, the amount of coal recovered from a coal seam by underground mining can only approach roughly 75 percent, whereas in surface mining, the coal recovery can be 90 percent or more. As compared to surface mining, underground mining presents a number of unique operational challenges arising from the confined environment and such factors as strata pressures, gas liberation, and dusty environment.

3.1 Surface or Underground Mining?

Whether a coal seam should be mined by surface or underground methods depends on a number of technical, economic, and social factors. Generally, technical factors, such as the thickness and inclination of the coal seams, depth to the coal seams, coal quality, and topography and types of strata, are primary and provide a clear choice between surface and underground mining. The cost of mining the strata over the coal seam, cost of mining the coal seam by surface methods, and selling price of the coal also dictate the extent to which a coal

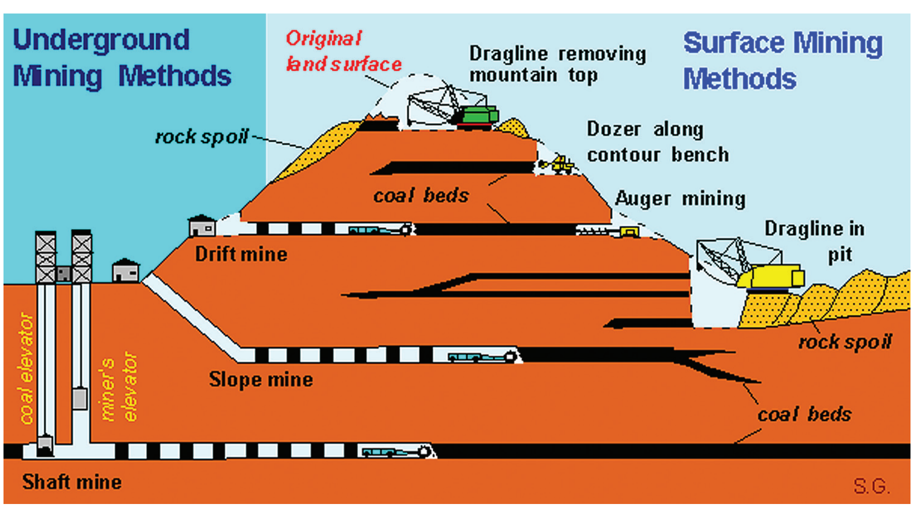


FIGURE 3.2 A generalized schematic of methods of mining a coal seam. SOURCE: Kentucky Geological Survey, 2007b.

seam can be surface mined at a profit. Important social factors include the ability to acquire both surface and underground rights and the acceptance by local communities. Wherever possible, it is common first to extract the surface-mineable reserves and then proceed with development of an underground mine for the reserves that cannot be recovered profitably by surface mining methods. When adequate reserves are not available for the continued recovery by surface mining methods, some remaining coal can be recovered by auger mining where the auger, much like a carpenter's drill, is worked into the side of the hill to recover the remaining coal (Figure 3.2). Alternatively, a method built on the auger mining process, and commonly known as highwall-mining (HWM) has evolved. In highwall mining, a remotely controlled mining machine (instead of an auger) is thrust into the coal seam from the vantage point of a surface mine bench, and the coal is recovered from a rectangular, instead of circular, opening. Auger and highwall mines are operated on surface mine benches (before they are covered up); the coal in the side of the hill that cannot be reached by contour mining is drilled (or augered) out.

Technical and economic factors are used to determine the extent of surface mining that can be practiced in a coal reserve by calculating a "stripping ratio" for the property under consideration. The volume of soil and rock strata materials to be removed to expose a short ton of coal is termed the stripping ratio, often defined in units of "bank cubic yards" per short ton (bcy/ton). The basic input data to the calculation of the stripping ratio are the area under consideration, the thickness of the overlying soil and rock strata, and the thickness and density of the coal seam. The cost associated with the removal, disposal, and reclaiming of the soil and rock strata overlying a coal bed (or series of coal beds) can be expressed in terms of bank cubic yards (i.e., $/bcy). Thus, the higher the stripping ratio, the greater the total costs of removing the soil and rock strata to expose a ton of a targeted coal seam. It follows that given specific information on a prospective surface minable site, a stripping ratio calculation, based on the price of coal per ton, the cost of mining and marketing the coal per ton, and the cost of mining the soil and rock strata per cubic yard, can be used to identify the break-even stripping ratio for surface mining at that site. As advances in surface mining technology, such as use of draglines, decrease the cost of mining the soil and rock strata, the break-even stripping ratio becomes higher for the same price of coal. Similarly, a higher price for coal raises the break-even stripping ratio.

The relatively thin seams in Appalachia, which also occur under steep topography, expose prospective surface miners to extremely variable and often high stripping ratios. At best, this combination of characteristics makes it difficult to plan and execute surface mining. Additionally, social and environmental issues associated with surface mining in Appalachia, such as noise, dust, spoil storage, and water, directly affect the cost of mining, thereby affecting the break-even stripping ratio negatively. In contrast, the thick coal seams in PRB, for instance, which are under relatively shallow cover, provide both lower and more consistent stripping ratios. Further, the ability to use very large equipment provides significant economies of scale. These advantages tend to offset the lower price commanded by the subbituminous PRB coals.

3.2 Surface Mining Methods

There are several methods of surface coal mining. Irrespective of the methods, surface coal mining involves the following sequence of ***unit operations*** that constitute a production cycle (Figure 3.3):

- Construction/extension of infrastructure and environmental controls
- Clearing the land of trees and vegetation

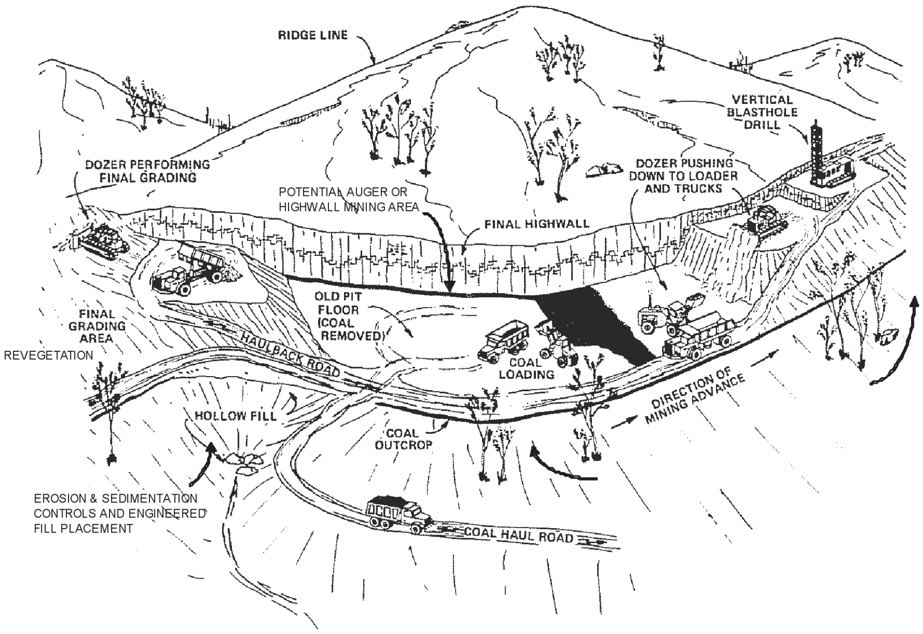


FIGURE 3.3 Schematic of single seam, single cut haulback mining method. SOURCE: Modified from Hartman and Mutmansky, 2002.

- Removing and storing designated layers of the unconsolidated soil (typically called topsoil, or approved alternatives to topsoil)
- Drilling the hard strata over the coal seam in preparation for blasting
- Fragmenting or blasting the hard strata with explosives
- Removing the blasted material (spoil) to expose the coal seam (overburden removal) and placing the blasted material in approved sites
- Cleaning the top of the coal seam and drilling and blasting the coal seam, if required
- Loading the coal onto haulage vehicles to transport from pit to coal handling plant for subsequent processing, storage, and eventual shipment to customers
- Reclaiming the land, including backfilling, grading, topsoiling, and seeding/planting in accordance to an approved post-mining land use plan

The chosen method to surface mine a coal seam may not include all the above unit operations. Where the overburden material or the coal is soft, there may be no need for drilling and blasting. Specialized equipment, such as dozers, scrapers, drills, blasting trucks, draglines, bucket wheel excavators, shovels (hydraulic or electric), backhoes, stacker-reclaimers, wheel loaders, trucks, road graders, and watering trucks, are available for each unit operation. Overburden removal is the most important operation in the system; considerable planning is required to ensure effective removal and placement of fragmented material so as to reduce, if not eliminate, rehandling of this material, minimize environmental impacts, and to aid subsequent grading in reclaiming the mined-out area. A typical surface mine has facilities for machinery maintenance and a range of equipment for road maintenance, dust suppression, water handling and treatment, and coal and waste handling.

Surface mining methods used in the United States are broadly classified into contour mining, area mining, and open-pit mining. The principal difference among these methods involves the transport and placement of fragmented overburden materials. The term mountain top mining, sometimes used to describe surface mining in the steep terrains of Appalachia, has created considerable confusion as it is not obvious which method of mining—contour, area, or open pit—is being referred to by this term. ***Contour mining*** is commonly employed in the hilly Appalachian terrain of the eastern United States. In this case, mining proceeds along the trace of coal bed outcrop, generally along a topographic contour, by cutting into the side of the hill to a depth determined by the economic stripping ratio. Figure 3.3 shows the ***haulback*** type of contour mining, where fragmented overburden material is transported by trucks along the bench and placed directly in the void created by the removal of coal. That process eliminates the highwall and restores the mined-over land to an approximate original contour.

FIGURE 3.4 Coal Augers. SOURCE: BryDet Development and Salem Tool, Inc.

Excess spoil material, a result of the swelling of the rock volume after it is blasted, that cannot be placed into the mined-out void may need to be deposited into valley (or "hollow") fills or other similar approved structures.

Auger mining recovers coal by drilling into the coal seam at the base of the highwall (Figure 3.4). Normally one of the lowest-cost mining techniques, it is limited to horizontal or slightly pitched seams, recovering coal for a limited depth into the seam. ***Highwall mining*** is an evolution from auger mining, where coal is recovered from the final highwall of a surface mine. Currently, there may be up to 60 highwall mining systems and as many as 150 auger mining systems operating in the nation's surface coal mines, producing upwards of 45 million clean tons annually and thus representing about four percent of total U.S. coal production (Zipf, 2005).

A highwall mining system, consisting of a cutting machine attached to a conveyor, and other elements, is set up at the face of the final highwall (Figure 3.5). The cutting machine, a continuous miner that is typically used in underground mines, begins mining its way under the mountain. The coal is transported from the back of the miner to the surface on a conveyance system that is incrementally increased in length as the miner advances into the mountain. The mining machinery is operated remotely from an operator's cab located on the surface. The tunnel is mined the maximum distance allowed by equipment

ADDCAR (ICG Industries) HWM System

Superior Highwall Mining Systems (Terex)

FIGURE 3.5 Highwall mining system. SOURCE: Addcar Systems (http://www.addcarsystems.com) and Superior Highwall Mining Systems (http://www.terexshm.com/mining-system-overview).

design and geological conditions. When the maximum distance is reached, the equipment retracts from the hole and moves down the highwall and drives another entry parallel to the area previously mined.

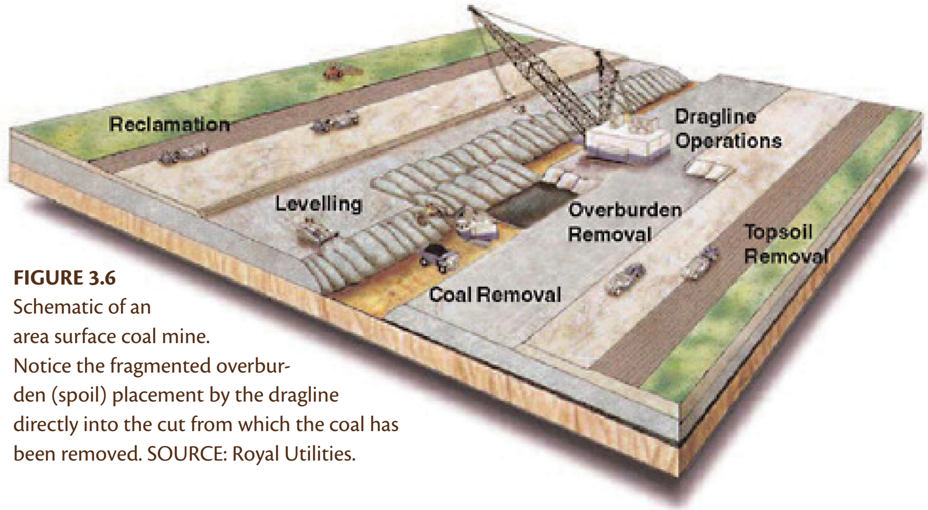


FIGURE 3.6
Schematic of an area surface coal mine. Notice the fragmented overburden (spoil) placement by the dragline directly into the cut from which the coal has been removed. SOURCE: Royal Utilities.

Area mining is usually carried out in relatively flat terrain with flat-lying seams (Figure 3.6). As shown in the figure, mining cuts are straight and parallel, proceeding in a sequence. The primary overburden removal equipment can be a dragline (Figure 3.7), or shovel, or combinations of loading shovels or front-end loaders and trucks. The most common and major overburden removal equipment used in large area mines is a dragline, which has a large-capacity suspended bucket at the end of a large swinging boom. One of the largest draglines ever manufactured was the "Big Muskie," which had a bucket capacity of 220 yd^3 and a boom length of 360 feet. It could pick up over 200 yd^3 of fragmented overburden from the active cut and swing 90 degrees or more to dump the material in the previous cut. The fragmented overburden from one cut is placed directly into the void of the previous cut from which the exposed coal has been loaded out. The method is common in Interior and in several Western mines.

FIGURE 3.7 Example of a dragline operation. SOURCE: Bucyrus-Erie.

Mountaintop removal mining (Figures 3.8 and 3.9), a form of area mining, involves removing an entire coal seam or seams from the outcrop on one side of a mountain or hill to the other side. A portion of the overburden from the top of the mountain (typically, at least, the "swell" portion of the broken rock) is transported for permanent placement in a valley fill (excess spoil disposal area). The balance of the broken/shot overburden is mandated by regulation to be placed onto the mountaintop area to achieve the approved post-mining land use. There is much controversy about the placement of excess fill in valleys adjacent to the mountaintop removal mining area, particularly with regard to the disturbance of perennial steam flows and the ensuing modification to the original topography. In any event, mining generally proceeds from one side of the mountain to the other, using a series of parallel strip pits, and overburden is removed using one or more (or a combination) of the following systems: cast-blasting, wheel-loaders/trucks, tracked bulldozers, draglines, cable-shovels/trucks, and hydraulic-excavators/trucks. Because of the location of these operations, and some similarities in disposal of excess spoil,

FIGURE 3.8 Conventional wheel-loader/truck mountaintop mining. SOURCE: various.

some consider mountaintop removal mining a variation of contour mining, discussed earlier. Mountaintop removal mining differs from contour mining, however, in that the sequence for removal of coal generally does not follow the contour of the mountainside.

Under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mining operations permitted as mountaintop removal mining are exempted from the approximate original contour (AOC) requirement providing that the mine operator commits to one or more of the post-mining land uses acceptable by regulations promulgated pursuant to SMCRA. (In fact, SMCRA provisions allow other types of surface coal mining operations in steep slope areas to apply for and receive a waiver from the AOC requirement, again in exchange for creation of specific post-mining land use(s) compliant with current regulations.) Most types of coal operations on the tops of the mountains of Appalachia, however, must be reclaimed to the AOC.

FIGURE 3.9 Dragline-styled mountaintop mining.
SOURCE: EPA, 2004.

As stated earlier, the use of the broader term "mountaintop mining" creates confusion, because it is not always obvious which type of mining is being referred to by the term. In the Draft Programmatic Environmental Impact Statement on Mountaintop Mining and Valley Fills (EPA, 2004), mountaintop mining is referred to as "coal mining by surface methods (e.g., contour mining, area mining, and mountaintop removal mining) in

BOX 3.1 BLACK THUNDER SURFACE COAL MINE CASE STUDY

Black Thunder Coal Mine is the first of the mega surface mines to open in the Powder River Basin in Wyoming. ARCO Coal, the first owners of the mine, performed extensive mine planning, reclamation, and environmental planning studies and determined that a shovel-truck open pit operation would create the most desirable reclaimed land surface consistent with the original topography. Construction began at Black Thunder in 1976 with the installation of crushing, conveying, sampling, and high-speed train loading systems with the first coal shipped at the end of 1977. Over time, the productive capacity of the operation and the size of equipment deployed have grown. Haul trucks of 170-ton capacity were part of the original fleet. In 1985, 240-ton capacity trucks were introduced, followed in 1998 by 340-ton capacity trucks. By 1988, a dragline was added to aid in stripping the deeper overburden. Continuous improvement of the coal handling system led to computer control of all processes. A near-pit crushing and conveyor system was installed in 1989. In 1998, Arch Coal, Inc., of St. Louis, Missouri acquired the mine.

By 2002, Black Thunder had shipped 750 million tons of Powder River Basin coal to power plants outside of Wyoming, and by 2004, one billion tons. Today, Black Thunder production stands at about 92.5 million tons per year. This amount is equivalent to producing about 3 tons per second, 24 hours a day, 365 days a year.

Black Thunder mines the Wyodak coal seam in the Fort Union formation. Wyodak is a major coal seam in the Powder River Basin. This subbituminous coal seam ranges from 25 to 190 feet thick and covers an area of over 14,000 square miles in the states of Wyoming, Montana, and the Dakotas. The average thickness of the seam is about 100 feet. The Wyodak surfaces in a narrow north-south band mined by 18 of the largest open-pit mines in the world; Black Thunder is one of them. At Black Thunder, the seam is about 72 feet thick, gently dipping until it splits into the Anderson and Canyon beds, separated by up to 60 feet of rock, or innerburden. The coal at Black Thunder has an average heat content of 8,840 Btu per pound, ash of 5.1 percent, and sulfur of 0.28 percent. It is suitable for use as thermal power station fuel without any preparation other than crushing. The mine currently ships to over 100 domestic power plants as well as exports its production to foreign markets.

At present, Black Thunder operates several individual open pits using five large draglines for overburden handling. The dragline fleet includes the third largest dragline ever built, with a boom over 360 feet long and an over 160 cubic yard bucket capacity (Bucyrus-Erie, BE 2570WS). Typically, after topsoil is stripped and stored for use during reclamation, pre-strip shovels excavate

...continues on next page

BOX 3.1 continued...

a bench 50 to 75 feet deep and then large blast holes are drilled into the overburden. Cast blasting is used to directly place about 20 to 30 percent of the blasted material in the final position.

Draglines are used to complete overburden removal and expose the coal. The coal is also drilled and blasted and then loaded by electric mining shovels on to large coal hauling trucks for transport to one of three near-pit dump and crusher stations. At Black Thunder, the coal is stored in two separate storage systems. The North Loadout consists of two 12,500 ton silos and a 100,000 ton slot that feeds twin rail loadouts with capacities of 4,100 tons per hour (tph) and 10,800 tph, while the South system consists of a 50,000 ton slot that feeds a 4,100 tph loadout. Currently, a third loadout is under construction that will have two 17,500 ton silos feeding a 10,800 tph loadout. The mine employs approximately 1,000 persons.

the steep terrain of the central Appalachian coalfields. The additional volume of broken rock that is often generated as a result of this mining, but cannot be returned to the locations from which it was removed, is known as 'excess spoil' and is typically placed in valleys adjacent to the surface mine, resulting in 'valley fills.'" This terminology considers all steep-terrain surface mining as one method—mountaintop mining—without clarification of AOC requirement.

Where thick coal seams are overlain by thick or thin overburden, it may be necessary to have several benches in the overburden and the coal, much like in ***open-pit mining*** of metallic ore bodies. In this case, the direct casting of spoil (as with a dragline in area mining) may not be possible. Usually, trucks or conveyors are employed around the pit. Until sufficient area has been created in the pit for direct placement of the fragmented overburden in mined-out voids, the spoil material is stored outside the pit. Initially, in the PRB, shovels and trucks were employed to transport the spoil around the pit. Figure 3.10 shows a large surface mine in the PRB with benches in the coal and overburden. Currently, draglines are generally employed in the lower bench to cast the spoil directly into the previous pit, whereas in the top benches, shovels and trucks are used to transport the fragmented overburden around the pit.

FIGURE 3.10 Powder River Basin surface coal mine. Notice the coal loading in the foreground, overburden removal in the background, and spoil dumped in the area where coal has been removed in the lower right hand corner. SOURCE: Peabody, http://www.peabodyenergy.com/Operations/coaloperations-PowderRiver.asp.

3.3 Underground Mining Methods

An underground coal mine consists of the entrances and exits to the mine (portals), the mains, the sub-mains, the panels, and the working faces (Figure 3.11). The panels are the working sections and are the hubs of the production operation.

Depending on the mining method, a working section can have several working faces or one working face. The working face is where the ***unit operations*** take place in a planned cycle. This cycle depends on the equipment employed at the face. In "conventional mining," equipment assembly requires a sequence that entails cutting, drilling, blasting, loading, hauling, supporting the roof, and extending the ventilation. The use of "continuous mining machines" (or, continuous miners) simplifies the process by eliminating the need for cutting, drilling, and blasting.

Items that deal with the overall mine production-support systems, such as the stability of the openings (e.g., shafts, slopes, and mains), ventilation of the entire mine, the coal clearance system (haulage), transportation of men and supplies, water handling (drainage), and power distribution, are the ***auxiliary operations*** that must be adequately designed to ensure a safe and productive mine. The need for good ground control in underground coal mines to ensure stability in the working sections (local stability) and in the overall mine (global stability) has been recognized from the earliest of times. The importance of mine design to handle the overall ground pressures arising from the stresses of nature, dictated by the geological setting, superposed with the induced stresses of mining, cannot be overemphasized.

Another major aspect of underground coal mine planning is the design of the ventilation system to provide adequate fresh air to miners and to dilute and carry away the gases and dusts that are released during the mining process. Methane is often associated with coal seams, particularly deep coals seams, and does not support life. Of equally great concern is that methane is explosive when it constitutes 5 to 15 percent of the content of the surrounding air. Not surprisingly, the dilution and safe removal of methane from active underground

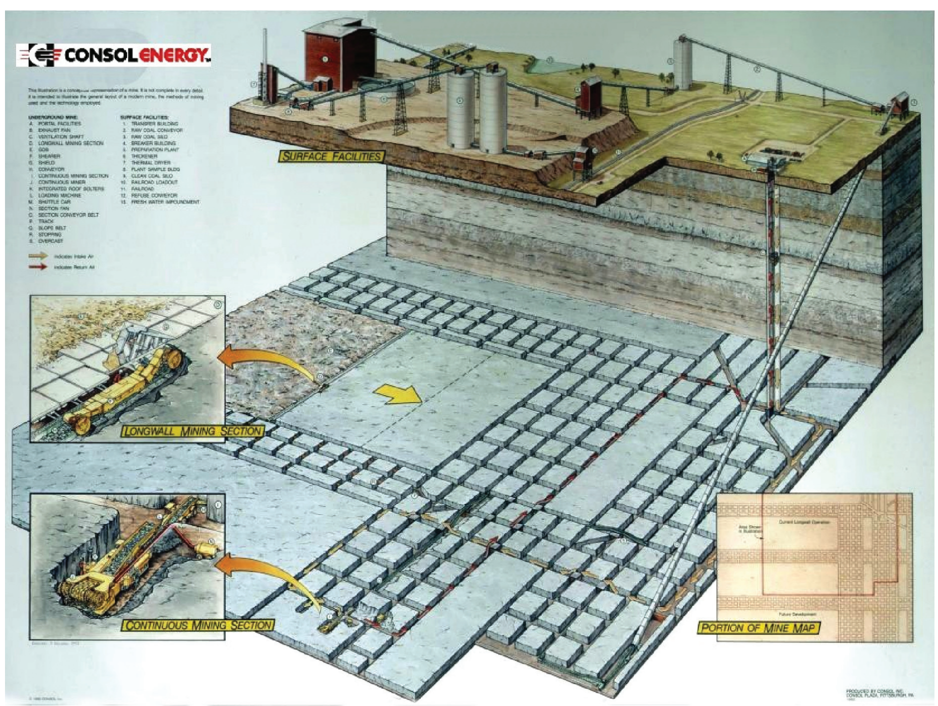


FIGURE 3.11 Schematic of an underground coal mine. Notice the two working sections (the longwall section and the continuous miner section), the belt conveyor coal conveyance system carrying coal from the sections through the slope to the surface, and the surface facilities, including the coal cleaning and loading plant. SOURCE: Consol Energy Inc., 1992.

coal mines has always been a major safety concern and a number of strict mining regulations address that issue. Furthermore, in addition to the hazards that methane presents to coal miners, this gas is also a very potent greenhouse gas when released to the atmosphere through the mine ventilation system. Therefore, efforts to capture and utilize coal bed methane (CBM) before, during, and after mining have gained increased attention in the last three decades.

The two major methods of underground mining are the ***room and pillar method*** and the ***longwall method.*** There are several variations of each method.

In the ***room and pillar*** method, a number of parallel entries (or openings or roadways) are driven in the coal seam. The number of parallel openings usually ranges from five to ten. The openings are generally 16 to 20 feet wide and are spaced, center to center, from 50 to 100 feet apart. Entries, called crosscuts, are driven at right angles to the first set of openings, again 16 to 20 feet wide and spaced anywhere from 50 to 100 feet apart. This pattern of entries and crosscuts creates square or rectangular blocks ("pillars") of coal (Figure 3.12). The height of the entries is generally equal to the thickness of the coal seam, although equipment needs and geological conditions may dictate entry heights greater or less than the seam thickness. For instance, where the coal is thin (less than four feet), the entries may be driven to a greater height, taking some roof rock and often some floor rock. If the coal seam is thicker than approximately 16 feet, the entries may be driven to a suitable height, with the roof often close to the top of the seam, leaving a floor-coal that is often recovered upon retreat from the panel. Generally, each entry or crosscut is advanced by a "cut" that is anywhere from 10 to 40 feet long. The entries and crosscuts are advanced by a planned sequence of cuts to develop the working section toward the property limit or other predefined limit. A properly planned and executed sequence ensures that unit operations are performed in each entry to effect an efficient lineal advance of the working section.

As indicated earlier, there are two major room and pillar techniques: the ***conventional mining*** technique and the ***continuous mining*** technique. In the ***conventional mining*** technique, employed in flat-lying (or nearly so) coal beds, the sequence of unit operations includes cutting, drilling, blasting, loading, hauling, and roof bolting, all performed by different machines (Figure 3.12). (Steeply pitching coal beds may require some or all of the above

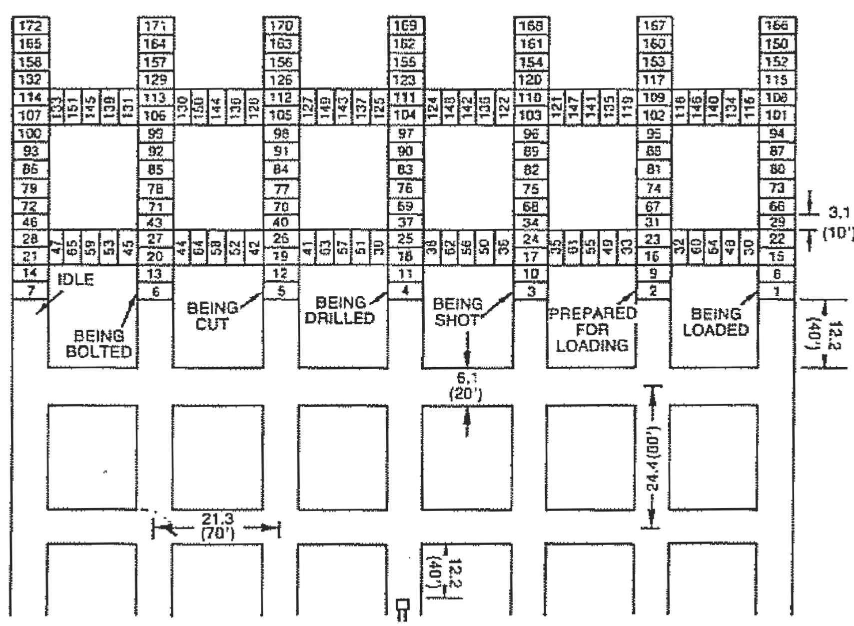


FIGURE 3.12 A conventional mining cut plan for a seven-entry section, showing the sequence of 172 cuts for a lineal advance of 160 feet. The machines move from right to left after finishing the work in an entry, cycling back to the first entry on the right. SOURCE: Stefanko, 1983.

machines). Because of the large number of unit operations and machines employed, the conventional room and pillar method is more labor intensive than the continuous mining technique and requires more faces. Although a number of other face haulage options are available, typically a "shuttle car" is employed to haul coal from the working face to the panel conveyor belt (and from there it is transported to the surface). Shuttle cars generally operate in tandem—when one is being loaded, the other is en route, either from the loader to the dump point or from the dump point to the loader. In most cases, shuttle cars are powered by electric motors from a trailing cable connected to the power supply center of the mining section. Variations of the shuttle car, powered by lead-acid batteries, have been used for many years. In recent years, and in response to regulatory modifications, an increasing number of diesel-engine-powered cars have also been used. Both the battery powered and diesel-engine-powered cars eliminate the need for trailing cables. The immediate roof is supported in accordance with an engineered and regulatory approved system that typically relies on long steel bolts, set on a regular pattern (e.g., four feet apart in a row and rows of bolts four feet apart) driven into the roof and secured by one or more combinations of expanding anchor-shells and resin grout. It is estimated that about two percent of U.S. underground production comes from conventional room and pillar sections.

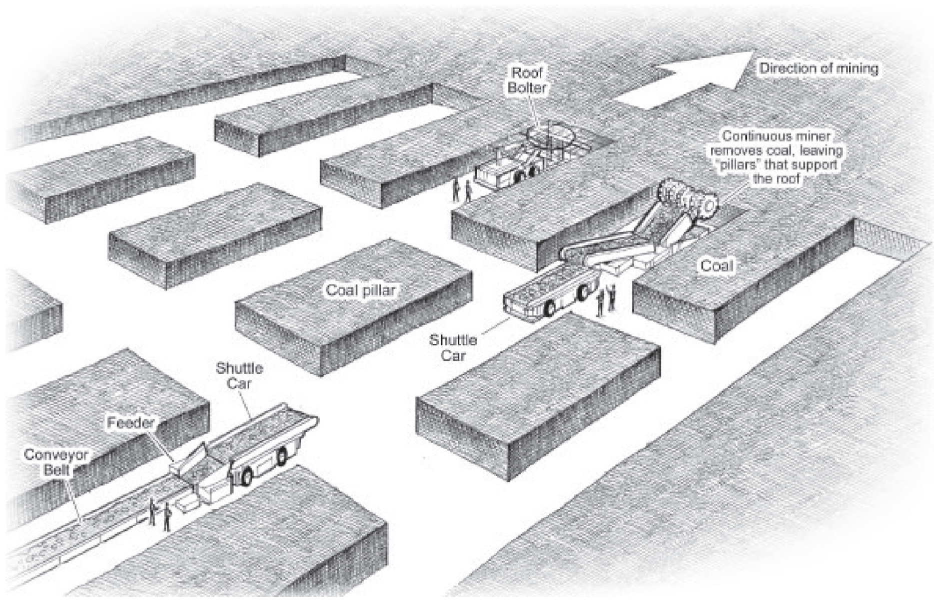


FIGURE 3.13 Continuous mining room and pillar method. SOURCE: U.S. Securities and Exchange Commission, 2006.

In the ***continuous mining*** technique, the unit operations of cutting, drilling, blasting, and loading are all combined in one mechanical excavator called a continuous miner, which cuts and loads the coal. Shuttle cars haul the loaded coal to the section or panel belt for transfer to other belts leading to the surface. Once the face has been advanced by the length of the cut, the continuous miner is withdrawn from the face and moved to a new face. A roof bolter is moved into the face vacated by the continuous miner to support the newly exposed roof with bolts, plates, and straps, as needed. Figures 3.13 and 3.14 show a five-entry continuous miner section. Several variations on the basic mining plan, such as extended cuts and super-sections, have been developed to increase the production time by decreasing the dead time between cuts. In some cases, continuous miners with satellite bolters or integrated bolters have also been used to allow long cuts in an entry. About 48 percent of the U.S. underground production comes from mines employing room and pillar continuous mining.

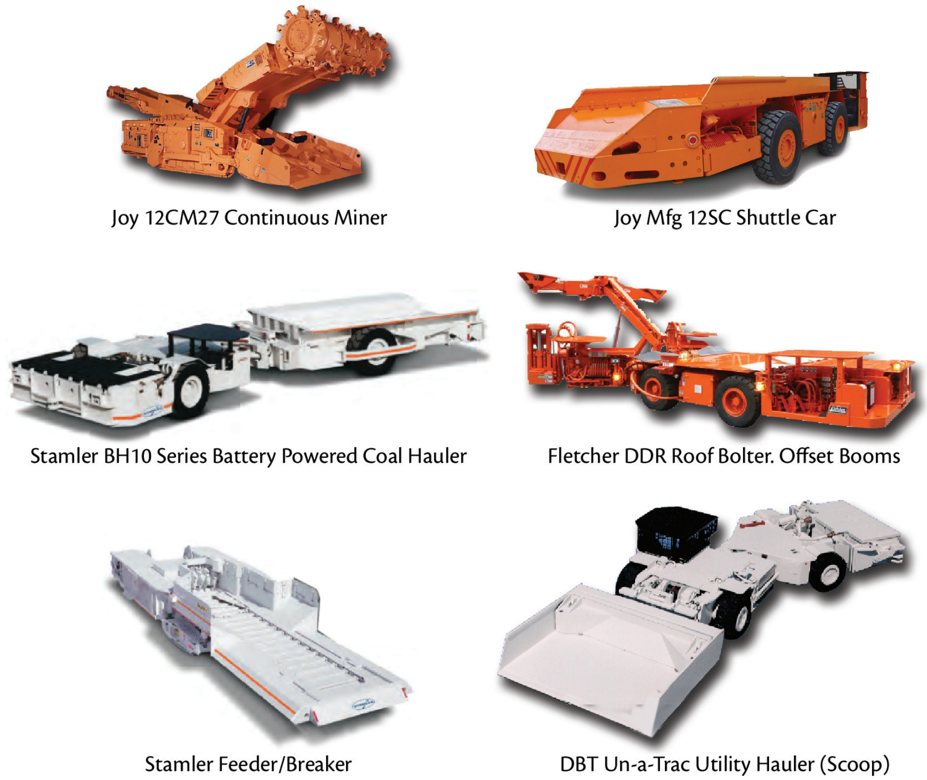


FIGURE 3.14 Typical equipment associated with a continuous mining room and pillar mine.

Depending on the mining conditions and feasibility of mining, coal that is in the pillars is either mined or left unrecovered. There are several techniques, collectively called "***pillaring techniques***," that are used to recover coal in the pillars. It is estimated that about 10 percent of U.S. coal production (about 100 million tons) comes from mines that practice pillar recovery. Assuming that pillar recovery, in general, accounts for about 30 to 35 percent of total production from these mines, at present, pillaring practices produce about 35 million tons per year. Pillar recovery practice is most prevalent in the central Appalachian coalfields of West Virginia, Virginia, and eastern Kentucky, which account for 90 percent of the U.S. pillar recovery production (Mark et al., 2003).

In ***longwall mining***, a large block of coal is developed for mining by longwall panels. Figure 3.15 shows the layout of the longwall retreating method. In this method, a longwall panel is developed from the mains or sub-mains by driving the head and tailgate entries to the furthest extent of the panel. The block of coal between the two entries is then mined back to the mains. Considerable development work is needed to protect the main entries, at the front of, and the bleeder entries, in the back of, the longwall panel. Continuous miners develop the panels. In general, panels are arranged parallel to each other. When one panel has been extracted, the equipment is moved to the adjacent panel.

Figures 3.16 and 3.17 show the details of a longwall face. Working faces typically range from 800 to 1,200 feet wide, bounded on either ends by continuous miner-developed headgate and tailgate entries, as shown in the figure. The block of coal may be 12,000 to 15,000 feet long. The height of the block is usually the height of the coal seam.

The cutting machine is called a shearer and operates much like a cheese slicer, slicing away about 42 inches of coal as it passes from one gate to another. The cut coal falls on to a chain conveyor, also called an armored face conveyor (AFC), where it is transported to the belt conveyor at the headgate through a stage loader. The shearer, the AFC, and the miners are all under a canopy of steel supports called shields. Shields are self-advancing, powered hydraulic roof supports that carry the load of the overlying strata above it that separated from the main roof. Each shield is about five feet wide (manufacturer's specifications are

1.5 m and 1.75 m, or 4.92 ft and 5.74 ft, respectively) and has a designed load-bearing capacity in the range of 800 to 1,300 tons. Thus, a longwall face that is 900 feet wide may have about 180 shields. As the shields advance with each pass of the longwall shearer, the material that was above the shield falls into the void behind. Caving of the overlying strata into the mine void can extend all the way to the surface, resulting in surface subsidence. The amount of surface subsidence depends on factors such as geology, seam thickness, mining geometry, mining depth, and mining sequence.

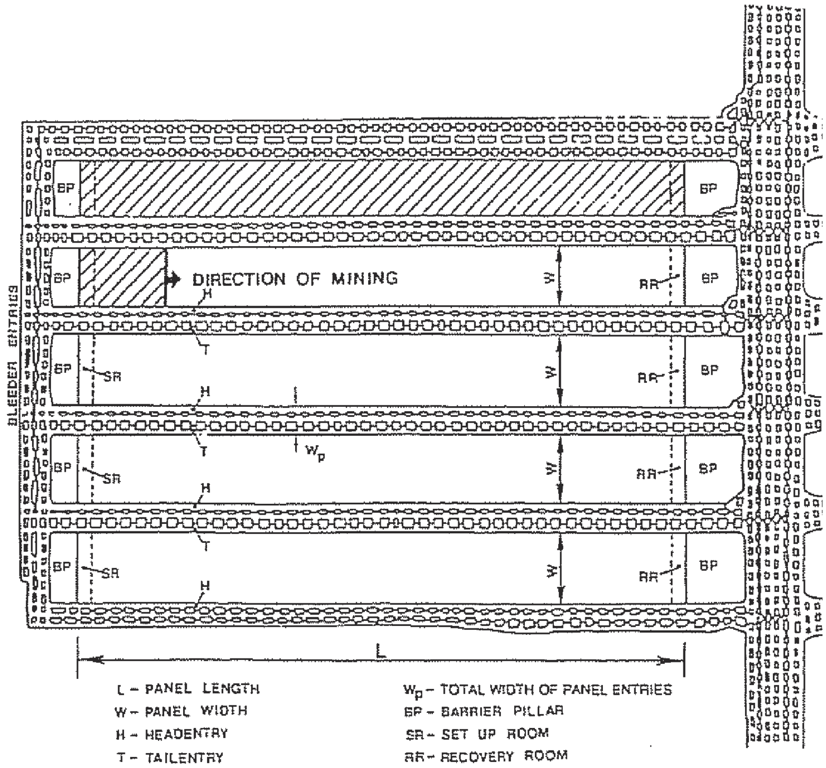


FIGURE 3.15 Layout of longwall panels. Transport of miners, supplies, coal, and intake ventilating air is through the headgate entries. Tailgate entries conduct return air out of the section. Note that the headgate entries of one longwall panel become the tailgate entries of the next panel. SOURCE: Peng and Chiang, 1984.

The high production and productivity capacities of the longwall technique arise from both the truly continuous mining system it provides and the great potential it offers for automation. Proper planning and development of the longwall block and the head and tailgate entries from ground control and ventilation considerations are very critical to the successful implementation of the longwall. When the coal in a longwall panel is mined out, the equipment and utilities are moved to the adjacent panel and mining is restarted with the headgate of the preceding panel becoming the tailgate of the next panel. As Figure 3.15 shows, coal is

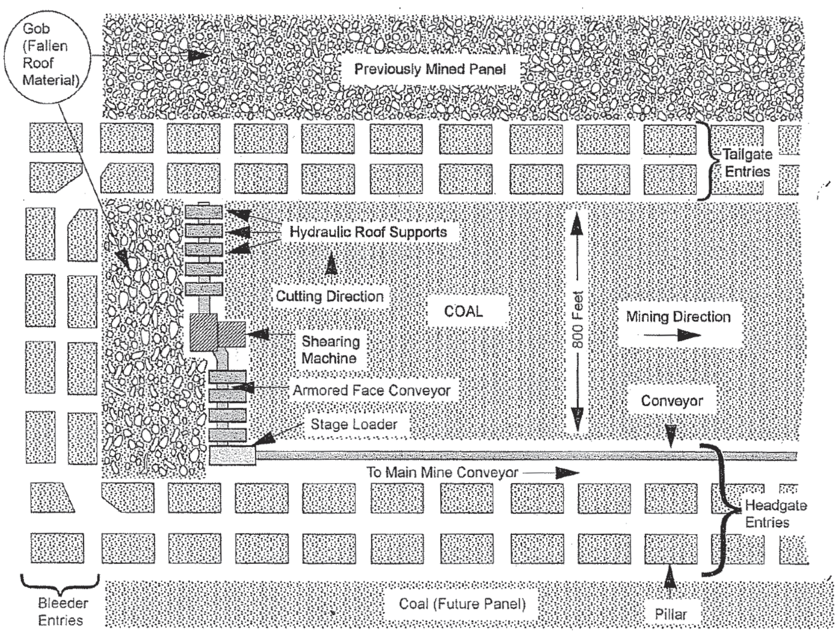
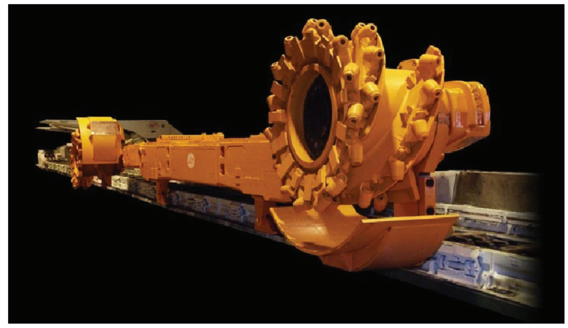


FIGURE 3.16 Details of a longwall panel layout. SOURCE: EIA, 1995.

Joy Mfg, Two-Legged Shield and Portion of AFC

Joy Mfg, 7LS03 Shearer on AFC



DBT Shearer and Shield Supports in Action

BMA Pump Station

FIGURE 3.17 Longwall mining machinery. SOURCE: Various manufacturers' brochures.

lost in the barrier pillars, in the head and tailgates, and in the mains. Typically, in a longwall mine, longwall production would be 70 to 75 percent of the total mined, with remaining coal coming from continuous miners that develop the mains, the sub-mains, and the gates of the panels. The overall recovery of coal from the seam can be in the range of 70 to 80 percent.

3.4 Distribution of Production and Number of Mines in the United States by Mining Method

Along with production shifting west of the Mississippi since the 1970s, there has also been a shift in production from underground mining to surface mining. Table 3.1 shows the production distribution by mining methods for nine leading coal-producing states (accounting for 85 percent of the total U.S. production). In 2006, 26 states produced coal, with total coal production approximately 1,160 million tons and a 70/30 split between surface and underground production. The Western region accounts for 69 percent of the surface production, with the Appalachian and Interior regions accounting for the remaining 18 percent and 13 percent, respectively. Wyoming alone accounts for 80 percent of the Western region's surface production. The Appalachian region accounts for 70 percent of the total underground production, with the Interior and Western regions accounting for 15 percent each. In particular, mining in Kentucky, Pennsylvania, and West Virginia contributes nearly 68 percent of total U.S. underground production. Mining of lignite and subbituminous coals in the western United States and Texas is characterized by large surface mines.

Table 3.1 also shows the distribution of surface and underground coal mines in the United States in 2006 in the same coal mining states. Of approximately 1,400 coal mines in the United States in 2006, about 800 were surface mines and 600 underground mines. Though these numbers

BOX 3.2 ENLOW FORK UNDERGROUND COAL MINE CASE STUDY

Enlow Fork Mine (Pennsylvania) of CONSOL Energy is the top-producing underground coal mine in the United States, with an annual production of over 11.2 million tons. The mine, which began production in 1991, presently has two longwall faces and six active continuous miner sections. The Pittsburgh No. 8 seam is being extracted, and varies in thickness from 62 to 72 inches, and in depth from 600 feet to 1,000 feet. Enlow Fork has, in addition to the slope, three intake shafts, three main fans, and six bleeder fans to ventilate the underground workings. Some in-seam horizontal de-gas drilling is done ahead of gate road development, and adequate ventilation keeps gas problems under control.

Average longwall panel size in Enlow Fork is about 1,100 feet wide and 12,000 feet long. There are three gate entries. The average cutting height is about 84 inches and the cutting depth is about 42 inches. Equipment in the various faces is from different manufacturers. For example, in one longwall face, the cutting machine is a Joy 7LS-2A shearer with 63-inch diameter drums and 1,680 installed horsepower. The face is supported by 192 two-leg shields that are manufactured by DBT, each with a yield in excess of 750 tons and a working range of 45 to 100 inches. The armored face conveyor, supplied by Longwall Associates, is about 40 inches wide (about 1,000 millimeters), and is a 42-millimeter twin in-board type with three 800 horsepower motors, running at 334 fpm. The stage loader and crusher are also supplied by Longwall Associates. The operating voltage of the face is 4,160. On average, the longwall face retreats approximately 80 to 90 feet per day, or about 1,500 to 2,000 feet per month. When a longwall panel is completed, it takes about 10 days to move the face to a new panel.

Longwall development is achieved by full-face continuous miner units with integral roof bolters. Particular attention is paid to the installation of wire meshes in the roof and ribs, as required for main track, belt entries, and headgate entries.

Coal is transported from the faces to the surface by belts. In total, the mine contains about 15 miles of belt, with about seven miles of main belts. The main-entry belts are 72 inches wide and the headgate belts are 54 inches wide. Panel belts are designed for 3,500 tph, whereas the main slope belt is designed for 5,500 tph. At the surface, the coal is fed to the Bailey Central Preparation Plant, which is a full wash, wet separation plant with a 6,300 tph raw-coal-feed capacity. The cleaned coal is shipped to customers through rail transportation from the mine load out. The mine employs approximately 600 persons.

TABLE 3.1 Coal production (millions of tons) by mining methods and number of mines in selected states during 2006.

STATE	PRODUCTION (MILLION TONS)			NUMBER OF MINES		
	SURFACE	UNDERGROUND	TOTAL	SURFACE	UNDERGROUND	TOTAL
Colorado	10	27	**37**	50	7	**12**
Illinois	5	27	**32**	15	7	**22**
Indiana	24	11	**33**	21	7	**28**
Kentucky	47	73	**120**	215	227	**442**
Pennsylvania	12	54	**66**	216	54	**270**
Texas	46	0	**46**	12	0	**12**
Virginia	11	19	**30**	51	76	**127**
West Virginia	68	85	**153**	116	174	**290**
Wyoming	446	-	**446**	20	1	**21**
TOTAL	**669**	**296**	**965**	**671**	**553**	**1224**

Source: EIA, 2006d.

have not changed much in the last five years, the total number of mines today is about 40 percent of the operating mines 25 years ago. This decrease is a result of the increasing consolidation of mining companies, the ever-growing size of individual mines, and the increasing complexity of health, safety, and environmental requirements.

The 100 largest mines produced over 800 million tons in 2006 (about 70 percent of total production). Production from the top 10 surface mines, all in the Powder River Basin, was nearly 400 million tons (over 50 percent of all surface production), with the largest mine producing over 90 million tons. The top two surface mines (Black Thunder and the North Antelope/Rochelle Complex) accounted for 15 percent of the entire U.S. production. Other major surface producers are in North Dakota, Montana, and Texas. There are also several smaller surface operations (3 to 5 million tons per year) in West Virginia. Table 3.2 shows the coal mines in the United States with over 4 million tons of production in 2006.

Production from the top 10 underground mines was over 80 million tons, over 25 percent of all underground production. Forty-eight of the 600 underground mines use longwall mining (a total of 52 faces) and produced about 200 million tons. The geographical distribution of the top 10 underground mines is diverse, though most of them are in Pennsylvania and West Virginia. Operations in Utah, Colorado, New Mexico, and Illinois are also among the largest underground coal mines. The top-producing underground coal mines use longwall as the main production method, with continuous miners being used for longwall gate and mine development. Three mines (Enlow Fork, McElroy, and Bailey) have two longwall faces and each produces over 10 million tons per year.

There are, however, a large number of small surface and underground operations in Kentucky, Pennsylvania, Virginia, and West Virginia. These four states collectively account for over 80 percent of the number of mines (1,129 mines) and about 32 percent of production (370 million tons). These statistics reflect the variations in the geological occurrence of coal deposits across the United States, coal quality considerations, and the significant differences in mining conditions, which lead to alternative selection and practice of mining methods.

Table 3.2 Major U.S. coal mines, 2006.

RANK MINE NAMES/COMPANY	MINE TYPE STATE	PRODUCTION (SHORT TONS)
1 Black Thunder/Thunder Basin Coal Company LLC	Surface Wyoming	92,653,250
2 North Antelope Rochelle Mine/Powder River Coal, LLC	Surface Wyoming	88,527,969
3 Jacobs Ranch Mine/Jacobs Ranch Coal Company	Surface Wyoming	40,000,376
4 Cordero Mine/Cordero Mining Company	Surface Wyoming	39,747,620
5 Antelope Coal Mine/Antelope Coal Company	Surface Wyoming	33,879,292
6 Caballo Mine/Caballo Coal Company	Surface Wyoming	32,775,697
7 Eagle Butte Mine/Foundation Coal West Incorporated	Surface Wyoming	25,355,158
8 Belle Ayr Mine/Foundation Coal West Incorporated	Surface Wyoming	24,593,035
9 Buckskin Mine/Triton Coal Company	Surface Wyoming	22,768,303
10 Rawhide Mine/Caballo Coal Company	Surface Wyoming	17,032,317
11 Freedom Mine/Coteau Properties Company	Surface North Dakota	15,243,391
12 Spring Creek Coal Company/Spring Creek Coal Company	Surface Montana	14,541,054
13 Rosebud Mine & Crusher/Conveyor/Western Energy Company	Surface Montana	12,731,701
14 Enlow Fork Mine/Consol Pennsylvania Coal Company	Underground Pennsylvania	10,703,230
15 McElroy Mine/McElroy Coal Company	Underground West Virginia	10,477,398
16 Bailey Mine/Consol Pennsylvania Coal Company	Underground Pennsylvania	10,174,574
17 Foidel Creek Mine/Twentymile Coal Company	Underground Colorado	8,635,561
18 Navajo Mine/BHP Navajo Coal Company	Surface New Mexico	8,438,711
19 Kayenta Mine/Peabody Western Coal Company	Surface Arizona	8,216,255
20 Falkirk Mine/Falkirk Mining Company	Surface North Dakota	8,155,004
21 Sufco/Canyon Fuel Company LLC	Underground Utah	7,907,935
22 Cumberland Mine/Cumberland Coal Resources, LP	Underground Pennsylvania	7,515,984
23 Galatia Mine/The American Coal Company	Underground Illinois	7,214,080
24 Decker Mine/Decker Coal Company	Surface Montana	7,044,226
25 San Juan South/San Juan Coal Company	Underground New Mexico	6,993,143
26 Absaloka Mine/Washington Group International	Surface Montana	6,806,854
27 Jewett Mine/Texas Westmoreland Coal Co.	Surface Texas	6,781,523
28 Three Oaks/Alcoa Incorporated	Surface Texas	6,724,731
29 Century Mine/American Energy Corporation	Underground Ohio	6,450,932
30 Loveridge No 22/Consolidation Coal Company	Underground West Virginia	6,383,219
31 Colowyo Mine/Colowyo Coal Company L P	Surface Colorado	6,222,002
32 Beckville Strip/TXU Mining Company LP	Surface Texas	6,103,037
33 West Elk Mine/Mountain Coal Company, L.L.C.	Underground Colorado	6,011,620
34 Emerald Mine No. 1/Emerald Coal Resources, LP	Underground Pennsylvania	5,922,161
35 Dry Fork Mine/Dry Fork Coal Company	Surface Wyoming	5,860,998
36 Robinson Run No 95/Consolidation Coal Company	Underground West Virginia	5,740,172
37 Lee Ranch Coal Company/Lee Ranch Coal Co. Div. Peabody	Surface New Mexico	5,502,565
38 Jim Bridger Mine/Bridger Coal Company	Surface Wyoming	5,414,423
39 Elk Creek Mine/Oxbow Mining, LLC	Underground Colorado	5,128,389

Continued on next page...

Table 3.2 Continued...

RANK MINE NAMES/COMPANY	MINE TYPE STATE	PRODUCTION (SHORT TONS)
40 Blacksville No 2/Consolidation Coal Company	Underground Pennsylvania	5,039,423
41 Buchanan Mine #1/Consolidation Coal Company	Underground Virginia	5,008,813
42 McKinley/The Pittsburg & Midway Coal Mining Co	Surface New Mexico	4,978,104
43 Oak Hill Strip/TXU Mining Company LP	Surface Texas	4,843,839
44 Dotiki Mine/Webster County Coal LLC	Underground Kentucky	4,733,296
45 Wyodak/Wyodak Resources Development Co	Surface Wyoming	4,698,473
46 Federal No 2/Eastern Associated Coal Corp	Underground West Virginia	4,621,992
47 Kemmerer Mine/The Pittsburg & Midway Coal Mining Co	Surface Wyoming	4,565,158
48 Twilight MTR Surface Mine/Progress Coal	Surface West Virginia	4,493,422
49 Cardinal/Warrior Coal LLC	Underground Kentucky	4,487,614
50 Big Brown Strip/TXU Mining Company LP	Surface Texas	4,462,066
51 Bowie No 2 Mine/Bowie Resources LLC	Underground Colorado	4,420,073
52 Dugout Canyon Mine/Canyon Fuel Company LLC	Underground Utah	4,387,000
53 Powhatan No. 6 Mine/The Ohio Valley Coal Company	Underground Ohio	4,370,226
54 Center Mine/BNI Coal Ltd	Surface North Dakota	4,302,567
	SUBTOTAL	**715,789,956**
	ALL OTHER MINES	**446,959,703**
	U.S. TOTAL	**1,162,749,659**

NOTE: Major mines are mines that produced more than 4 million short tons in 2006. The company is the firm operating the mine.
SOURCE: EIA, 2006e.

4. THE PRESENT COAL INDUSTRY

Several aspects of the coal industry have been identified in the preceding sections, including production terms, production distribution, and mine number and size. Within the last three decades, mergers and acquisitions increased significantly in the coal industry. Currently, the top ten producing companies account for over 67 percent of production. This consolidation of mining companies has important implications for mine operations. Also, coal supply has recently become dominated by publicly traded companies. This situation has created a need to pay greater attention to both stock price performance and public sentiment. About one-third of the supply is from privately held companies. Large companies with a diverse portfolio of mines, mining regions, and markets can better manage the risks associated with mining, shift production between operations, and react to business opportunities. Additional advantages accrue to these companies when they get involved in downstream operations such as transportation, waste disposal, waste use, power generation, and coal use opportunities such as coal-to-liquids.

4.1 Employment

Employment in the mining industry has been steadily declining since the mid 1980s, from a period of steady growth that started in the late 1960s. In 1983, the number of miners employed in surface and underground coal mines was, approximately, 64,000 and 112,000, respectively. These numbers decreased to 37,000 and 65,000 in 1993 (EIA, 2006d). Trends towards increased surface mining, increased production from longwalls, advancements in mining technology, consolidation of mining companies, and closure of small operations have resulted in continued erosion of employment in the coal mining industry. Currently, using 2006 data, about 100,000 miners are employed in U.S. coal mines: 52,000 in underground mines and 48,000 in surface mines (see Chapter 7 for discussion). According to the EIA, 27.5 percent of the total coal mine workforce involves union miners working in 147 mines. The United Mine Workers of America (UMWA) is the largest of the unions, representing about 60 percent of the union miners at 131 mines (NRC, 2007a).

The mean age of the coal mining workforce is just over 50 years, with a median work experience of about 20 years. Over 50 percent of miners have a high school diploma and another 15 percent have some college education (NMA, 2007). When this educational background is coupled with mandatory and other training that is provided, the U.S. coal mining workforce today is well qualified. However, the situation with regard to miners today resembles the conditions that existed in the mining industry in the late 1960s—an aging, experienced workforce poised for retirement and the need for new miners to replace retiring miners and to operate the new mines of the future, as discussed in Chapter 7.

4.2 Mine Productivity

There are several measures of productivity of an industrial process; the productivity of the mining process is no exception. Here, mine productivity is defined as the tons of saleable coal produced by a mine, divided by the employee hours expended in the process of mining and marketing the coal during a defined period of time. Productivity is expressed as tons per man-hour (tpmh). The productivity of a mine is influenced by several factors, including the seam thickness, the method of mining employed, mining conditions (such as depth to the seam, roof and floor conditions, and gas content), equipment conditions and maintenance, worker experience and training, laws and regulations, and management skills. Across the United States, there are considerable differences in all these factors, and hence there is a wide spread in productivity values. The increased introduction of longwall technology in underground mines, increased production from surface mines, the increased introduction of innovative mining practices, the greater reliability of equipment, and the greater share of production from the PRB have been generally responsible for both a steady decline in the number of miners employed in the coal mining industry and a continuous growth in mine productivity since 1975.

According to agencies collecting mine productivity information (MSHA and EIA), productivity at coal mines in 2006 decreased by 1.5 percent to a level of 6.26 tons per miner per hour. Although total productivity declined for the year, surface productivity actually increased from 2005 by 1.5 percent to a level of 10.19 short tons per miner per hour. Additionally, some longwall mines in the east and west have productivity approaching 10 tpmh, the general underground productivity dropped in 2006 by 7.0 percent to a level of 3.37 short tons per miner per hour, resulting in the decrease in total productivity for the year. This shows a continuing trend of steady productivity decline since peaking in 2000 when 11.01 and 4.15 short tons per miner per hour were achieved in surface and underground operations, respectively. Part of the decline in underground productivity was due to difficult mining conditions, challenging reserves, and increased miner hours to comply with new health and safety provisions (MINER Act of 2006).

Changes in regional productivity varied across the United States in 2006, with the largest decline in the Appalachian region (-4.6 percent), a considerable decrease (-3.7 percent) in the Interior region, and the smallest decline in the Western region (-1.4 percent). In the Appalachian region, productivity in 2006 declined to a level of 3.13 short tons per miner per hour; the decrease in underground productivity in the region was 7.6 percent, while the surface productivity actually increased slightly by 0.4 percent in 2006. In the Interior region, productivity declined to a level of 5.10 short tons per miner per hour in 2006, with declines in both underground and surface productivity. The Western region had the smallest drop in total productivity in 2006, to 20.19 short tons per miner per hour. Productivity in underground mines in the Western region dropped by 10.1 percent to 6.77 short tons per miner per hour, while surface productivity increased slightly by 0.3 percent to a level of 25.70 short tons per miner per hour.

4.3 Health and Safety

Increased attention to mine planning and engineering, increased productivity, advances in mining technology, more selective worker hiring and increased training, and improved safety equipment and practices, along with more effective laws and regulations, have made mines safer. The late 1960s and 1970s were characterized by passage of landmark legislation with regard to mine health and safety and by increased demands for stricter mine environmental standards. Chapter 5 provides an expanded discussion of health and safety issues. Over the years, there have been significant improvements in health and safety statistics related to coal mining, such as injury and illness rates, number of disaster events, and number of fatalities. The effectiveness of safety programs is measured in the United States in terms of incidents/events per 200,000 manhours worked. Given that measure, in the mining industry, the fatality rate has declined by 74 percent since 1970 and the injury rate by 71 percent (AFL-CIO, 2007). The number of fatalities and the fatality rate in coal mining has been decreasing over the years, reaching lows of 23 and 0.02, respectively, in 2005. The number of "days lost" injuries and injury rates have also been decreasing, reaching lows of 3062 and 3.51, respectively, in 2005. Substantial progress has been made in the traditional problem areas of roof falls, traumatic injuries, and airborne respirable dust control.

The continued occurrence of disasters, such as explosions, fires, and inundations, and of injuries and fatalities at work, such as from roof fall, materials handling, and heavy equipment, is an indication of the need for increased attention to health and safety conditions at the mines. The situation was never more apparent than in 2006 when the year started out with disasters at the Sago Mine followed by a similar event at the Aracoma Alma Mine No. 1. Both mines were located in West Virginia. There were 45 fatalities in 2006 for a fatality of rate of 0.05. Following the Sago tragedy, Congress enacted new legislation—the Mine Improvement and New Emergency Response Act of 2006 (or MINER Act)—that requires mine operators to develop accident response plans that mandate additional oxygen, improved communications, stronger mine seals, underground emergency shelters, additional mine rescue teams, and enhanced training. The consequences concerning seals, emergency shelters, and rescue teams are yet to be fully determined. There is continued activity in Congress on mine safety legislation.

The accident at Crandall Canyon in Utah in 2007 points to the need for greater attention to mine planning, mine design, and mine monitoring when working under deep cover, a matter likely to be of increased importance as future underground mining is likely to occur at greater depths. Several major coal-producing states, such as West Virginia, Pennsylvania, Kentucky, and Utah, have been assessing their mine safety laws and regulations for revisions in light of the disasters at Sago, Aracoma, and Crandall Canyon.

On the health front, significant progress has been made in reducing the ambient airborne respirable dust concentration in underground coal mines. The prevalence of coal workers' pneumoconiosis or (CWP), greater than or equal to Category 1/0, the earliest stage of the disease that requires reporting, declined significantly from 1987 to 2002 (NRC, 2007b). Although there are no such data on silica exposure, silica exposure in certain coal mine occupations, such as roof bolters in underground mines and drillers on surface mines, have been recognized as a continuing problem. Exposure to noise in the confined underground coal mine environment and to diesel particulate matter also continue to be problems. Furthermore, as the use of chemicals is increasing in the mining industry, the hazards from these substances remain a matter of concern. Issues concerning diesel exhaust, musculoskeletal disorders, and chemical hazards are receiving increasing scrutiny.

4.4 Environment

The global footprint of all mining activity (coal and other mineral resources) is relatively small, on the order of one percent of overall land surface (MMSD, 2002). In the United States, it is about 2.5 percent. Although this proportion is small compared to the footprint of other industries (such as agriculture and forestry), mining, as a temporary use of land, may profoundly impact future social development potential. The small land area covered by mining operations is not representative of the total impacts of both upstream and downstream activities associated with the extraction and combustion of coal. Assessment of the environmental effects of mining operations on other natural and cultural resources and the efforts to reduce, if not eliminate, the negative impacts, are part of the entire process of mine planning, designing, permitting, operation, and closure. Reclamation and rehabilitation refer to activities directed at reducing the impacts of mining and processing operations and are ongoing during mining and after mining has ceased.

The impacts of coal mining on the environment may be felt on and off site, and from the near term to long into the future. The impacts are physical, affecting the land, water, air, wildlife, and vegetation, and economic, affecting the supply and demand of coal, revenues, tax base, and employment. These impacts may have health and safety implications for individuals and for communities. Environmental impacts also arise from operations upstream of mining (such as prospecting, exploration, and development) and from those downstream from mining (such as processing, transport, and use). The impacts may continue after the mine has been closed and rehabilitated. The lifetime of a mine can be quite variable—from a few years to several decades.

All mining operations today are conducted under several state and federal environmental mandates whose broad objectives are to support and regulate the mining operations so as to ensure that environmental standards with regard to air, water, and land are met. In general, today's mining operations are more environmentally responsible than ever before and problems of air, water, and land are being addressed in a manner consistent with applicable laws and regulations, with input from local communities. In fact, in several cases, reclamation plans have enhanced the land use potential of mined lands.

However, the effects of alterations caused by coal mining on the stability of regional ecosystems are not always well understood. Natural conditions, such as the steep topography in Appalachia, require the placement of excess overburden (e.g., spoils) in valleys adjacent to the mine. Subsidence disturbs land above the mines, affecting groundwater flow. Surface subsidence and groundwater hydrology are not easily modeled and create significant controversy. Long-term environmental effects often associated with mining include the use of lands for placement of mine and processing wastes, disruption of the hydrologic cycle, possible loss of biological diversity through deforestation, and limited future economic development potential.

Current concerns about the environmental impact of the upstream aspects of coal mining and coal use will require new approaches to meet the challenges posed, which are discussed further in Chapter 6.

5. EMERGING TRENDS

Review of the growth in U.S. coal production since the 1970s reveals several important trends with regard to the evolution of the mining industry. Coal production in the United States hit a low of around 430 million tons between 1958 and 1961 after hitting a previous record high of 685 million tons in 1944. By 1970, production was again over 600 million tons. Production has been increasing ever since, reaching the one billion mark by 1990. Unless there is a major policy shift with regard to the use of coal in supplying the energy needs of the United States, it would appear that the demand for coal is likely to keep pace with the growth of energy consumption. ***Therefore, coal mining will likely grow in importance in coming years.***

In 1968, coal production was around 545 million tons, with underground mining accounting for 63 percent of the production. Almost 40 years later, surface mining now accounts for nearly 70 percent of coal production. It is almost assured that ***surface mining will continue to be the major supplier of coal in the coming years.*** There has also been an equally dramatic transformation in the application of underground methods of production. In 1968, continuous and conventional mining units represented similar shares of the bulk of underground production, with longwall mining accounting for less than two percent of the underground production. Today, longwall mining accounts for nearly 50 percent of the underground production with continuous mining accounting for most of the remainder. ***Most underground production in the future will likely come from longwall mines.***

Prior to 1960, the contribution of mines west of the Mississippi River was fairly small. Since the 1970s, this contribution has changed rather significantly. Figure 2.10 shows that the growth of production from western mines has been steep. Today, mines west of the Mississippi account for 55 percent of U.S. coal production. ***This increasing production shift from eastern coalfields to western coalfields is likely to continue in the coming years.*** These changes have important implications on the infrastructure needs for transportation of coal and power from suppliers to customers in the future.

It is reasonable to assume that there will always be niche markets for small operators, but it is equally reasonable to assume that the decline in their numbers will continue. The increasing complexity of health, safety, and environmental requirements is expected to have a more severe impact on the small operators. A large measure of the production increases has come from large surface mines in the west and very large underground mines in northern Appalachia. Given the nature of remaining reserves and projected mining conditions, ***there is reason to believe that this trend— increase in large surface operations in the west and large underground mines in selected areas—will continue well into the future.***

Although some major new mines, either surface or underground, have been opened in the last two decades, mine size increases have been accomplished by mining companies incrementally expanding their existing operations. Undoubtedly, such production increases have been aided by enhancements in production methods that in turn were facilitated by advancements in equipment capacities, maintainability, reliability, and monitoring and control. For example, the Bailey underground coal mine was designed with two longwalls to produce a total of around three million tons per year in 1986. Very shortly thereafter, production from the mine was in the six to seven million tons per year range. In 2006, production from Bailey was over 10 million tons. Such increases require the availability of large reserves and extensive additions to underground and surface coal handling facilities. Often, with infusion of capital, technical know how, and new management, acquired mines have been redesigned to increase production and productivity. In the Black Thunder surface mine, production has consistently increased from the initial 25 to 30 million annual tons in 1978 to the current 92.5 million tons in 2007. Such huge increases in production capacity need ready access to and control of large tracts of mineable reserves. If the past is any indicator of the size of future mines, barring major restrictions from availability of mineable reserves, ***future mines will be large in terms of their production capacities.*** Given that observation, an assessment of the ability of present operations to meet the large increases in production envisioned for the future through expansion and of the feasibility of opening very large new mines in a timely manner is required.

The trend in equipment development in the last two decades has been one of growth in size, power, and computer control. Longwall mining has continually used more powerful equipment on wider faces and longer panels, with a greater amount of remote control and automation. In underground continuous mining, which in effect was never continuous, there are a number of developments with regard to miner-bolter combinations, continuous face haulage, and remote control and automation that are likely to enhance production and productivity. Surface mining operations, particularly in the PRB coal field, are relying more on draglines, shovels, and trucks of unprecedented scale. In-pit or near-pit crushing and conveying of sized material from the pit to the load out with belt conveyors is becoming more common. The production and productivity increases of the past have been sustained with these developments even when mining moves to areas with greater stripping ratios. Innovative applications of mining technology, such as cast blasting, shovel and truck combinations in conjunction with large draglines, computer-controlled operations, and the increasing scale of operations, are likely to increase the production and productivity of the PRB operations.
Any prediction on mine productivity must take into account a number of factors such as the current decline in mine productivity, the continuing

impact of MINER Act 2006 and legislative proposals in process, the future production distribution between the regions, the future mining conditions, and the changing work force characteristics. ***As a result, one cannot rule out a continuing decline in mine productivity at least in the short term as was experienced in the 1970s.***

Increased legislative attention to the health and safety issues in mining is likely to continue at both the state and federal levels. The impact of the 1969 Coal Mine Health and Safety Act (CMH&SA) on production, productivity, and costs has been studied by government agencies, independent groups, and coal companies. Although there were many confounding factors affecting coal mine productivity during the 1970s, including the CMH&SA, high oil prices, labor unrest, the 1977 SMCRA, and changing mining technology, there was "pretty much a consensus view that regulatory policies to protect health, safety, and environmental values had a substantial downward effect on coal mine productivity, at least for a limited span of years" (Darmstadter, 1997). The several provisions of the MINER Act, such as improved communications, seals, and emergency shelters, cannot be implemented without much new research, development, and demonstration. ***The additional health and safety requirements in the enacted and proposed laws and regulations are likely to impact mine investment, mine production, productivity, and costs, at least in the short run.***

Concerning environmental issues, in most cases, legal requirements and permitting processes ensure that mine operators reach an accommodation with land owners on issues of underground and surface mining on air, water, land, and other resources by using the best available practices in their operations. However, ***issues such as surface subsidence in northern Appalachia and Illinois and mountaintop mining in central Appalachia continue to be contentious issues.*** Threats to the public's health, safety, and general welfare from coal mine operations, although generally under control, continue to be a problem, in particular, issues of surface blasting, impoundments, and waste piles. These environmental issues still evoke opposition to opening mines. The increasing concern with global warming and the contribution of coal mining and coal burning to greenhouse gas emissions is important to the coal mining industry. The public's reaction to siting coal power plants in their states is becoming more intense. Although it is not clear as to what the U.S. policy will be, it is evident that ***any action on carbon constraints will affect the demand for coal or at least increase the cost of using coal as an energy source.***

Coal use is increasing worldwide and seaborne coal sales are expected to continue rising. It is not clear how these trends will impact U.S. domestic coal production. The United States has not been a major player in the import or export of coal (e.g., NRC, 2007a); imports and exports account for a small component of coal production or use in the United States. However, coal exports have increased in the past few years and are expected to continue to do so. According to the *New York Times*, exports increased from 49 million tons in 2006 to 59 million tons in 2007, and the United States is expected to export 80 million tons in 2008—seven or eight percent of its coal production, up from about five percent in 2007 (Krauss, 2008). According to Gregory H. Boyce, chairman and chief executive of Peabody Energy, "The export boom right now is the difference between slow growth in our markets and hyper-expansion in our markets" (Krauss, 2008).

Exports have a pronounced impact on pricing, at least in the short term. The largest increase in consumer prices was in the coking coal sector. The limited availability and tight specifications needed for coal to produce coke influence the price. High international prices for exported metallurgical coal

BOX 3.3 PRAIRIE STATES ENERGY CAMPUS

The involvement of mining companies in downstream operations is exemplified by Peabody's Prairie State Energy Campus in southern Illinois, with a capital investment of around $2 billion. In the complex, a 1,600-megawatt generating plant will be supported by a new six million ton per year coal mine.

Prairie State is being built in Washington County, Illinois, and will be among the cleanest U.S. plants. Emission rates are expected to be approximately 80 percent lower than existing U.S. power plants. Carbon dioxide emission rates will be approximately 15 percent lower than the typical U.S. coal plant.

This project, a cooperative effort between state and private industry, is slated to generate power by 2011. Several mines will share the large preparation plant and load-out facilities to realize economies of scale. The mine and power plant will create more than 500 permanent jobs and will inject nearly $125 million into the region's economy each year, according to a recent study by researchers at the University of Illinois at Urbana-Champaign.

throughout 2007 and 2008 also affected both metallurgical and steam coal prices in the U.S. market.

The vibrant export market has also impacted coal imports into the United States, as traditional exporting countries such as Colombia and Venezuela have shifted focus to other markets to take advantage of higher prices. According to Krauss (2008), the impact of this shift has caused further tightening of coal supplies in the eastern United States, where increased regulations and mine closings have limited output in recent years.

In an effort to be a part of the emerging world coal export market, several U.S. companies have ventured into coal operations in Asia, Africa, South America, and Australia. Several other companies are engaged in developing a bigger market for their metallurgical-grade coals. Coal companies have also entered into partnerships with companies involved in coal-to-liquids or other methods of coal use so as to be a part of the larger coal system.

Coal companies are increasing efforts to work with communities to enhance the sustainable economic development of mining areas. Although the concepts of industrial ecology and development of energy complexes have not taken deep roots in the coal industry, the opportunities are worth exploring. This research is particularly true in areas where low-cost energy, industrial steam, clean water/recreation amenities, transportation networks such as highways and rail, and bulk storage capacity offer the opportunity for energy park developments.

6. MAJOR FACTORS AND CHALLENGES

Two primary factors need to be addressed to evaluate production plans for the coal industry of the future. The first is acknowledging that the projected demand for coal to the year 2030 will materialize. The second is industry's ability to meet anticipated production. There is a good chance that the demand for coal will grow at a rate exceeding 1.2 percent a year for next 25 years unless there are sudden developments in the economy and energy supply that would negatively affect the coal industry. The increase in production from the current 1.16 billion tons to 1.6 billion tons by 2030 will require the opening of new underground and surface mines.

The process of opening a new mine is long and complex. It involves gaining access to properties that contain sufficient mineable coal without any pre-emptive environmental issues, securing a market commitment for a substantial fraction of the production from the property, producing a bankable document of mining and marketing plans, obtaining the necessary clearances and permits to open a mine from all relevant agencies, and starting and completing construction and development phases on time. In some cases, this process has taken 15 or more years. As such, there is an urgent need to examine specific factors that would have significant impact on decisions to open mines.

Further, this increase in production has several implications for the mining industry. The ability of the mining industry to sustain and improve on production and productivity will be determined by the quality and quantity of reserves, the ability to attract capital and labor to open new mines, the changing environment with regard to health, safety, and environmental regulations, and developments in mining technology. The downstream aspects of waste handling, transportation, and use are all important. Their planning and execution are vital for the mining industry to meet its targets. The major factors and challenges that are likely to confront the coal mining industry are briefly discussed below.

6.1 Coal Resources and Reserves

It is often cited that United States has 27 percent of the world's coal resources and possibly adequate coal reserves to meet the U.S. coal production demand for the next 200 years. Such statements often ignore the amount of exploration required to outline a reserve and determine the economically recoverable coal from a coal seam or an area. This issue has been discussed in detail in Chapter 2.

6.1.1 COAL QUANTITY AND QUALITY

Site-specific exploration is needed to define the quantity (tonnage) of economically recoverable reserves and the quality (e.g., Btu, sulfur, and saleable coal) with assurance. As better deposits are being exploited, the coal seams that are available to mine in the future are more likely to have unfavorable depth, thickness, mining conditions, and quality parameters. Increased processing of raw coal to produce a marketable product may be necessary. Thinner seams are generally more difficult to mine. Also, modifications to longwall mining equipment for application to thin seams are required. Deep seams are usually associated with higher gas and greater roof control problems. In surface mining, increasing stripping ratios will increase spoil handling problems and the mining cost.

6.1.2 REGIONAL IMPACTS

The impact of the distribution of the current reserve is likely to be more problematic on a regional basis than on a national basis. The central and southern Appalachian reserves are less likely to have the potential for very large mines. Because of extensive mining activities in the past and the high cost of underground and surface mining at present due to seam conditions and topographical considerations, the central Appalachian reserves are less likely to contribute extensively to future demand. In fact, there is little projected growth in Appalachian coal production from 2004 to 2030 (from 403 million tons in 2004 to 412 million tons in 2030). According to EIA predictions, the Appalachian Basin has been mined extensively, production costs have been increasing more rapidly than in other regions, and low-cost western coal continues to gain market share east of the Mississippi River. Further, productions from Western and Interior regions are projected to nearly double over the same period. The PRB reserves are favorable among the available reserves, though even here the coal seams will be at a greater depth. Although large tracts of northern Appalachian reserves are committed under supply contracts, they also represent good potential for the immediate future.

6.1.3 ADEQUACY OF RESERVES

Chapter 2, "Coal Resources and Reserves," raises a number of questions on published reserve numbers. It is sufficient to state that whatever demonstrated reserve figures are available, it is necessary to account for loss due to mining. The net marketable tonnage as compared to the in situ tonnage therefore is much smaller, on the order of 30 to 50 percent. In room and pillar methods, the most one can recover as raw coal may be 40 to 60 percent of the coal in a block. With longwall mining, this recovery may increase to 70 to 80 percent. The need for an expanded program of characterizing reserves that are likely to be mined by underground methods in the future to ensure a supply of quality coal cannot be overemphasized. Although surface mining does not result in as much resource loss as underground mining, greater depths of surface mining would create conditions where coal recovery may be affected.

Geological abnormalities result in unmineable areas, and previously mined areas need to be better located to ensure safe mining. Expected thinner seams, seams with partings, and poorer strata control conditions will result in more difficult mining conditions. There is a need to enhance reserve characterization at both enterprise and national levels through the application of existing advanced exploration techniques. The parameters of reserve characterization should be expanded to include documentation of conditions that have been identified as being critical to future mining.

6.2 Mining Conditions

Future mining conditions are likely to differ from those today. Changes in mining conditions will likely have an impact on production increases and productivity. In the eastern United States, coal seams that need to be mined are deeper, gassier, and thinner. Further, seams that are below or above previously mined seams are required to be mined. The quality of raw coal is likely to be poorer, and raw coal will require greater preparation for marketability. In the PRB, mining depths will increase, resulting in higher shipping ratios and larger areas of land affected by mining.

6.2.1 THICK AND THIN SEAMS

Thick seams are a gift of nature. When present near the surface, as in the PRB, they contribute to rapid growth of production and productivity. When they are sufficiently deep, their exploitation presents significant challenges. Traditional practice has been to extract the best part of the seam and leave behind the rest. For example, it is not uncommon to mine only 12 to 20 feet of a 50-foot-thick seam. In addition to a permanent loss of coal, the coal left behind can occasionally pose serious safety and environmental problems, particularly if it spontaneously combusts or contains acid-forming materials.

Although it is possible to extract by surface mining several thin seams that are near surface, deep thin seams present challenges to extraction. The cost of mining increases rapidly as the capital investment and fixed costs are generally the same irrespective of seam thickness. Further, dilution increases as mine roadways have to be driven to a greater height than the coal seam to accommodate men, equipment, materials, and transportation. This situation creates a need for greater coal cleaning and larger associated waste disposal facilities. The ergonomic aspects of working under thin seams require careful consideration to avoid awkward postures for long time periods. In fact, increased use of remote control and automation is a desirable goal for the exploitation of thin seams.

6.2.2 DEPTH OF WORKINGS

Many seams that will be mined in the future are likely to be deeper than currently exploited seams. For seams that can still be surface mined, the increasing stripping ratios mean larger overburden handling and higher costs. Handling larger amounts of overburden presents environmental challenges and increases production costs. A major technical aspect is the stability of the benches in the solid and the spoil. Hydrological issues will also be important. In addition to the effect of coal production on water quality and quantity, water affects the site's stability.

In underground mining, deeper seams are usually associated with greater amounts of gas liberation during mining. Strata control also becomes more difficult in this environment, and there is less flexibility with regard to materials and personnel transport. Seams at great depth are advantageously mined by the longwall method, though longwall gate road and panel design must negotiate the large abutment pressures that are encountered at greater depth.

6.2.3 GROUND CONTROL AND VENTILATION

Two major aspects of operating a mine safely are ground control and mine ventilation. From the discussion above it can be concluded that, as underground mines go deeper, the problems due to ground control and mine ventilation are likely to be more severe. These problems have been experienced at deep operating mines in Alabama, Virginia, Colorado, and Utah. Greater depth increases ground pressures on pillars and workings. The number of entries, the width of entries, and the size of pillars need to be so designed so as to ensure stability during first mining and second mining. Longwall is usually the chosen method for extraction purposes. Investments in access facilities and costs of ground control are therefore likely to be higher as depth of cover increases. Deeper seams will require greater attention to methane emission control during mining. Methane drainage prior to and during mining may be required to keep emissions under control. From an environmental point of view, the subsidence aspects of mining deeper seams need to be evaluated carefully. Full extraction at depth has the potential to impact larger surface areas.

6.3 Mining Technology Development

Larger and more powerful mining equipment has been the most significant technological development in surface and underground mining. Equipment improvements have allowed mining operators to develop operating practices (e.g., cut plans, mine layouts, and operating schedules) that have led to more production time and less idle and delay times. Coal mining equipment developments have generally followed an evolutionary path rather than a revolutionary path. There have been no new dramatic developments in the methods of underground and surface mining during the past half a century, even though the methods have successfully incorporated advancements in equipment technology. An experienced workforce is a definite asset in introducing the new equipment and practices. It is doubtful if incremental and evolutionary practices will be enough to sustain, let alone increase, production and productivity gains in the wake of more difficult mining conditions.

6.3.1 MINING COMPANIES

In general, mining companies focus on identifying bottlenecks in operating practices and improvements to equipment design that would benefit health, safety, and productivity. Increased applications of deep-cuts, super sections, and miner-bolter combinations in room and pillar continuous mining are good examples of companies leading the introduction of more productive practices and innovative equipment applications. In longwall mining, increases in panel sizes, enhancements in the longwall cut plans, and improvements in move times were also evolutionary. Investment in research and development that is needed to develop new equipment and practices for thin seam or thick seam mining is generally not a high-priority item for mining companies.

In surface mining, companies have generally adopted the latest equipment and technology available to move enormous volumes of materials. Operators have increased the use of sensors, automated sequences, computer control, and global positioning systems for their large equipment. Yet, there is a need to develop better fragmentation techniques (explosives) and cast blasting techniques to enhance mining performance. There have been limited efforts in developing continuous mining or materials movement technologies for surface mining.

6.3.2 MANUFACTURERS

The number of mining equipment manufacturers serving the United States and worldwide mining industry is limited. In fact, due to the small and specialized market for underground equipment, the manufacturers of major production equipment for this sector have been through a process of acquisition and consolidation in the United States and the rest of the world. However, they play an important role in technology transfer of productive practices to all mine operators; they work with selected operators or conduct research funded by public sources to modify their existing lines of equipment. Production equipment manufacturers are also involved in developmental work to increase the strength, durability, and maintainability of their equipment so as to position themselves in a more competitive situation in the limited mining market.

Surface mining technology has benefitted from the fact that the massive earth-moving operations associated with many large civil engineering works are, in some cases, similar to those of large surface mines. Major suppliers of surface mining equipment are often the suppliers of major earth-moving equipment for other industries. Even many of the reclamation and revegetation practices in surface mining are similar to those in agriculture. Therefore, several manufacturers who provide surface mining equipment have a large market outside of the mining industry. Mining equipment development benefits from research and development performed for other industries. Nonetheless, there are equipment types that may need special attention, including draglines, loaders, and trucks and the specialized parts associated with the equipment. The mining worksite also introduces limitations to equipment deployment in view of the clearances that are required for larger and larger equipment.

6.3.3 GOVERNMENT-SPONSORED RESEARCH

Federal government involvement in technology development for the mining industry often is limited to the mission and scope of individual government labs. In the area of mine production technology, this involvement, for all practical purposes, is non-existent. The NRC (2007a) report on research and development needs clearly discussed and presented recommendations on this topic. Prior to 1995, the U.S. Bureau of Mines had an advanced mining technology group and more recently (prior to 2007), the Department of Energy (DOE) was supporting an "Industry of the Future" initiative for the mining industry. However, these efforts were not solely directed at coal mining but pertained to the entire mining sector. Given the high risk and high cost of mining technology research and the need for new technology to go after deeper and thinner or thicker reserves, the ability of individual mining companies or manufacturers to advance beyond incremental improvements in technology is limited. There is a need for greater involvement and support of mining technology research by the federal and state agencies and the coal industry (NRC, 2007a).

Because of changes in coal reserve characteristics (thinner, deeper, gassier) and the changes in operating environment (health and safety laws, environmental laws, and newer workforce), there will be a need for increased use of remote, automatic, and autonomous control of mining equipment. New technology will be needed for both surface and underground mining, and for thin and thick seams. In the current economic climate, it will be difficult for mining companies and manufacturers to contribute extensively to new equipment development. Fortunately, growing hardware and software developments elsewhere are likely to benefit the mining industry. Research, development, and demonstration will be required for their introduction into the mining industry, as the environment and culture of mining applications are quite different from those in other industries.

6.4 Health and Safety Issues

Reference has already been made to the MINER Act of 2006. New technology needs to be developed to enhance communications, miner location, and miner refuge underground in the event of a disaster. In general, mine production and productivity are negatively affected, at least temporarily, when health, safety, or environmental laws change. This situation was experienced when the CMH&SA and SMCRA were passed in 1969 and 1977, respectively. After a period of adjustment, production and productivity not only recovered to past levels, but has continued to rise. It is very likely that the current concerns about health and safety will affect the coal industry's productivity, production, and cost in the short term.

There is every indication that there will be more action on the health and safety front at both federal and state levels. Another important factor that should not be overlooked is the potential for increased health and safety hazards whenever there are changes in mining operations or practices, such as by the introduction of new equipment, exploration of virgin areas, development of new practices, and the influx of new workers.

The passage of new laws at the state and federal levels is likely to have major consequences for the operation of current and future mines. Although there is increased funding for development of technological solutions to some of the prescriptions in the new laws, such as communications, rescue, and refuge chambers, it is clear that future mines will have to meet more stringent provisions with regard to mine seals, miner training, rescue teams, and communications. It is also expected that small operations will find it more difficult to meet the requirements of the new laws.

In this context, the aging of the workforce is a major concern for the mining industry. Timely recruitment and training of young workers will be required for both the replacement of retiring workers and new hires that will be required for the new mines that are projected. Chapter 7 discusses personnel issues in more detail.

6.5 Environmental Issues

In the future, as in the recent past, mining will be affected by environmental regulations that are omnibus (like the Clean Air Act and the Clean Water Act) and industry-specific (such as SMCRA). Continued tightening can be expected in all aspects of environmental control, from mine opening, to mine operations, to mine closure. However, as discussed before, in underground mining, there are unresolved problems with subsidence and subsidence-associated problems such as hydrology. The impact of local disturbances created by surface mining on regional ecosystems is not well understood. For example, resolving the issue of mountaintop mining is important to West Virginia and Kentucky. Loss of production and associated employment in communities and the sterilization of mineable coal reserves are often the negative consequences of abandonment of mining due to environmental consequences. The past history of abandoned mine lands and impoverished communities around mining districts has caused some communities to oppose opening new mines and constructing power plants.

According to the recent NRC (2007a) report on coal, of the many factors that influence coal use, its environmental impact, especially its contribution to carbon dioxide emissions associated with global climate change, pose the greatest potential constraint. Uncertainty associated with policies to control carbon dioxide emissions can itself constrain future coal use, which affects coal mining.

6.6 Interruptions to the Supply Chain

The coal supply chain is the result of a complex relationship among the producers (coal companies), consumers (power companies), transporters (rail, water, electrical power, and other transportation companies), government actions (health and safety, environmental, and other laws and regulations), and the public. Although coal supply is relatively stable, unexpected supply or market surges or interruptions can impact the supply-demand balance, causing increases in demand and, at least in the short term, significantly increasing coal prices. The recent disruption caused by transportation and weather problems in Australia is a good example of what could occur in the United States (Oster and Davis, 2008).

Threats to the assured coal supply of 1.6 billion tons by 2030 can arise from several sources, including challenging coal reserves, the location of consuming markets, transportation infrastructure, the lead times to open new mines, the large capital required to build new energy complexes, and the attractiveness of export markets. Continued uncertainty about the role of coal in the future energy supply and, therefore, the nation's commitment to increase production, will have a serious impact on whether mining companies can secure capital and open new mines in a timely manner. Even if the financing problem is resolved, the reserves to be mined still need to be identified and the necessary permits obtained, which can take several years to over a decade.

The limited number of mining equipment suppliers can lead to further problems for the mines by delaying the equipment and supplies in time to mine and process the coal. Recent market surges have demonstrated that a significant backlog of orders can quickly develop, which can affect the mine development schedule. In most cases, mines rarely carry excess equipment and rarely have excess capacity to handle huge production increases, except for short periods of time, to meet the growing demand without additional development of facilities. Mining companies will likely continue to evolve mining systems that will make operations less sensitive to these interruptions (such as employing in-seam crushing, conveyor transport, more automation and remote control, and adequate storage for raw and processed coal); the need to ensure adequate capital and operating supplies and suppliers could be a major concern.

Other supply-chain issues arise from the aging workforce and the coal transportation network. The shortage of technical workforce that will emerge, if the present situation is not properly addressed, can result in production, productivity, and health and safety problems. The major issues with transportation in the United States will be the ability to take western coal to eastern markets through an adequate maintenance and upgrade of the present rail transportation network. The problem of increasing capacity is one that has to be resolved in a timely manner by rail operators, mining companies, and government agencies.

6.7 Community Resistance

Given the legal requirement for environmental protection and the progress that has been made in the areas of air, water, land, and aesthetic restoration, many community concerns about coal mining have been addressed. In Appalachia, the opposition to mountaintop mining and valley fills is one area where community opposition remains high. In other areas of the country, concerns about subsidence and hydrological impacts, and air quality, have created controversy. Additionally, the contribution of coal mining to greenhouse gas generation (methane release during coal mining and processing, and carbon dioxide from burning coal) and therefore to global warming are beginning to be critically assessed. More detailed discussion of these issues is provided in Chapter 6.

This report does not address environmental issues related to coal usage. However, opposition to coal usage has mobilized community involvement in coal mining development and permitting. Unless the uncertainty with regard to carbon dioxide emission control is resolved, either through policy or technology, greenhouse gas emissions from coal-fired power plants is likely to become a major issue that can impact coal mining.

A number of U.S. coal producers are involved in sustainable development activities, including economic support of communities and regions, and environmental protection and restoration. These companies have corporate sustainable development policies and guidelines in place that provide guidance for operations and community involvement. Some key components of determining how coal mining and related activities can be conducted in a sustainable manner include issues related to the environment, such as the establishment of post-mining land uses; the development of a skilled workforce in the areas where mining occurs; the development of community infrastructure, including educational resources, as a part of the mining operation and post-mining reclamation; and the realistic assessment of the life of remaining reserves and mining activity.

6.8 Additional Issues

Coal mining is but one component of the total coal system. There are a number of other upstream and downstream components, such as exploration and transportation, that can have a significant impact on the opening of new mines. Rail transportation, for example, is key to delivery of the projected increases in production from the Western region to markets in the east and south. It is necessary for rail operators, mine operators, and government agencies to work together to increase capacity through the addition of rail lines. Although not as critical, transportation by water is important to several eastern states and requires, at least, adequate construction and maintenance to be able to function effectively in the future.

Similarly, the potential for the development of alternative energy sources affects the demand for coal. For example, there is considerable interest in the government, industry, and society to search for energy sources, such as ethanol, wind, solar, geothermal, biomass, and hydroelectricity, as alternates for not only imported oil but also coal. The contribution of nuclear energy to U.S. production has been increasing through increased plant utilization, and there appears to be support to further increase the number of nuclear plants in operation. In recent years, the contribution from renewable energy sources has also been growing. Various sources of renewable energy have the potential to grow incrementally from their current positions, particularly if the conditions for coal use are unfavorable or become costly. On the other hand, a factor for increased coal use is the conversion of coal to liquids, which government forecasters and industry groups predict will grow to an extent that it will become the second largest use of coal by 2030.

7. CONCLUSIONS

This chapter discussed in detail the main factors and challenges impacting coal extraction in the United States. The issues and challenges that confront the mining component of the coal system with regard to reserves, mining conditions, health and safety, environment, and technology are discussed in other chapters. In several cases, these issues and challenges are likely to have a negative impact, at least in the short term, on permitting, production, productivity, and cost performance of the mining component. The issues and challenges are further exacerbated due to uncertainties arising from the following:

- Wide range in the forecast of demand for coal to the year 2030
- Future direction of mine health and safety laws and regulations
- Mining conditions in the future, particularly for underground mining
- Meeting the technological developments needed for the future
- Future direction of environmental regulations, particularly CO_2 control
- Current climate for acceptance of coal-fired power plants

To minimize uncertainties, industry, government, and the public need to work together. There is also potential for long-term interruptions to the coal supply chain because market response by mining companies is affected by the long lead times needed to plan, finance, permit, and develop a mine.

The recommendations below relate to mining technology and resource optimization:

- ***Reduce the uncertainties associated with mining conditions.*** This recommendation addresses the needs of existing mines and new mines. Accurate prediction of mining conditions is essential for a productive and safe operation. Exploration and conversion of resources to reserves, whether expanding existing operations or opening new mines, is essential in the face of depleting reserves in current operations. As mining in the future is expected to move into virgin areas, the importance of intense and detailed exploration cannot be over emphasized. New remote-sensing and in-seam geophysical exploration techniques that are applicable to mining need to be developed.

- ***Develop new mining equipment and mining technologies.*** In underground coal mining, longwall mining should be adopted wherever applicable, although it is clear that the technology for mining thin or thick seams in the western United States with longwall has not yet been developed and deserves critical attention. In continuous mining, current methods are not truly continuous due to the intermittent haulage system and the need for frequent moves from working faces to support the roof. Continuous mining will remain as the main method of extraction for seams where longwall is not applicable, and improved methods are developed for mains, sub-mains, and gate entries in longwall mines. Better integration of coal cutting, roof support, and coal clearance unit operations is required to a truly continuous mining operation. Further development and increased introduction of automatic mine monitoring systems for air, water, ground stability, and other items are needed for enhancing health, safety, productivity, and production.

  To reduce the ergonomic stresses that accompany working in thin seams, it is necessary to develop automatic and autonomous controls on underground mining machinery.

  Surface mining developments have been characterized by an increase in the size of equipment. Greater surface mining production, productivity, and safety can be achieved through the introduction of continuous mining methods in surface mining. Although continuous excavators and belt conveyors have been successful applied in a few instances, development of equipment and systems that would be applicable in the United States is necessary. There is a need for mining companies and equipment manufacturers to pool their resources to advance innovative ideas at the design and prototype development stage. Government involvement through programs such as the now eliminated Department of Energy's "Industries of the Future" is needed to bring additional resources to further these ideas.

- ***Address changing mining conditions.*** Changes in the physical mining environment, such as depth and thickness of the coal, will result in a number of changes in mining conditions—gas, heat, and ground stresses. Existing equipment or new equipment in these changed physical conditions also create new hazards. The anticipated replacement of older and retiring workers with new workers will bring a new set of conditions and requirements. The adaptation to new laws and regulations and to new equipment and processes will have to be managed. New equipment, including several new personal protective devices, has to be researched, developed, and demonstrated. There is also a need to increase funding for mine health and safety research, as discussed in Chapter 5.

- ***Develop energy complexes.*** It is well accepted by industry that future coal mines, particularly in the Appalachian and Interior regions, may have to be developed to exploit reserves that are less attractive. Such future reserve blocks are likely to be smaller, thinner, and deeper, of inferior quality, and located farther from transportation and other infrastructure facilities. To economically justify mining these reserves and to enhance economic performance while attaining production and productivity targets, it may be necessary to capitalize on synergies associated with integrating facilities and plants into energy complexes. The opportunity of creating polygeneration facilities that may include traditional and alternative fuels and products and incorporate renewables and biofuels sources as part of the mix, offers great potential for such integrated energy complexes.

- ***Promote engagement with local communities.*** The mining industry today must clearly understand that local communities and people who are affected by a mining operation must be engaged at a much higher level and through a process based on respect and dialogue. The coal mining sector must create opportunities and seek out engagement with communities so as to achieve the desired outcome—ensuring that local community concerns and aspirations are important elements of mining planning, development, and post-mining land use. The industry must transition from an information-sharing, crisis-based, and defensive mentality to one that promotes proactive dialogue, transparency, and participation among all stakeholders. Successful strategies to promote engagement include patience and trust-building, openness and transparency, respect for traditional structures and practices, and delivering on promises.

Chapter 4 Coal Preparation

1. SUMMARY

Coal processing technologies play an important role in the electrical power supply chain by providing high-quality fuel for coal-fired utilities and industrial boilers. At present, more than one-third of the coal tonnage consumed in U.S. coal-fired power plants is prepared for market by coal processing facilities. Modern processing plants incorporate a complex array of solid-solid and solid-liquid separation processes. These processes remove unwanted impurities such as ash, sulfur, and moisture from run-of-mine (that is, unprocessed coal) feedstocks in order to improve coal utilization properties. Examples of separation technologies used by the coal industry include screening, classification, dense medium separation, gravity concentration, froth flotation, centrifugation, filtration, and thickening. Several of these processes also play an important role in environmental control for the preparation facility.

This chapter provides a brief overview of some of the technological systems used in coal processing and discusses the current state of the industry in the United States. The purpose of this discussion is to provide a fair and balanced examination of benefits resulting from coal preparation activities as well as issues associated with the sustained operation of coal processing facilities. The information provided in this document was compiled from a wide range of sources, including industrial mining companies, process equipment manufacturers, environmental organizations, governmental agencies, and a variety of technical reference sources.

The analyses performed in this study suggest that coal preparation will continue to have a significant impact on the cost, recovery, and quality of coal produced in the United States. However, these analyses also suggest that improvements in separation technology and practices are needed to provide further reductions in waste generation and downstream environmental impacts. In many cases, these improvements may also generate revenue from the recovery of usable coal from waste streams, which could provide a financial incentive for private companies to pursue these activities. Recommendations that may lead to these improvements include: (1) development of improved technologies for solid-solid and solid-liquid separations that impact coal productivity and waste reduction; (2) development of new and improved methods for online analysis of coal quality and plant optimization; (3) development of next-generation upgrading systems, including mild conversion processes, that are suitable for improving the quality of western coals in water scarce regions; (4) streamlining of permitting protocols for facilities designed to recover coal and reclaim abandoned refuse and impoundment areas; (5) support for expanding and updating the database of cleanability data for U.S. coal reserves; and (6) support for training and education of a balanced workforce of laborers, technicians, and professionals capable of running sophisticated plant processes.

2. INTRODUCTION

2.1 Background

2.1.1 WHAT IS COAL PREPARATION?

Coal preparation, which is also called washing, cleaning, processing, and beneficiation, is the method by which mined coal is upgraded in order to satisfy size and purity specifications dictated by a given market. The upgrading, which occurs after mining and before transport of the cleaned product to market (Figure 4.1), is achieved using low-cost, solid-solid and solid-liquid separation processes that remove waste rock and water from the mined coal. The processing is driven by a desire to reduce freight costs, improve utilization properties, and minimize environmental impacts.

2.1.2 WHY IS COAL PREPARATION NEEDED?

Coal preparation is required because freshly mined coals contain a heterogeneous mixture of organic (carbonaceous) and inorganic (mineral) matter. The inorganic matter includes noncombustible materials such as shale, slate, and clay. These impurities reduce coal heating value, leave behind an undesirable ash residue, and increase the cost of transporting coal to market. The presence of unwanted surface moisture also reduces heating value and can lead to handling and freezing issues for consumers. Therefore, essentially all coal supply agreements with electrical power stations impose strict limitations on the specific energy (heat), ash, and moisture contents of purchased coal.

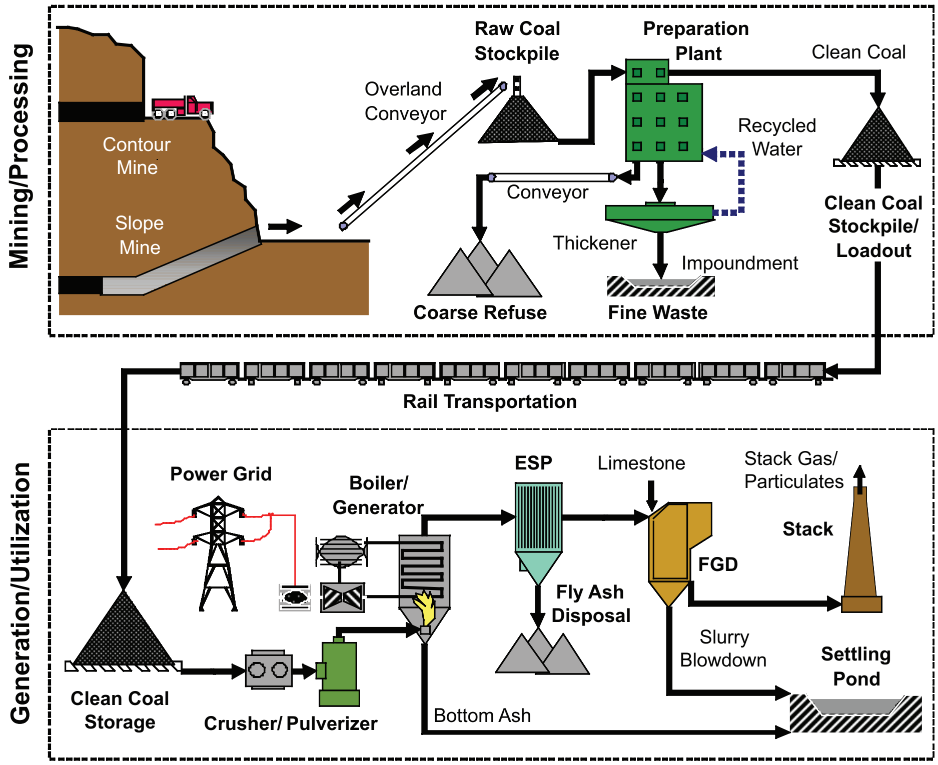


FIGURE 4.1 As the first step in quality control, coal preparation has a large impact on transportation demands, boiler performance, and emission controls.

2.1.3 COAL WASHABILITY

The capability of coal preparation to improve coal quality varies widely from site to site. The most significant part of this variation occurs because of inherent differences in the liberation characteristics of run-of-mine coals. The degree of liberation is determined by the relative proportion of composite particles (i.e., particles of coal and rock that are locked together) that are present in a particular coal. The presence of composite particles makes it impossible to physically separate all of the organic matter from all of the inorganic matter. Consequently, plant operators purposely sacrifice coal recovery by discarding some composite particles as waste to improve coal quality to a level that can meet customer specifications. This loss often accounts for 10 to 15 percent of the heat value contained in the source coal (Figure 4.2).

Coal preparation operations make it possible to meet coal quality specifications by removing impurities from run-of-mine coals prior to shipment to power stations. Moreover, as the first step in the power cycle, coal preparation plants improve the environmental acceptability of coal by removing impurities that may be transformed into harmful gaseous or particulate pollutants when burned. These pollutants typically include particulates (fly ash) and sulfur dioxide (SO_2), as well as air toxins such as mercury. The presence of mineral impurities can also influence the suitability of coal for high-end uses such as the manufacture of metallurgical coke or generation of petrochemicals and synthetic fuels. Coal preparation is typically needed to achieve the levels of coal purity demanded by these secondary markets.

2.1.4 ORGANIC EFFICIENCY

Coal washability has a tremendous impact on how effectively a preparation plant can upgrade a particular run-of-mine coal. Separating densities in a plant are often set in response to changes in coal washability to ensure that product coal continues to meet quality specifications. However, the types of processes employed and practices used for operation and maintenance can also greatly influence

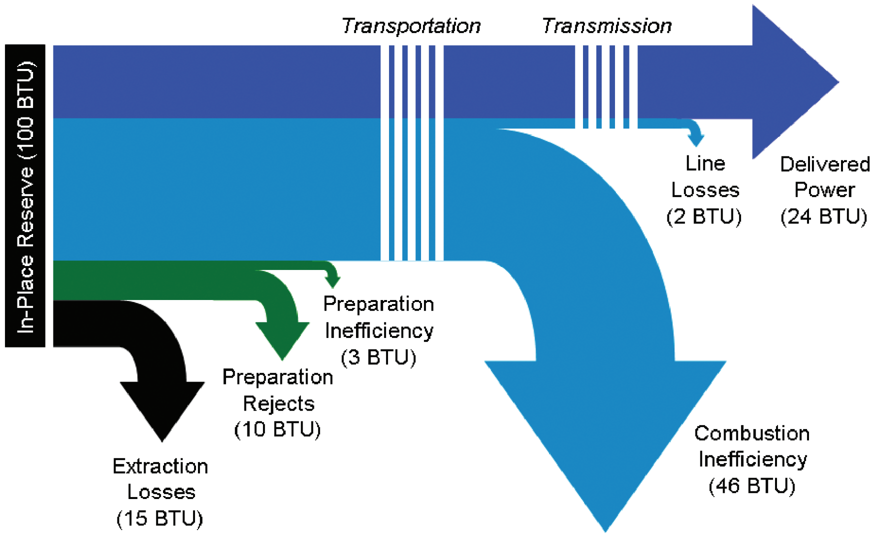


FIGURE 4.2 Flow diagram comparing in-place heating value to delivered power. (Note that combined losses for mining extraction and coal preparation exceed that of the delivered power.)

The large financial impact of poor efficiency has pushed the industry to abandon old technology and to develop and adopt new processes and practices for cleaning run-of-mine coals. Labor-intensive methods such as manual sorting via hand picking were employed by many mine operators during the early part of the twentieth century in an attempt to deal with increasing amounts of rock in their coal seams. This inefficient approach was soon replaced by simple mechanical separation processes that reduced misplacement and provided higher levels of productivity. These early "washers" typically cleaned only the coarser particles (usually larger than one fourth inch) and either recombined the untreated fine particles, or "fines," back into the washed product or discarded the fines as a waste product. These inefficient systems dumped large tonnages of coal into waste piles, some of which are being remined and reprocessed today. These historic periods were followed by many decades of technology development that ultimately led to the design and operation of relatively efficient plants that are capable of complete or partial upgrading of the entire size range of mined coals. Many modern coal preparation plants now in operation in the United States are as complex as industrial facilities once employed only by the chemical processing industry.

the performance of the preparation facility. This effectiveness is typically reported as organic efficiency, which is defined as the yield of coal product produced by the separation divided by the theoretical maximum yield of coal that could be achieved at the same ash content according to a washability analysis. Organic efficiencies may be in the high ninetieth percentile for well-designed and well-run operations, although lower values are not uncommon for problematic plants. These inefficient processes or practices misplace significant amounts of potentially recoverable coal into waste and rock into the washed product. Although this misplacement is typically small in comparison to losses created by washability constraints, these inefficiencies have a large impact on plant profitability (Akers and Cavalet, 1988). For example, consider a hypothetical "perfect" plant producing 500 tons per hour of product coal at a profit of two dollars per clean ton ($40 per ton sales price). A decrease in organic efficiency of just one percentage point would reduce the clean tonnage by five tons per hour, which would reduce revenue by $200 per hour (e.g., $40/hr x 5 ton/hr). As such, the loss of just one percentage point in efficiency lowers the hourly profit from $1,000 down to $800 per hour—a decrease of 20 percent.

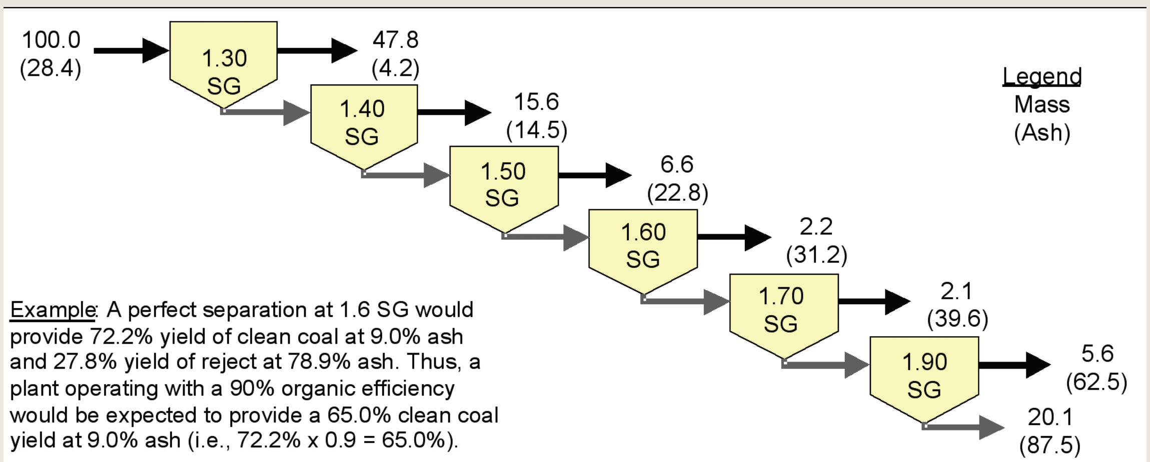
2.1.5 GENERIC FLOWSHEET

Despite the perception that coal preparation is a simple operation, it has become far more complicated than most realize. Plant flowsheets can be generically represented by a series of sequential

BOX 4.1 COAL WASHABILITY ANALYSIS

The theoretical trade-off between coal recovery and quality can be quantified in the laboratory using float-sink (washability) analysis. An example of experimental data collected from a float-sink analysis is shown below. The analysis is performed by sequentially passing a coal sample through flasks containing liquids (usually organic) of increasingly higher densities (ASTM International, 1994). The density is normally reported in specific gravity (SG) units, which is simply the density of the substance divided by the density of water. Pure coal has a relatively low density (SG ≤1.3) and is collected as a float product from the first flask, whereas pure rock is much denser (SG ≥2.2) and is collected as a sink product from the last flask. Composite particles report as float products in the intermediate flasks containing liquids with densities between that of the first and last flasks. After density partitioning, the products from this procedure are then dried, weighed, and analyzed for quality (e.g., ash, sulfur, mercury). Float-sink data are very useful for predicting and analyzing the performance of coal preparation plants because most cleaning processes separate coal and rock based on differences in density.

Example of float-sink (washability) analysis for a 28.4% ash run-of-mine coal.



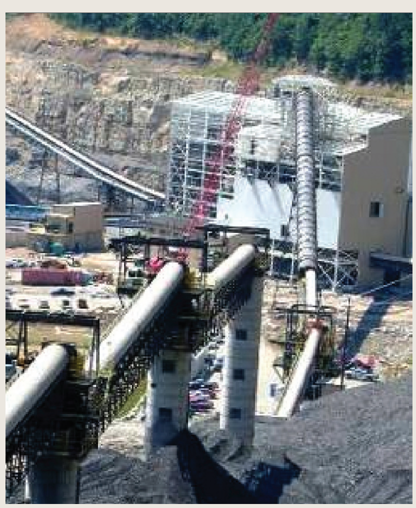
				CUMULATIVE FLOAT		C SINK	
SPECIFIC GRAVITY		MASS	ASH	MASS	ASH	MASS	ASH
SINK	FLOAT	(%)	(%)	(%)	(%)	(%)	(%)
	1.30	47.8	4.2	47.8	4.2	100.0	28.4
1.30	1.40	15.6	14.5	63.4	6.7	52.2	50.5
1.40	1.50	6.6	22.8	70.0	8.3	36.6	65.9
1.50	1.60	2.2	31.2	72.2	9.0	30.0	75.4
1.60	1.70	2.1	39.6	74.3	9.8	27.8	78.9
1.70	1.90	5.6	62.5	79.9	13.5	25.7	82.1
1.90		20.1	87.5	100.0	28.4	20.1	87.5
TOTALS		**100.0**	**28.4**				

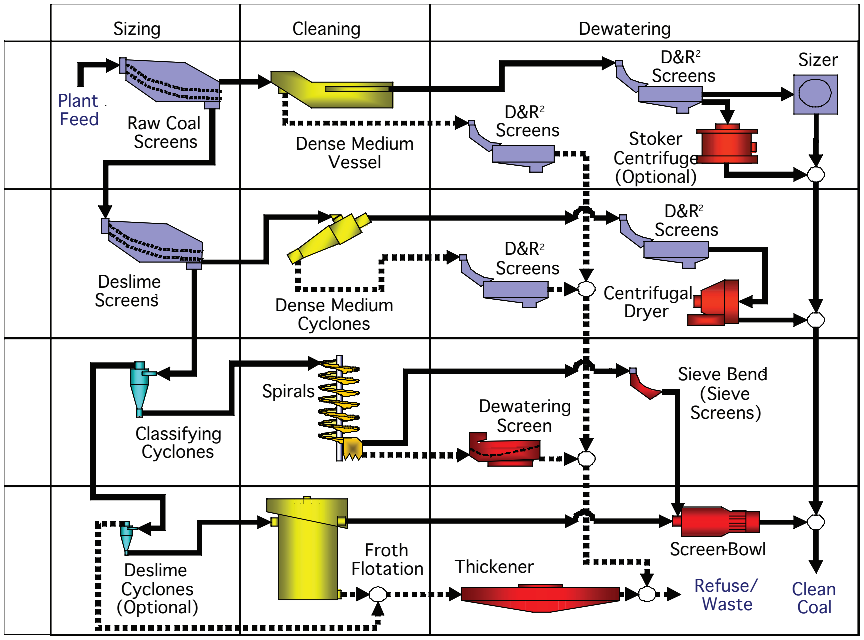
unit operations for particle sizing, cleaning, and dewatering (Figure 4.3). This sequence of operations, commonly called a circuit, may be repeated several times. The repetition is needed to maintain efficiency, because the processes employed in preparation plants each have a limited range of applicability in terms of particle size (Figure 4.4). In the United States, modern plants may include as many as four separate processing circuits for treating the coarse (greater than 10 mm), small (between one and 10 mm), fine (between one and 0.15 mm), and ultrafine (less than 0.15 mm) material. Although many commonalities exist, the final selection of what number of circuits to use, which types of unit operations to employ, and how they should be configured is highly subjective and dependent on the characteristic properties of the feed coal in terms of size, composition, and washability.

In a typical plant, feed coal is sorted into narrow particle size classes using vibrating screens for coarser particles and classifying cyclones for fine particles (Figure 4.3). The coarse fraction is usually cleaned using a chain-and-flight dense medium vessel (DMV), while the smaller fraction is upgraded using dense medium cyclones (DMCs). These processes use a dense medium suspension to separate coal from rock based on differences in particle densities. The fine fraction is usually cleaned by water-only cyclones, spirals,

BOX 4.2 CARDINAL PREPARATION PLANT

One of the most modern coal preparation facilities in the eastern United States is the Arch Coal Cardinal Plant. The 2,100 ton/hr plant was commissioned in May 2006 to treat a large reserve block of high-quality bituminous coal in the vicinity of the town of Sharples in Logan County, West Virginia. The plant incorporates three identical 700 ton/hr modules incorporating a single raw coal/deslime screen, dense medium vessel, dense medium cyclone, and vibratory centrifuge. Fine coal is treated using a bank of classifying cyclones, spirals, flotation columns, and screen-bowl centrifuge. Coarse waste rock is transferred to a disposal area via belt conveyor, while the fine waste slurry is passed to a thickener and pumped to an impoundment. To simplify maintenance, all primary unit operations can be accessed using an overhead crane built into the plant structure. The plant incorporates the latest technology for automatic operation and control, including a microprocessor-based controller, automated batch loadout system, and nuclear online ash analyzer. The safety of the slurry pipeline disposal system is monitored using an array of cameras, pressure sensors, and capacity detectors (Bethell and Dehart, 2006).





Notes: 1 - Raw coal and deslime screen decks may be on the same machine, 2 – D&R screens primarily used to recover dense medium, 3 - Sieve bends may also be combined with clean coal classifying cy clones.

FIGURE 4.3 Simplified flowsheet for a modern coal preparation plant.

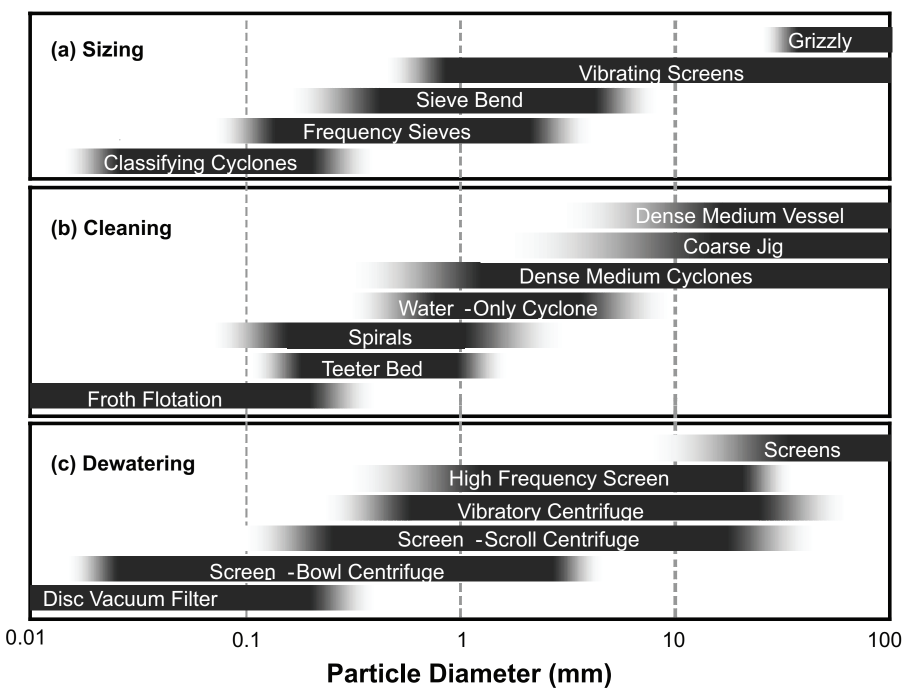


FIGURE 4.4 Effective range of particle sizes treated by various coal preparation processes.

or a combination of these separators. These water-based processes exploit differences in particle size, shape, and density to separate coal from rock. Unfortunately, conventional density separators cannot be used to upgrade the ultrafine fraction because of the low mass of the tiny particles. This fraction is usually upgraded using a process known as froth flotation, which separates coal from rock based on differences in the surface wettability of organic and inorganic matter. In many cases, the ultrafine fraction is resized ahead of flotation to remove particles under 40 microns (called slimes) that are detrimental to flotation and downstream dewatering (Bethell and Luttrell, 2005). In a few plants, ultrafine solids may be uneconomical to recover and are discarded as waste slurry without cleaning.

Finally, the water used in processing is removed from the surfaces of coarse particles using combinations of screens and centrifugal basket-type dryers. Screen-bowl centrifuges or vacuum filters are usually employed to dewater fine coal that tends to retain larger amounts of moisture.

Typically, the dewatered coarse waste (refuse) is transported by overland conveyor or truck to a disposal area, while the fine waste slurry is pumped from the plant thickener to a waste impoundment.

The various unit operations used in coal preparation are described in greater detail in the next section of this chapter.

3. COAL PROCESSING OPERATIONS

3.1 Particle Sizing

3.1.1 OVERVIEW

Run-of-mine coal produced by mechanized mining operations can contain particles as small as fine powder and as large as several hundred millimeters. After crushing to an acceptable maximum size, the feed is sized into groups using various types of equipment. Figure 4.4a shows the typical sizes of particles that can be produced by common types of industrial sizing equipment.

3.1.2 VIBRATING SCREENS

Screens are mechanical sizing devices that use a mesh or perforated plate to sort particles into fine (particles that pass through the screen openings) and coarse (particles that are retained on the screen surface). Vibrating screens (Figure 4.5), which are the most common, use a shaking rotating mechanism to segregate particles and to move material along the screen surface. High-frequency screens (Figure 4.6) vibrate very rapidly to enhance the passage of fine particles and are normally used for dewatering fine coal or rock.

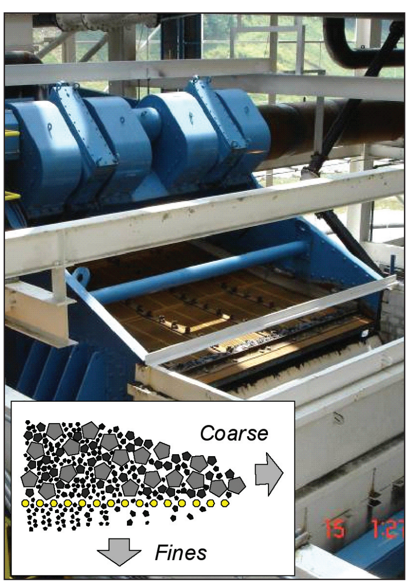


FIGURE 4.5 Vibrating screen used for feed coal sizing.

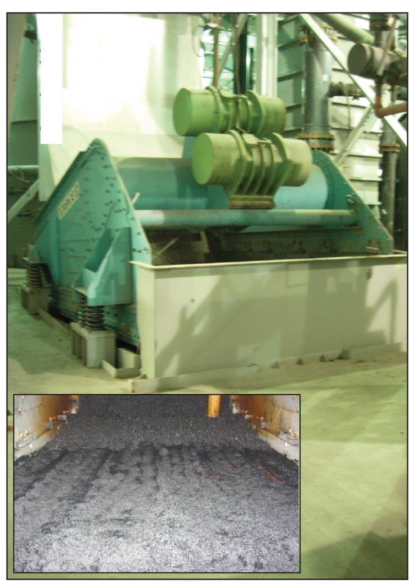


FIGURE 4.6 High-frequency screen used for dewatering of fine rock.

3.1.3 SIEVE BENDS AND CLASSIFYING CYCLONES

Sizing of fine coal is difficult because of low capacity and the increased likelihood of plugging openings in the screen surface. To overcome this shortcoming, many operations employ sieve bends and classifying cyclones for fine particle sizing. A sieve bend (Figure 4.7) consists of a curved panel that “slices” material from the flowing stream by placing slotted bars perpendicular to the

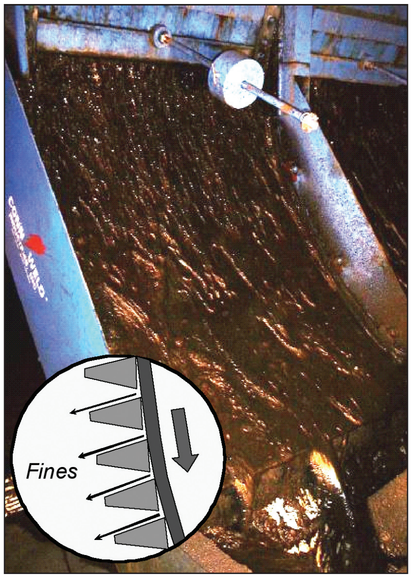


FIGURE 4.7 Sieve bend used to remove fine "slimes" from coal.

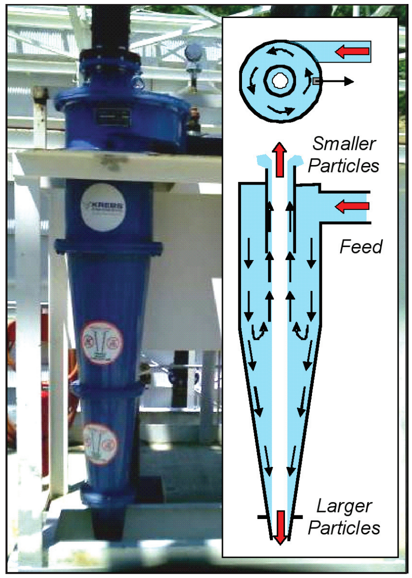


FIGURE 4.8 Classifying cyclone used to hydraulically size fine coal.

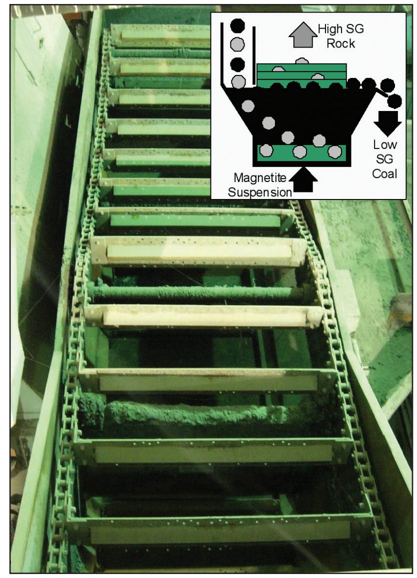


FIGURE 4.9 Chain-and-flight dense medium vessel used to separate coarse coal and rock.

flow. Classifying cyclones (Figure 4.8) are used where conventional screening or sieving becomes impractical. Classifying cyclones are commonly applied to size (cut) at 0.10 to 0.15 mm and represent the only practical option for sizing ultrafine particles (at a cut of 0.045 mm). This sizing device exploits differences in the settling rates of particles of different size (i.e., smaller particles settle slower than larger particles).

3.2 Solid-Solid Separation

3.2.1 OVERVIEW

The separation of valuable carbonaceous material from waste rock is typically accomplished using low-cost processes that exploit differences in physical properties that vary with mineral content. Some of the common properties that are used to separate coal and rock include size, density, and wettability. The effectiveness of different types of separators is limited to a relatively narrow size range (Figure 4.4b) to ensure the efficiency of the process.

3.2.2 DENSE MEDIUM SEPARATORS

A popular process for cleaning coarse coal (greater than 12.5 mm) is the dense medium vessel (Figure 4.9). This density-based separator consists of a large open tank through which a dense suspension of finely pulverized magnetite is circulated. Because of the high density of the suspension, low-density coal particles introduced into the suspension float to the surface of the vessel where they are transported by the overflow into a collection screen. Waste rock, which is much denser, sinks to the bottom of the vessel where it is collected by a series of mechanical scrapers called flights. The washed coal and rock products pass over drain-and-rinse (D&R) screens to wash the magnetite medium from the surfaces of the products and dewater the particles. Magnetite is used since it can be readily recovered and reused using magnetic separators.

DMCs are commonly used to treat particles of coal and rock that are too small (usually 0.5 to 12.5 mm) to float or sink in a static vessel. These high-capacity devices (Figure 4.10) make use of

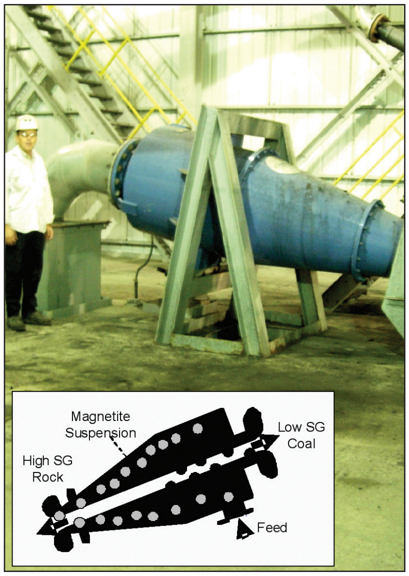


FIGURE 4.10 Dense medium cyclone used to separate small coal and rock.

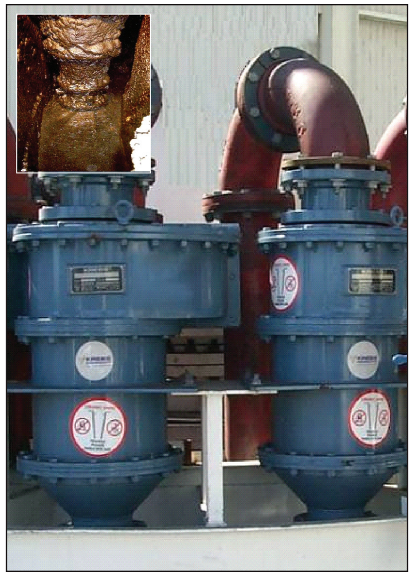


FIGURE 4.11 Bank of twin water-only cyclones used to separate fine coal and rock.

FIGURE 4.12 Bank of spirals used to separate fine coal and rock.

the same basic principle as dense medium vessels (i.e., an artificial magnetite-water medium is used to separate low-density coal from high-density rock). In this case, however, the rate of separation is greatly increased by the centrifugal effect created by passing medium and coal through one or more cyclones.

3.2.3 WATER-BASED DENSITY SEPARATORS

A variety of density-based separators are available for separating coal and rock in the particle size range between 0.2 and 1.0 mm. The most common methods include water-only cyclones and spirals. A water-only cyclone (WOC) is similar to a classifying cyclone, but typically has a broad wide-angled conical bottom (Figure 4.11). Separation of coal and rock occurs because of the formation of dense suspension created by the natural fines already in the feed slurry. A spiral (a) consists of a corkscrew-shaped device that sorts coal from rock by selective segregation that occurs as particles move in the flowing film along the helical trough. Because of the low unit capacity (two to four tons per hour), spirals are usually arranged in groups that are fed by an overhead distributor. WOCs and spirals are often employed in two stages or in combination with other water-based separators to improve performance.

3.2.4 FROTH FLOTATION

Froth flotation is currently the only viable process for treating very fine coal (< 0.20 mm). This process exploits inherent differences in the surface wettability of coal and rock. During flotation, air bubbles are passed through a pulp containing coal and rock. Coal particles selectively attach to air bubbles and are buoyed to the surface for collection, while common mineral impurities are easily wetted by water and remain in the waste slurry. A chemical, called a frother, is added to promote the formation of small bubbles. The addition rates are very small and typically on the order of 0.1 to 0.5 pound of reagent per ton of coal feed. Another chemical additive, called a collector, may be added to improve adhesion between air bubbles and coal particles. Collectors are commonly hydrocarbon liquids such as diesel fuel or fuel oil. In some cases, clay slimes (< 0.03 mm) may be removed before

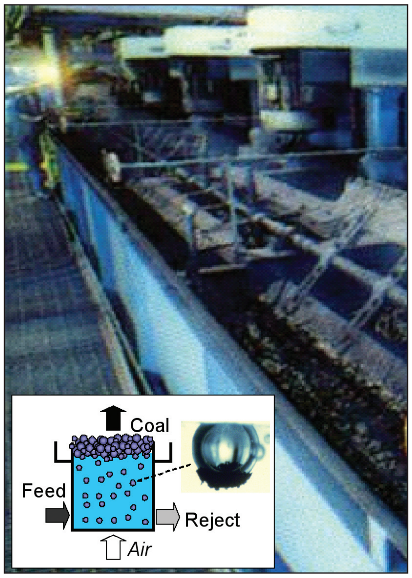


FIGURE 4.13 Conventional flotation bank used to clean ultrafine coal.

FIGURE 4.14 Column-type flotation cell used to clean ultrafine coal.

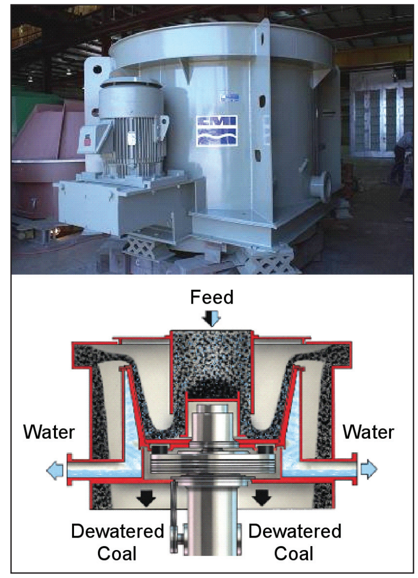


FIGURE 4.15 Vibratory centrifugal dryer used to dewater small/fine coal.

flotation using classifying cyclones to improve separation performance. In the United States, industrial installations use either mechanical stirred-tank flotation machines (Figure 4.13) or column flotation cells (Figure 4.14).

3.3 Solid-Liquid Separation

3.3.1 OVERVIEW

Solid-liquid separators are used downstream of coal cleaning processes to remove unwanted surface moisture that lowers heating value, leads to handling/freezing problems, and increases transportation costs. As shown in Figure 4.4c, several different types of mechanical dewatering methods are required, depending on the size of particles to be treated. The removal of water from the surfaces of coarser (> 5 mm) coal is predominantly carried out using simple screens. Fine particles, which have a higher surface area and tend to have correspondingly higher moisture content, are typically dewatered using centrifugal methods or filtration systems.

3.3.2 CENTRIFUGAL DEWATERING

Centrifugal dewatering systems, which use centrifugal force to pull water away from the surfaces of coal particles, operate in much the same fashion as the spin cycle in a home washing machine. For coarse particles, centrifugal dryers that use either a rotating scroll or vibratory action (Figure 4.15) to transport solids are commonly used. For fine particles (< 1 mm), another popular design, known as a screen-bowl centrifuge (Figure 4.16), may be used. These units are capable of providing low moisture products, although some ultrafine solids can be lost as waste effluent with the bulk of the water.

3.3.3 FILTRATION DEWATERING

Filtration processes may be used to dewater fine coal in cases where high coal recovery is desirable. Filtration involves the entrapment of fine solids as a cake against a porous filtering medium. Traditionally, flotation concentrates have been dewatered using some form of vacuum filtration. These units are capable of maintaining high coal recoveries (greater than 97 percent) while

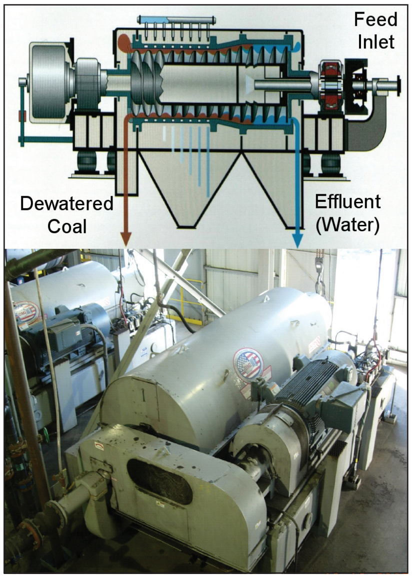


FIGURE 4.16 Screen-bowl centrifuge used to dewater fine coal.

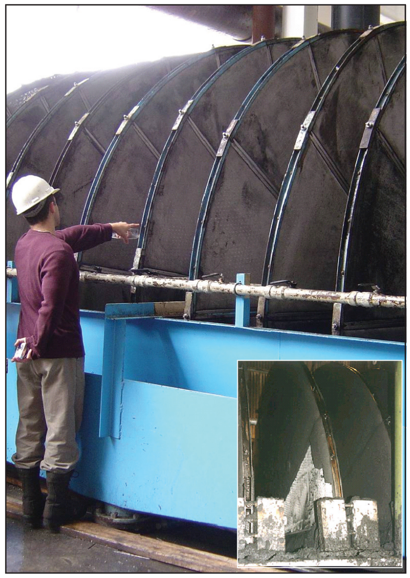


FIGURE 4.17 Disc vacuum filter used to dewater fine coal.

FIGURE 4.18 Thermal dryer used to dry coal to low moisture contents.

generating product moisture contents of approximately 20 to 30 percent. The most popular type of vacuum filter used in the United States is the disc filter (Figure 4.17).

3.3.4 THERMAL DRYERS

Thermal dryers can be used to reduce coal moisture to very low levels if dictated by market demands. The most popular design is the fluidized bed dryer (Figure 4.18), which uses coal, oil, or coalbed methane as the fuel source (Miller, 1998). Thermal dryers can reduce coal moisture to less than six percent by weight at a cost of about $10 to $15 per ton of water evaporated (Meenan, 2005). Unfortunately, thermal dryers require high capital costs (approximately $250,000 per ton per hour of evaporative load) and can suffer from emission problems associated with fugitive dust and poor opacity. Emissions of nitrogen oxides, sulfur dioxide, and volatile organic compounds (VOCs) may also present issues in some cases. Moreover, thermal drying of combustible particles such as coal can present safety hazards resulting from accidental fires or dust and gas explosions.

3.3.5 CLARIFICATION AND THICKENING

Thickening is an essential solid-liquid separation process used to treat the process water so that it can be recycled and reused within the plant. A thickener (Figure 4.19) consists of a large tank (50 to 200 feet in diameter) in which particles are forced to settle, thereby producing a clarified overflow and thickened underflow (20 to 35 percent solids). The thickened sludge is typically pumped to an appropriate disposal area or is further dewatered before disposal. Chemicals such as coagulants and flocculants are usually introduced before the thickener to promote the aggregation of ultrafine particles to increase settling rates.

3.4 Waste Handling and Disposal

3.4.1 REFUSE PILES

The final step in coal preparation involves the disposal and permanent storage of large volumes of waste rock and slurry in various types of surface or underground repositories. Refuse piles are designed to receive coarse particles of waste rock that can be easily dewatered by screens or sieves and stacked in piles. This material is relatively easy to handle and can be transported by truck or belt haulage systems to the disposal area.

3.4.2 SLURRY IMPOUNDMENTS

Because fine coal wastes are difficult to dewater, typically, they are discarded in slurry form. The waste slurry contains water, coal fines, silt, clay, and other fine mineral particles from the processing plant. In most cases, the slurry is discarded into an impoundment (Figure 4.20). An impoundment is an engineered structure consisting of a large-volume earthen settling basin formed behind a manmade dam or embankment. The dam or embankment is usually constructed from compacted coarse refuse material. The waste slurry is transferred to the impoundment by pumping thickened underflow from the plant thickener through a pipeline. The volume of the impoundment must be sufficiently large to ensure that fine particles settle by gravity before the clarified water at the surface is recycled back to the plant for reuse. In some cases, chemical additives may be used to promote settling and to control pH.

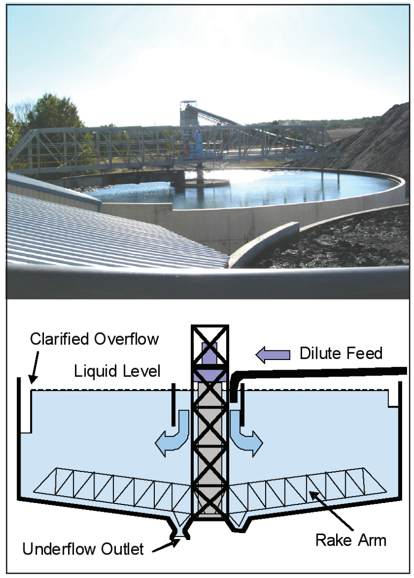


FIGURE 4.19 Conventional thickener used to clarify process water and thicken solids.

FIGURE 4.20 Active slurry impoundment used for fine waste disposal (before reclamation).

4. INDUSTRY OVERVIEW, ANALYSIS, AND ASSESSMENT

4.1 Industry Status

4.1.1 REGIONAL DIFFERENCES

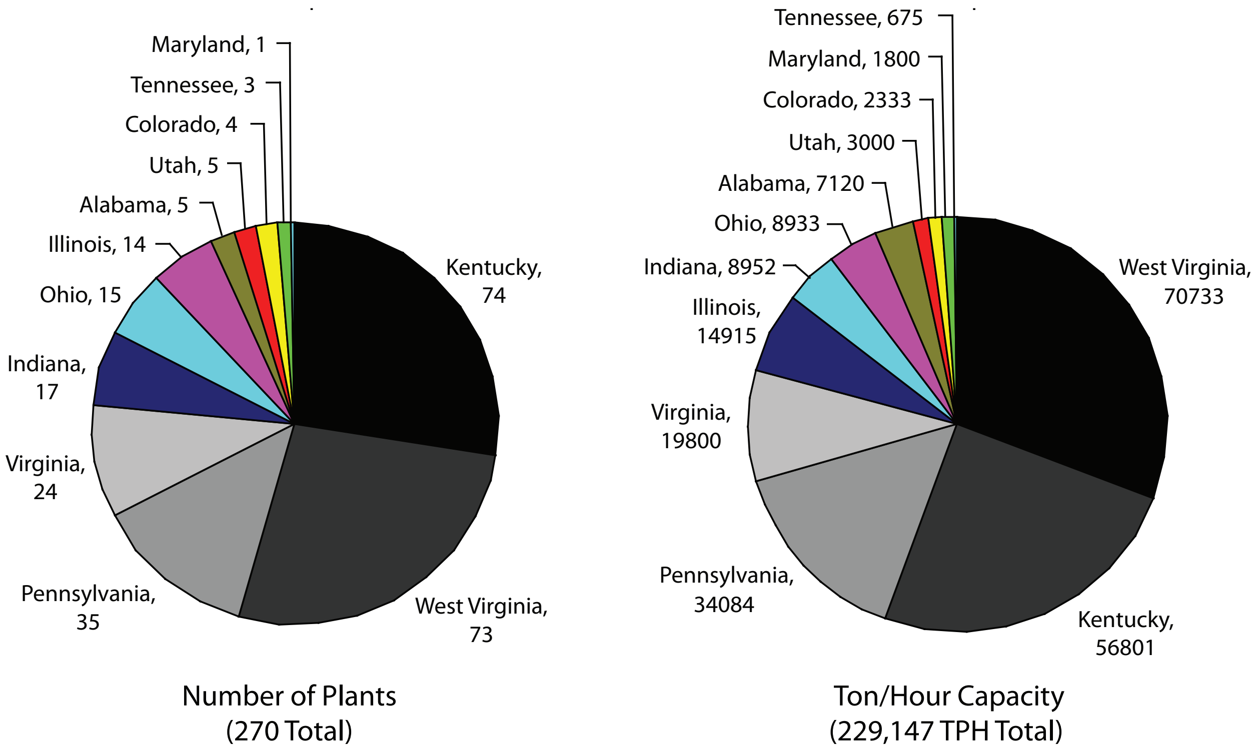
The United States produces coal from three major coal regions located in the eastern, interior, and western regions of the country (see Chapter 2). The western deposits are largely comprised of thick seams of subbituminous “compliance” coal that has an inherently low sulfur content. These reserves have traditionally required little coal preparation other than simple crushing and screening. On the other hand, increased levels of contamination from out-of-seam dilution have begun to generate some interest in developing preparation facilities for these coals and some of the other higher-rank coals in the western United States (Bethell, 2007). Much recent attention has focused on the development of dry coal cleaning technologies, because low-rank coals tend to disintegrate when exposed to water. In addition, the high cost of transporting low-rank coal has pushed the processing industry to consider nontraditional approaches for upgrading western coals such as mild conversion processes. These technologies, which typically involve thermal treatment, decrease the moisture and increase the specific heating value of low-rank coals so they can be more efficiently transported and burned by the existing fleet of coal-fired power stations.

The eastern coalfields are largely dominated by high-rank bituminous coals in the Appalachian and Illinois coal basins. These coal seams have a high specific heat value that makes them very attractive for transportation and power generation. Also, nearly all of the metallurgical coking coal consumed in domestic steel production is mined from this region. Unfortunately, most eastern coal seams occur as thin bands of coal-bearing sediments mixed with sedimentary rock. Hence, these seams often require coal preparation facilities to separate marketable coal from unwanted waste rock. The Department of Energy (DOE) estimates that more than three-quarters of all coal mined in the eastern United States are subjected to coal cleaning operations (DOE, 1993). In addition, eastern coals typically contain more sulfur than western coals because of differences in their geologic deposition. This is a particular problem for Illinois Basin coals that typically have high sulfur content (approximately three to seven percent) (Walker, 1993). Although coal preparation plants reduce the sulfur content of these coals, sulfur reduction is usually considered to be a secondary benefit since ash reduction is the primary focus of coal preparation in this region (Anon, 2007).

4.1.2 PLANT CENSUS

According to the annual census of coal preparation plants conducted by Coal Age (Fiscor, 2007), the United States operates 270 coal preparation plants in 12 states. This number is relatively small by comparison to number in the rest of the world, which is estimated to be 2,283 plants (Kempnich, 2003). U.S. plants are primarily concentrated in the eastern coalfields for the reasons cited previously (Figure 4.21). Kentucky and West Virginia have the largest number of coal processing facilities, with 74 and 73 plants, respectively. When combined with the plants in Pennsylvania (35) and Virginia (24), these four states represent more than three-quarters of all coal preparation facilities in the United States.

Because of gaps in the survey data reported by Coal Age, the total capacity of the U.S. fleet cannot be calculated exactly. However, available data suggest that the average plant has a capacity of 849 tons per hour, with about 20 percent of the fleet exceeding 1,000 tons per hour and 20 percent under 500 tons per hour. The state-by-state averages suggest that the total feed capacity for the fleet is in the range of 229,147 tons per hour. This production level equates to a total maximum capacity of just over two billion tons of feed annually (assuming around-the-clock operation). An estimate compiled from company production records suggests that about half this tonnage is washed coal product. Based on this value, the theoretical maximum production of washed coal product from the current fleet of plants is estimated to be approximately one billion tons annually. More than 85 percent of this capacity is available in Kentucky, West Virginia, Pennsylvania, Virginia, and Illinois. However, the actual production capability is probably much smaller than this upper limit because of constraints associated with plant availability. An availability correction accounts for losses in production because of mechanical failures, weather



STATE	FLEET SIZE		PLANT FEED CAPACITY		
	NUMBER	PERCENT	AVERAGE (TPH)	TOTAL (TPH)	TOTAL (%)
Kentucky	74	27.4	768	56,801	24.8
West Virginia	73	27.0	969	70,733	30.9
Pennsylvania	35	13.0	974	34,084	14.9
Virginia	24	8.9	825	19,800	8.6
Indiana	17	6.3	527	8,952	3.9
Ohio	15	5.6	596	8,933	3.9
Illinois	14	5.2	1,065	14,915	6.5
Alabama	5	1.9	1,424	7,120	3.1
Utah	5	1.9	600	3,000	1.3
Colorado	4	1.5	583	2,333	1.0
Tennessee	3	1.1	225	675	0.3
Maryland	1	0.4	1,800	1,800	0.8
TOTALS	**270**	**100.0**	**849**	**229,147**	**100.0**

FIGURE 4.21 Distribution of coal preparation plants in the United States. SOURCE: After Fiscor, 2007.

problems, power outages, or other shutdowns attributed to the operation of the preparation facility. Although this factor is highly site specific, an average availability of 85 percent is attainable based on production records provided by many of the larger producers. This correction reduces the total washed coal product capacity for the U.S. fleet to about 850 million tons per year. Another problem is that preparation plants are typically located at the mine site in order to keep haulage costs as low as possible. As such, many of the older plants are in locations that have been depleted of large blocks of coal reserves, thereby making full use of plant capacity unrealistic. One-third to one-half of the current fleet may be subject to this limitation. Therefore, based on these factors, the maximum annual production capability of the existing fleet of coal preparation plants is estimated to be only 430 to 570 million tons of washed coal product.

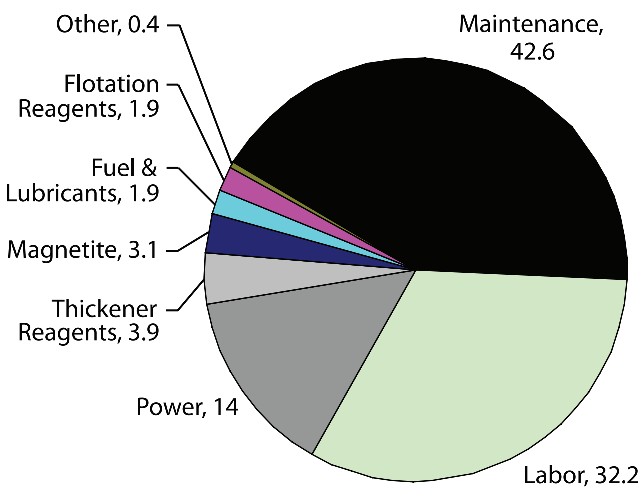
Cost also affects the production capability of preparation plants. The cost of constructing and operating facilities must be kept low to remain profitable in the very competitive U.S. markets. Capital costs for construction of a modern preparation facility (excluding external materials handling facilities) are typically $10,000 to $15,000 for each ton per hour of feed capacity, while the costs for operation of the facility are typically $1.50 to $2.50 per raw ton processed (Bethell, 2007). However, operating costs as high as $4.40 per ton have been reported for intensive cleaning (Anon, 2007). Operating costs typically include expenses associated with personnel labor, wear parts replacement, and consumables such magnetite, chemical reagents, and electrical power. A cost breakdown reported by Laurila (2000) for an average plant shows that labor, maintenance, and electrical power charges are responsible for nearly 90 percent of operational costs (Figure 4.22). These figures may vary significantly from site to site depending on the characteristics of the coal, scale of the plant, types of processes used, and intensity of the cleaning. Cleaning to lower levels of ash and sulfur typically increases the total cost per cleaned ton produced, since this process lowers the yield of recoverable coal and increases the rate of waste generation.

4.2 Beneficial Impacts of Coal Preparation

Coal preparation provides several attractive economic and environmental benefits, including increased coal reserves, lower transportation costs, improved utilization properties, and abatement of pollution. These factors are discussed in the following sections.

4.2.1 COAL RESERVES

Perhaps no other technology has had a greater impact on expanding the reserve base of economically recoverable coal than coal preparation. Preparation plants employ low-cost physical separation processes to convert run-of-mine coal resources into marketable coal reserves. The percentage of washed coal tonnage generated from



Cost Element	Percent
Maintenance	42.6
Labor	32.2
Power	14.0
Thickener Reagents	3.9
Magnetite	3.1
Fuel & Lubricants	1.9
Flotation Reagents	1.9
Other	0.4
	100.0

FIGURE 4.22 Breakdown of operating costs for a coal preparation plant. SOURCE: After Laurila, 2000.

each ton of run-of-mine coal is commonly referred to as plant yield. This parameter is difficult to estimate when evaluating the reserve base for a previously undefined coal property. The yield can be influenced by several factors, including (1) the quality of the in-place coal, (2) the washability (separating characteristics) of the run-of-mine coal, (3) the efficiency of the separation processes used by the preparation facility, and (4) the strictness of the quality demands imposed by the coal consumer. The quality of the in-place coal can be affected by small changes to mining practices that directly influence out-of-seam dilution. Variations in washability, which reflect the selective liberation of composite particles of intermixed coal and rock, can also make estimations of coal yield unreliable when coal is subjected to size reduction.

The average yield produced by coal preparation plants has steadily declined over the years because of depletion of lower ash feeds and less-selective mining due to mechanization. For example, Figure 4.23 shows the yield of washed coal product currently obtained from a random survey of several major plants operating in the eastern United States. It is not uncommon for eastern operations to experience yields under 30 percent, thereby producing only one ton of washed coal product from three or more tons of mined product. An estimate compiled from production records supplied by coal producers suggests that the average yield is now less than 50 percent (49.8 percent ±3.5 percent, to be exact) for the total United States. This situation is expected to worsen as eastern reserves become thinner and more challenging to mine (Milici, 2000). A study reported by Weisenfluh et al. (1998) indicated that nearly 52 percent of the remaining eastern Kentucky coalfield resources are located in coal seams that are 14 to 28 inches thick, while 31 percent are in 28 to 42 inch thick seams. Likewise, a study of Virginia coalfields found that 30 percent of the total reserve base (203 million tons) exists in seams with a thickness less than 28 inches (Sites

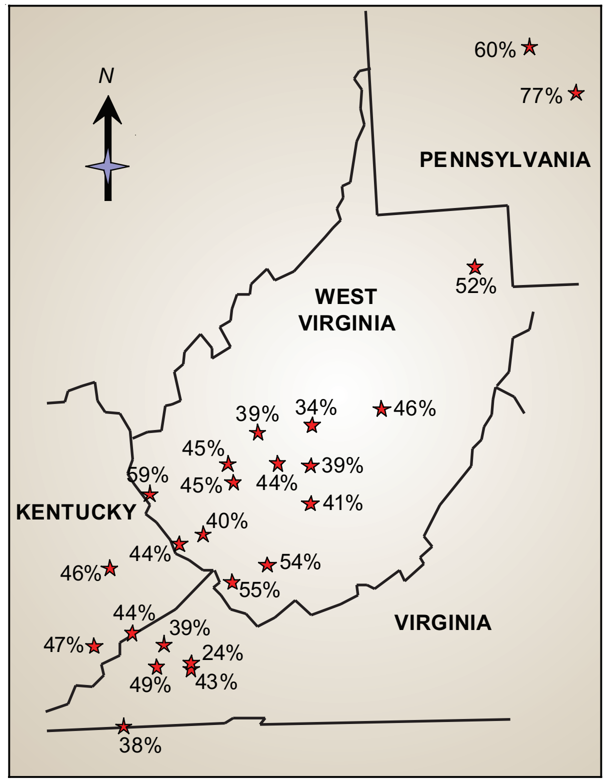


FIGURE 4.23 Examples of coal yield for a random sampling of eastern plants.

and Hostettler, 1991). Consequently, ever increasing amounts of rock from out-of-seam dilution are being mined, loaded, and hauled to preparation plants for removal and disposal.

4.2.2. COAL TRANSPORTATION

Most coal consumed in the United States is used for the production of electricity. The cost of transporting coal to the power station is usually borne by the utility and paid based on the delivered tonnage. The mine operator is also paid by the utility based on tonnage, although the unit price is typically adjusted up or down to account for the actual heat content of the supplied coal fuel. In most cases, this simple pricing structure provides the base economic justification for the operation of coal preparation facilities. The high-ash rock rejected by coal preparation plants contains insufficient heating value to justify its shipment to the utility. The savings in transportation costs are directly proportional to the increase in heating value.

Cost-benefit studies suggest that the economics of coal production are more sensitive to transportation cost than to any other factor. For example, Norton (1979) was one of the first to demonstrate how unfavorable changes in the cost of mining, processing, and transportation affect profitability. The study (Figure 4.24) concluded that coal transportation costs had the greatest overall impact on total revenue. The study also indicated that the yield of washed coal was second only to transportation cost in determining revenues. Increases in capital and operating costs of the coal preparation plant had only a minor impact on revenue. Therefore, any steps taken to reduce preparation costs (such as fewer capital improvements, less maintenance, and workforce reductions) need to be closely examined to ensure that coal yield is not adversely impacted by these cost-cutting measures.

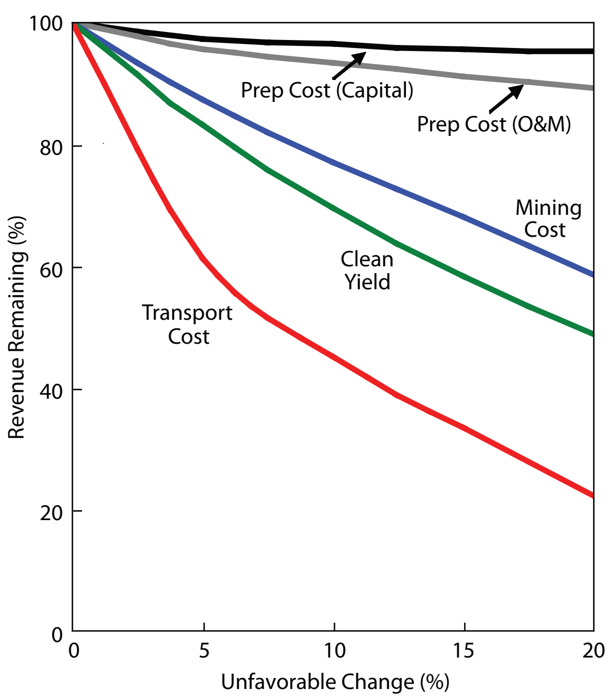


FIGURE 4.24 Effect of various factors on revenue for the coal production cycle. SOURCE: After Norton, 1979.

This study stresses the importance of coal washability and organic efficiency in determining profitability.

4.2.3 UTILITY PERFORMANCE

a) Thermal Efficiency

The thermal efficiency of a power station is very important. A higher efficiency is obviously economically beneficial, because it provides a proportional improvement in generated revenue for the power station. Moreover, higher efficiency also reduces the production of greenhouse gases and other environmental pollutants, because less coal fuel needs to be burned per unit of electrical power generated. One method for improving thermal efficiency is to use washed coals of higher quality that can significantly improve the thermal efficiency of a boiler (Harrison and Hervol, 1988; Davidson et al., 1990; Kehoe et al., 1990; Harrison et al., 1995). Higher-quality coals are more reactive and require less excess air for effective combustion, thereby improving efficiency via a reduction in heat lost with the flue gas. Higher-quality coals also improve efficiency by avoiding fouling/slagging problems in the boiler, which tend to raise flue gas temperature and increase heat loss (Skorupska, 1993).

The extent to which the proper application of coal preparation technology improves thermal efficiency is highly case specific and difficult to predict from purely theoretical considerations. Therefore, the most reliable data for quantifying efficiency improvements are typically based on actual plant studies. One such study (Smith, 1988) monitored improvements to boiler performance that resulted from switching from run-of-mine coal (15 percent ash and 3.5 percent sulfur) to washed coal (nine percent ash and 2.8 percent sulfur) from the same mine. Despite modest improvement in coal quality, boiler efficiency increased from below 88 percent to about 89.5 percent as a result of burning better quality coal. Capacity also rose by almost 10 percent because of fewer fouling/slagging problems.

The use of coal preparation technologies to improve boiler efficiency has also been a major focus for the coal industry in other nations. The International Energy Agency (IEA) estimates that coal-fired power plants in India can increase thermal efficiency up to 10 percent by switching from unwashed to washed coal (Bhaskar, 2007). China also expects to make greater use of coal preparation technology to improve thermal efficiencies and environmental performance (Glomsrod and Taoyuan, 2005). Average thermal efficiency in China has been reported to be less than 29 percent (Blackman and Wu, 1999), compared to around 38 percent in OECD (Organization for Economic Cooperation and Development) countries such as Australia, Canada, United Kingdom, and United States. As such, coal preparation is expected to continue to have a large impact on the international community.

b) Operation and Maintenance

Another benefit of coal preparation is that it removes impurities that have a significant influence on the operation and maintenance costs of coal-fired boilers. Studies have demonstrated that the removal of abrasive mineral impurities such as pyrite and quartz can substantially reduce wear rates and increase the throughput capacity of utility pulverizers (Corder, 1983; Scott, 1995). The impacts associated with the abrasive wear and slagging/fouling of boiler tubes can also be mitigated to a large extent by using washed coals that have been properly cleaned to remove unwanted mineral matter (Raask, 1983; Couch, 1994; Hatt, 1995). Vaninetti and Busch (1982) provide a detailed description of these problems and have developed empirical formulae that can be used to assist in the evaluation of changes to coal quality in specific types of boilers.

c) Coal Handling and Storage

The handling characteristics of solid coal are an important issue. A poor-handling coal may hang in railcars, plug chutes, and bins, and stick to conveyor belts (Hatt, 1997). These problems may result in unscheduled shutdowns, thereby reducing power station availability. Washed coals from preparation plants typically have superior handling characteristics to run-of-mine coals, especially if all or a portion of the ultrafines have been removed. These coals also typically present fewer problems in terms of unwanted dust generation, solids run-off during precipitation events, and freezing problems during colder months (Jones, 1998).

4.2.4 POLLUTION ABATEMENT

Coal preparation plays an important role in reducing the emissions of pollutants that associate with the mineral matter contained in coal (Davidson, 2000). These emissions normally include solid particulate emissions such as fly ash as well as gaseous emissions of precursors associated with acid-rain and air toxins. These emissions are strictly regulated for coal-fired utilities through various legislative acts such as the 1990 Clean Air Act Amendment (CAAA) and 2005 Clean Air Interstate Rule (CAIR). Moreover, coal preparation has a beneficial impact on reducing greenhouse gas emissions by increasing the thermal efficiency of coal-fired boilers. These benefits are described in more detail in the following sections.

a) Sulfur Emissions

Although scrubbers and fuel switching have been used with great success in the United States to reduce SO_2 emissions, coal preparation has also played an important role by reducing the sulfur contained in coal feedstocks prior to combustion (Couch, 1995). Sulfur occurs in coal as three distinct forms (sulfate, organic, and pyritic). Sulfate sulfur is present in very small quantities and is not considered a serious problem. Organic sulfur, which is part of the basic structure of coal, is not removable by conventional cleaning. The precombustion removal of organic sulfur is possible using chemical cleaning methods; however, these elaborate processes are not economically competitive with flue gas scrubbing. Pyritic sulfur is present as discrete inclusions of iron sulfides distributed within the coal matrix. As such, this form of sulfur can be removed by physical cleaning processes such as coal preparation (Kawatra, 2001). Fortunately, many of the high-sulfur coals in the United States also contain a high proportion of pyritic sulfur (Figure 4.25).

Coal preparation plants have been reported to remove up to 90 percent by weight of pyritic sulfur, although rejections are typically in the 30–70 percent range because of liberation constraints (Cavallaro and Deurbrouck, 1977; Kawatra and Eisele, 2001). When compared to the postcombustion control of sulfur, coal preparation offers several distinct advantages, including improved

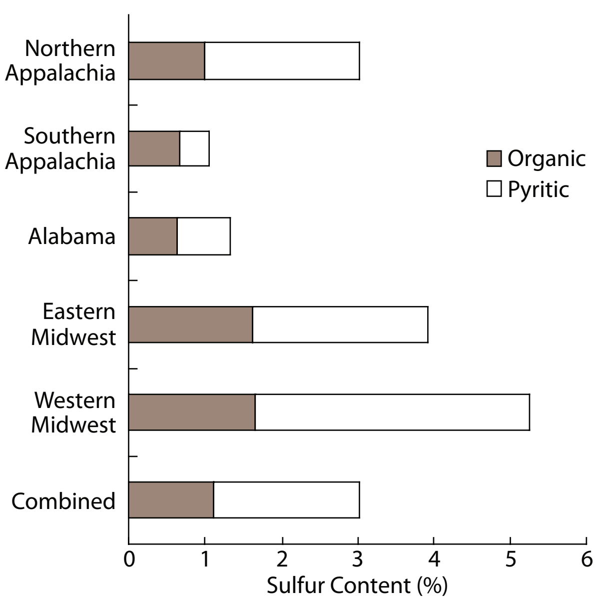


FIGURE 4.25 Distribution of sulfur types typically in U.S. coals.
SOURCE: After Cavallaro et al., 1976.

market flexibility, lower scrubber loading, and concurrent removal of other impurities (e.g., ash, trace elements, and moisture). Although coal preparation does not directly affect the nitrogen content of coal, washing has been shown to help reduce NOx emissions by providing a consistent high-quality fuel that provides for ease of control of the combustion environment (Couch, 2003).

b) Particulate Emissions

Noncombustible impurities present in the feedstocks supplied to coal power stations generate waste streams as either bottom ash/slag or fly ash. Of these, the finest particles of fly ash emitted to the atmosphere are considered to be of greatest environmental concern because of their potential adverse impact on human respiratory health (Smith and Sloss, 1998). Power stations make use of several types of effective control technologies to minimize fine particulate emissions. These postcombustion technologies include efficient processes such as electrostatic precipitators (ESPs), fabric filters (FFs), cyclones, and wet scrubbers. Modern control systems typically achieve better than 99.5 percent removal of all particulates and exceed 99.99 percent in some cases. However, standards for particulate emissions continue to become increasingly stringent as reflected in expanded regulations by the Environmental Protection Agency (EPA) to include particles smaller than 2.5 microns in new ambient air quality standards (EPA, 1997). As such, there is continued interest in removing greater amounts of particulates upstream of other emission controls using coal preparation technologies.

The separation processes used in coal preparation plants remove noncombustible minerals that ultimately affect the amount and type of particulate matter (PM) that passes downstream to emission control systems. For these systems, proper levels of coal washing can be identified that effectively reduce ash loading and improve removal efficiencies. A recent presentation by American Electric Power to the Asia Pacific Partnership (Doherty, 2006) concluded that "Consistent and proper quality coal is best tool to improve plant operating performance and reduce PM and SO_2 emissions. Removal of some of the coal ash (includes rocks) at the mine is more economic than in the pulverizer, boiler, precipitator and scrubber." Washing also minimizes the total amount of high-surface-area fly ash that is more hazardous to dispose because of its high reactivity. In cases where particulate controls are currently deemed adequate, greater use of coal preparation may be required in the future to compensate for deterioration in feedstock quality as higher-quality coal reserves become depleted.

c) Hazardous Air Pollutants

The 1990 CAAA contained provisions that established new emission standards for a variety of air toxins known as hazardous air pollutants (HAPs). Many of the HAPs identified in the CAAA are present as trace elements in coal (Obermiller et al., 1993; Meij and Winkel, 2007). Some of the most noteworthy of these are antimony, arsenic, beryllium, cadmium, chlorine, chromium, cobalt, fluorine, lead, manganese, mercury, nickel, selenium, and radionuclides. Concentrations of these elements are known to vary considerably from seam to seam, and in some cases within the same seam (Zubovic, 1966; Swaine, 1990). During combustion at electrical utilities, these elements may be released to the atmosphere as solid compounds with the fly ash and in the vapor phase with the flue gas. Existing post-combustion control technologies, such as electrostatic precipitators, can be reasonably effective in reducing the concentration of trace elements associated with fly ash. These elements commonly include antimony, beryllium, cadmium, cobalt, lead, and manganese. Capture efficiencies greater than 97 percent have been reported for electrostatic separators (Fonseca et al., 1993). On the other hand, trace elements such as arsenic, chlorine, mercury, and selenium have the potential to volatilize and are less-effectively controlled by postcombustion methods.

Studies have shown that many of the hazardous air pollutant precursors identified in CAAA are associated with mineral matter commonly rejected by coal preparation plants. This approach to trace HAP control is attractive, because the waste rock rejected by coal preparation plants is coarser and has a lower reactivity than the high-surface-area ash generated by power stations (Jacobsen et al., 1992). In-plant sampling campaigns conducted by various researchers (Ford and Price, 1982; Fonseca et al., 1993) suggest a good correlation between the rejection of mineral matter and the removal of trace elements during physical cleaning. These findings are also supported by laboratory float-sink tests performed using a variety of eastern coals (Akers, 1995, 1996; Akers et al., 1997; Palmer et al, 2004). These data suggest that trace elements are typically rejected at levels of 40 to 70 percent by weight using conventional preparation technologies. These values appear to be in good agreement with earlier values reported by Fonseca et al. (1993), which showed an average trace element removal by conventional coal preparation of approximately 64 percent for six different coals (Figure 4.26). On the other hand, the large degree of variability observed in the data from these and other studies suggest that the rejections of trace elements by coal preparation are very site specific and need to be quantified on a case by case basis.

d) Mercury

Mercury is the trace element in coal of greatest environmental concern (Swaine, 1990). Mercury can be released during coal combustion and subsequently deposited in the environment. Ecological studies have shown that mercury bioaccumulates in the food chain as higher species consume

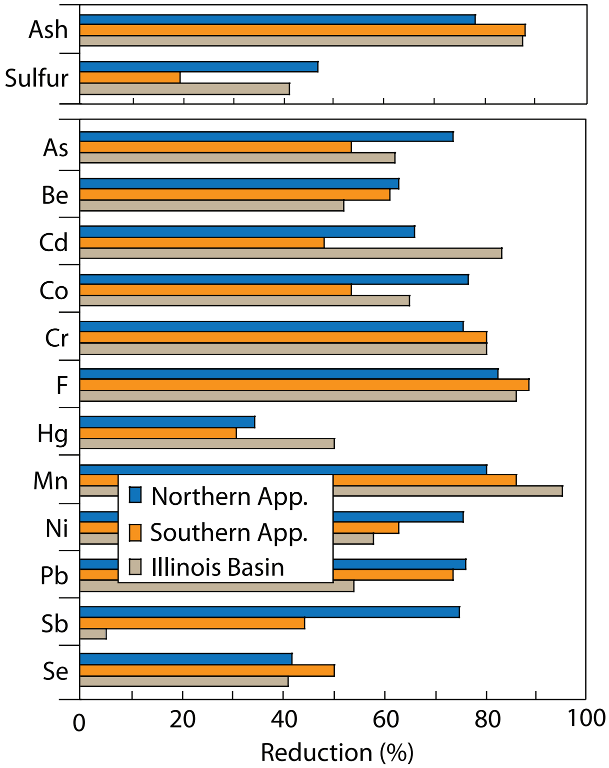


FIGURE 4.26 Reduction in trace element content after coal preparation. SOURCE: After Fonseca et al., 1993.

lower life forms exposed to mercury contamination (Trasande et al., 2006). Data reported by EPA indicate that coal-fired utilities are currently the largest human-generated source of mercury releases in the United States. It is estimated that these plants release approximately 48 tons annually (EPA, 2001). To curb these emissions, EPA issued the world's first-ever rule to cap and reduce mercury emissions for coal-fired power plants in March 2005. Compliance options available to utilities include postcombustion capture of mercury by existing or new flue gas scrubbing technologies as well as precombustion control of mercury by coal preparation and coal switching (Pavlish et al., 2003).

A recent study by Quick et al. (2002) showed that the mercury content of coal delivered to utilities (based on ICR data) was lower than that of the in-ground coal resources in the United States (based on COALQUAL data). This comparison is shown in Figure 4.27 for the primary eastern coal producing states. Based on this study, Quick et al. (2002) concluded that "selective mining and more extensive coal washing may accelerate the current trend towards lower mercury content in coal burned at U.S. electric utilities," and that "since recent reductions of sulfur emissions from coal-burning electric utilities are largely because of a declining sulfur content of delivered coal, rather than from scrubbing combustion gases, these simple, low-cost approaches to reduce Hg emissions should not be overlooked."

According to Alderman (2007), cleaning can reduce mercury by more than 50 percent in many eastern and western coals and lignites, excluding southern Powder River Basin (PRB) coals. Greater rejections of mercury by coal preparation appear to be limited by inadequate liberation and the presence of organically associated mercury. Several studies have suggested that mercury has some degree of association with the iron sulfides

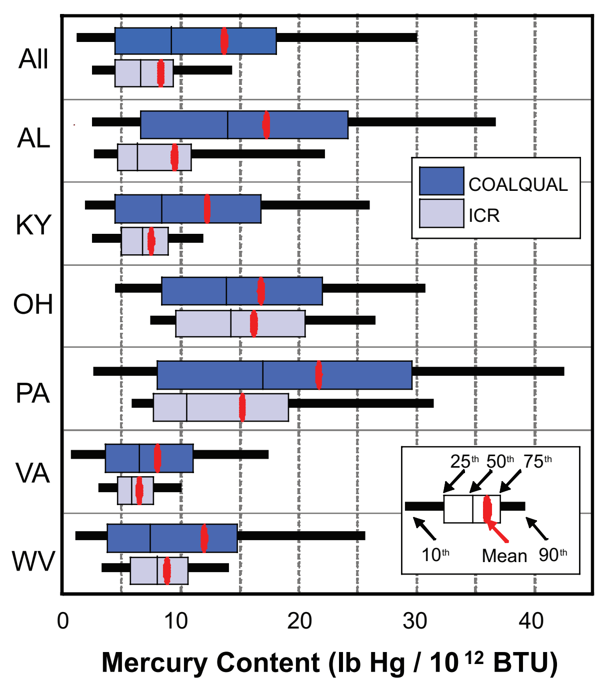


FIGURE 4.27 Comparison of mercury contents for delivered (ICR) and in-ground (COALQUAL) coals. SOURCE: After Quick et al., 2002.

present in many run-of-mine coals (Tkach, 1975; Finkelman et al., 1979; Minken et al., 1984). In fact, Figure 4.28 suggests that the concentration of many metallic elements found in coal often correlate well with the presence of sulfide minerals. As a result, the rejection level for mercury is often in the same range as the pyritic sulfur rejection for coals subjected to coal preparation. Although liberation can be improved by reducing the topsize of the feed coal (Hucko, 1984; Cavallaro et al., 1976, 1991), this approach is difficult to justify in today's marketplace because of the high costs associated with fine grinding (Kawatra and Eisele, 2001). Fine particles are also difficult and costly to upgrade, dewater, and handle in existing coal preparation facilities. The development of new and improved technologies for fine coal processing is needed to overcome this limitation. It should also be noted that thermal processing (e.g., K-Fuel process) can achieve high (up to 70 percent) mercury reductions for many western coals, including southern PRB coals (Alderman, 2007).

e) Greenhouse Gases

Coal preparation reduces emissions of greenhouse gases through an improvement in thermal efficiency; that is, less CO_2 is produced per unit of electricity generated. Calculations indicate that a one percentage point improvement in thermal efficiency provides a two to three percentage point reduction in CO_2 emissions for a typical coal-fired utility. An investigation conducted by Couch (2000) indicated that there are more than 4,000 coal-fired boilers worldwide that could improve thermal efficiencies and reduce CO_2 emissions by using coal preparation to improve coal quality. Moreover, Von Hippel and Hayes (1995)

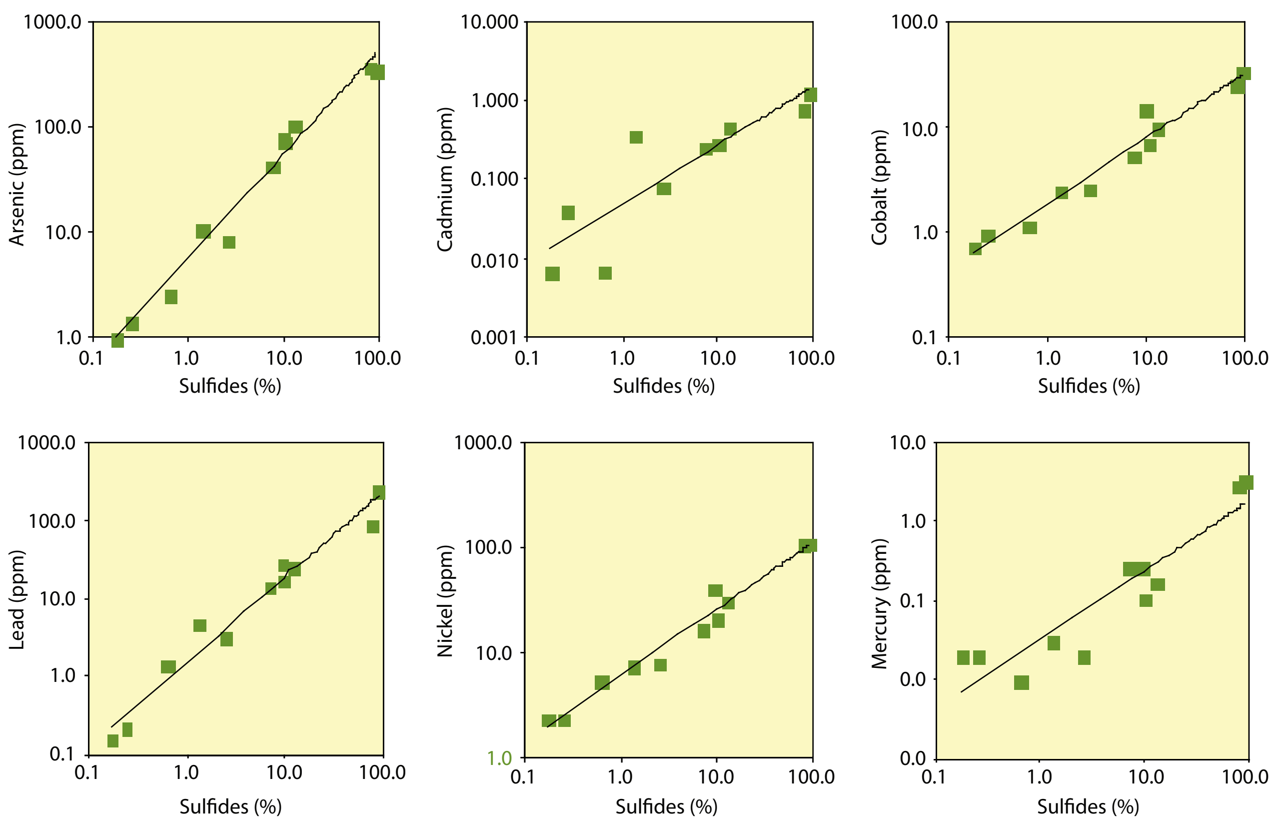


FIGURE 4.28 Effect of sulfide mineral content on the concentration of trace metals in a sample of Pittsburgh seam coal.
SOURCE: After Luttrell et al., 1998.

have noted that coal preparation reduces the amount of energy consumed (and CO_2 generated) during coal transportation by increasing the specific heating value of the delivered coal. Smith (1997) also found that freshly mined coals subjected to coal preparation processes tended to display slower releases of methane, another greenhouse gas.

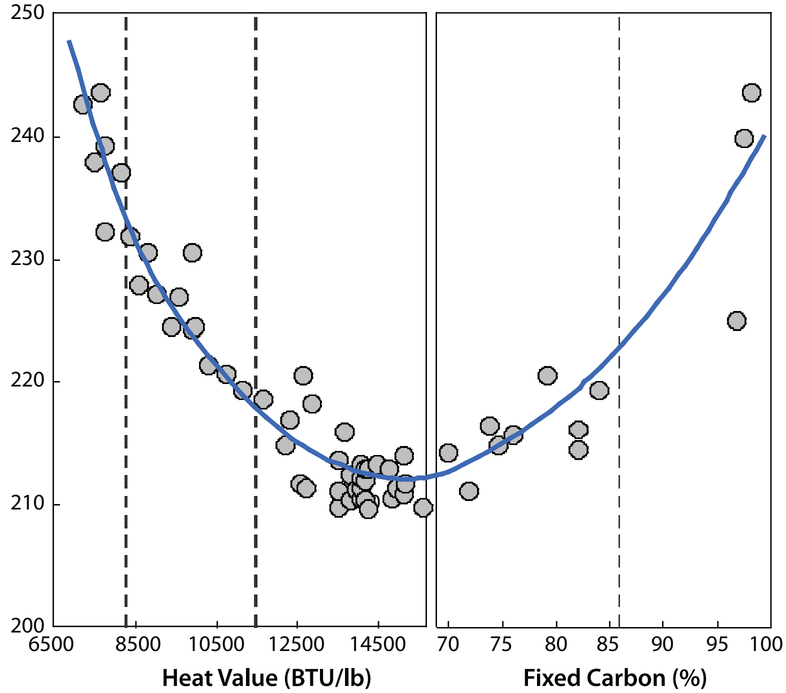


FIGURE 4.29 CO_2 emissions for different rank coals. SOURCE: After Quick and Glick, 2000.

It is interesting to note that U.S. sulfur legislation appears to have inadvertently contributed to increased production of greenhouse gases by spearheading the shift from high-sulfur coal reserves in the east to low-sulfur coals located in the west (primarily Wyoming). Western coals, which are of lower geologic rank, can produce up to seven to14 percent more CO_2 when burned than high-rank bituminous coals mined in the east (Winschel, 1990). Figure 4.29 provides a graphical comparison of the amount of CO_2 produced by different rank coals. For one midwestern utility, it is estimated that CO_2 emissions increased by six to eight percent by switching from a nearby supply of high-sulfur bituminous coal to a western supply of low-sulfur subbituminous coal (Quick and Glick, 2000). Moreover, this calculation did not take into account the additional CO_2 generated by transporting the coal over the long haulage distance from the western mine. These considerations provide an incentive for the continued use of eastern coals that are often subjected to coal preparation to provide high specific heat fuels. For sulfur control, the alternative to coal switching is to use flue gas desulfurization. Unfortunately, the chemical reaction used by scrubbers to convert and capture sulfur generates CO_2 as a byproduct (Dhir et al., 2000). In theory, one ton of CO_2 is generated for each ton of SO_2 captured by the scrubber, although the actual value is slightly higher after power consumption is factored in.

4.3 Issues and Concerns for Coal Preparation

Coal preparation offers many attractive benefits for coal-fired power generation. These typically include lower transportation costs, improved properties for coal utilization, and reduced emissions of particulate and gaseous pollutants. However, the industry also faces several challenges that need to be resolved to ensure that preparation plants can continue to operate at a profit without damage to the environment. These concerns can be generally classified as either (1) technical factors that relate to shortcomings in current processing systems, (2) environmental factors that involve improving waste handling and disposal, or (3) health and safety factors that may affect workers or citizens in the surrounding area. Each of these concerns is discussed in greater detail in the following sections.

4.3.1 TECHNICAL ISSUES

a) Fine Coal Cleaning

Run-of-mine coals that are fed to coal preparation plants are typically crushed to liberate rock before washing and to limit the size of particles that enter the plant. Operators prefer to keep particle top-size as large as possible (e.g., greater than 50 mm) because fine coal processes are considerably less efficient and substantially more costly (Osborne, 1988). Theoretically, crushing can increase the amount of high-quality recoverable coal within a given reserve. Size reduction improves liberation by reducing the population of intermixed composite particles of coal and rock. A study conducted by DOE (Cavallaro et al., 1991) indicates that the reserves of compliance coal in central Appalachia could be nearly doubled by efficient cleaning at a particle size of 1 mm (Figure 4.30). Although a systematic assessment has not been performed to date for trace elements, size reduction would also be expected to substantially improve the removal of coal-related pollutants other than just ash and sulfur. Unfortunately, inefficiencies associated with existing fine coal upgrading processes make size reduction for liberation purposes uneconomic in industrial practice.

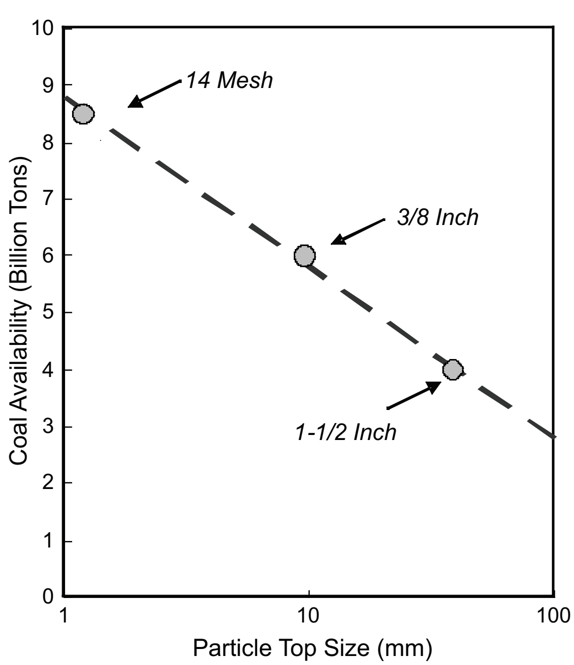


FIGURE 4.30 Effect of decreasing top size on low-sulfur coal availability. SOURCE: After Cavallero et al., 1991.

In industrial practice, the solid-solid separation processes used to treat fine coal represent the single greatest loss of potentially recoverable coal in a preparation facility (Bethell, 1998). Field studies indicate that the froth flotation process, which is normally used to recover coal that is smaller than 0.2 mm, typically recovers only 60 to 80 percent of the organic matter in this size range. This surface-based separation is inherently less effective in removing pyritic sulfur than density-based processes used to treat the coarser sizes of coal (Adel and Wang, 2005). As such, the desulfurization of fine particles is also often poor in many operating preparation facilities. Therefore, the continued development of effective, low-cost processes for treating fine coal is a major need for the preparation industry. Effective solutions need to be found for improving the recovery, selectivity, and capacity of froth flotation processes. This goal may be achieved through fundamental and applied studies that seek to understand and improve flotation chemistry, equipment design, and process control. In addition, new types of density separators need to be developed for treating fine coal. Centrifugal separators such as enhanced gravity concentrators, which have been successfully applied in the gold industry, may prove useful for this purpose. These devices have the potential to reject significantly greater amounts of pyritic sulfur (and mercury) that is not efficiently removed using surface-based separators such as froth flotation (Honaker, 1998; Honaker et al., 1996, 2000). However, these machines need to operate with higher throughputs, improved separation efficiencies, lower-density cut-points (i.e., higher-purity coal), finer particle size cutoffs, and lower operating and maintenance costs.

b) Fine Coal Dewatering

The solid-solid separation processes employed by modern coal preparation plants require large amounts of process water. After cleaning, the unwanted water must be removed from particle surfaces using mechanical dewatering equipment. Inefficient removal of moisture lowers the heating value, increases transport costs, and creates handling/freezing problems for the cleaned coal. Coarse particles can be readily dewatered using simple screening systems, while fine particles require more complicated unit operations such as centrifuges and filters. Unfortunately, the mechanical systems used to dewater fine coal are inefficient and costly (Le Roux et al., 2005). Fines often represent as little as 10 percent of the total run-of-mine feed; however, this size fraction may contain one-third or more of the total moisture in the delivered product.

The availability of low-cost mechanical dewatering equipment that can efficiently remove moisture from fine coal is widely considered to be an important need for the U.S. coal preparation industry. Existing technologies for fine coal dewatering tend to produce unacceptably high moistures, exceeding 25 to 35 percent by weight, or intentionally sacrifice half or more of the ultrafines as waste in an attempt to lower the product moisture. In addition, these processes are typically the most energy-intensive used in coal preparation, often consuming six to 12 kilowatt (kW) per ton per hour of dry solids processed (Yoon et al., 2006). Thermal dryer systems can effectively reduce moisture; however, these massive units require very large capital expenditures that are difficult to justify in the coal industry. Also, indirect thermal drying systems (e.g., Holoflite and Torus Disc) typically require 200 to 400 kW per ton per hour of product for drying fine coal solids to single-digit moistures (Van den Broek, 1982). Moreover, stringent air quality standards make it impossible in many cases to obtain new operating permits for thermal dryers. Therefore, the coal preparation industry needs to develop new mechanical solid-liquid separation processes that are substantially more efficient in terms of removing moisture and less expensive to purchase, operate, and maintain. Innovative systems are critically needed, which may require fundamental studies to identify controlling mechanisms that can lead to the development of "breakthrough" technologies.

c) Dry Coal Processing

Low-sulfur coal reserves in the western states have become the most important supply of domestic fossil fuel in the United States during the past few decades. Historically, the majority of coal mined in this region was of sufficient quality such that it did not require any coal preparation except for simple crushing and sizing. More recently, however, increased levels of rock dilution have been noted for coals mined in this region, largely because more challenging reserves are being mined and larger mining equipment that is less selective is being used (Bethell, 2007). This trend is pushing some coal producers to consider coal washing for the first time. In addition, new federal and state clean air quality requirements are pressuring utilities and coal companies to use precombustion cleaning as a means of reducing SOx and trace element emissions (Honaker et al., 2007). One example is the proposed Springerville power plant in New Mexico, which has been tentatively approved contingent upon the use of precombustion cleaning to improve the quality of the coal feedstock.

There are many challenges in using precombustion cleaning to upgrade western coals. The processes traditionally used to wash eastern coals cannot be readily adopted in the west because water resources are lacking and low-rank coals often disintegrate in water. As a result, current R&D efforts focus on the development of dry cleaning processes to upgrade these lower-rank reserves. Dry coal separators, such as pneumatic jigs and air tables, are already finding applications at selected mine and utility sites (Kelley and Snoby, 2002; Lu et al., 2003; Weinstein and Snoby, 2007). Other developing technologies that may be applicable for this purpose include various types of electrostatic (Yoon et al., 1995; Stencel et al., 2002) and magnetic separators (Oder, 2005a, 2005b). The continued development of these low-cost units is important for upgrading many of the western coal reserves where water is scarce. The development of automated sorters, which use optical, electromagnetic, or x-ray detection to identify and extract rock from coal, also show considerable promise for dry coal concentration (Jong et al., 2003). Optical sorters are used for separating particles that are liberated at relatively large sizes (greater than about 5 mm). These devices are already being used for separating diamond, gold, uranium, and sulfide ores as well as for separating plastic bottles in the recycling industry. Such devices are particularly useful for pre-concentration, which can increase throughput and result in energy savings for other types of solid-solid separators.

Continued R&D is necessary to improve separation efficiency (particularly for fine sizes), increase reliability, and lower costs for this new generation of coal preparation technology. The United States currently lags behind other countries in this area and needs to work more aggressively to ensure that the lack of dry cleaning technology does not become a barrier to the continued availability of good-quality western coals.

d) Online Analysis and Control

Tremendous strides have been made in the automation and control of coal preparation plants during the past several decades (Couch, 1996). The application of online sensors together with programmable logic controllers has allowed modern plants to operate more efficiently and to improve safety by reducing manpower requirements. On the other hand, the industry continues to struggle with the real-time determination of the quality of coal products (Belbot et al., 2001). Analyzers are commercially available for real-time analysis of many quality parameters for coal, including ash, sulfur, and moisture, although measurement accuracy is often poor because of sampling and calibration issues (Yu et al., 2003). Analyzers cannot be used to determine important data such as particle size distributions and real-time washability. Therefore, improving automation, control, and sensor technologies is a key challenge for the industry to overcome. Advances in real-time analysis will enhance the industry's ability to maximize the recovered energy in a marketable product and minimize the generation of unwanted wastes.

e) Particle Sizing

There are many technical challenges for the coal preparation industry that relate directly to size-size separations. Size-size separations are required before solid-solid separations because these units are only effective within a narrow particle size range. Vibrating screens are generally efficient and cost effective for sizing and dewatering coarser particles. On the other hand, screening systems for fine particles, particularly those smaller than 0.5 mm, tend to bind easily, wear quickly, and suffer from low throughput and low efficiency. The misplacement of incorrectly sized particles into equipment not designed to handle such sizes can have a large adverse impact on both the separating performance and maintenance requirements for a preparation plant. Another important issue with screening is the desliming of coal products to remove ultrafine mineral sediments that are detrimental to quality and moisture. Many in the industry believe that the ability to screen ultrafine particles at sizes of 0.15 mm and smaller is particularly important. Efficient methods for dry screening, usually in the size range of five to 10 mm, are also needed to complement the dry coal cleaning processes that are being developed for upgrading lower-rank coals or coals in water-scarce regions. Decreasing noise, vibrations, maintenance costs, and energy consumption are also factors of interest in improving screening systems.

In addition to new screening systems, breakthrough technologies in ultrafine sizing are also needed in the coal preparation industry (Mohanty et al., 2002). Classification is the separation of particles by differences in settling velocities, which depends not only on particle size, but also on particle density and shape. Firth and O'Brian (2003) noted that while existing classification systems were adequate for the coal preparation industry of the past, "it is apparent that further improvements in yield/ash/moisture relationship achieved by coal preparation plants will require increased efficiency in this size separation step." The ability to classify and better utilize ultrafine particles will increase industry productivity and reduce the generation of wastes. Many in the industry believe that there is currently a lack of efficient ultrafine sizing and desliming technologies for separating below 0.1 mm. The use of advanced analytical tools, such as computational fluid dynamics, may prove useful in the redesign of existing classifiers and in the development of new types of classification processes.

f) Coarse Coal Cleaning

Modern coal preparation plants make use of density-based separators to upgrade coarse particles. Dense medium processes, such as vessels and cyclones, have become nearly standard in new or newly renovated plants for treating particles coarser than 0.5–1.0 mm. These processes are typically very efficient and provide a high feed capacity per unit of cost. As such, revolutionary improvements in the design of dense medium separators may not be required; however, their efficiencies can be increased substantially by improving online instrumentation and control. Also, there is a need to find alternative sources of affordable magnetite in view of a recent closure of the only domestic magnetite source and a growing demand from the Chinese coal industry that is exhausting supplies on the international market (Honaker, 2006). Better methods for minimizing losses of magnetite within the plant and recovering magnetite from waste streams would also help companies cope with the dwindling supply of magnetite.

The coal preparation industry needs to find new alternatives to float-sink analysis for quantifying the performance of their dense medium separators. Current float-sink analysis methods use high-density organic liquids to partition coal particles according to density. This type of analysis is routinely used to characterize the potential cleanability of coal and to assess the efficiencies of coal cleaning processes. Unfortunately, the halogenated organic solvents used in float-sink testing, such as naphtha, perchloroethylene, and tetrabromoethane, are likely to be phased out because of toxicity concerns (Galvin, 2006). Therefore, new methods need to be developed for conducting float-sink analysis. Alternatives may include new non-toxic dense liquids/suspensions (Callen et al., 2002; Koroznikova et al., 2007) and the development of new methods such as computed tomography (Lin et al., 2000) or gas pycnometry (Cameron, 2004). Moreover, because float-sink testing is labor intensive and time consuming, a fast, automated system for laboratory and online washability analysis is needed.

g) Water Clarification and Thickening

Thickening is a method by which particulates are allowed to settle by gravity in a large settling tank so as to provide a high-solids underflow that can be discarded, and clarified overflow that can be reused as process water. Gravity thickeners require large areas and significant capital funds to install. Although these units are typically very effective, there continues to be great interest in finding methods to increase the specific capacity (tons or gallons treated per unit area) of a thickener. This may be achieved by improving the chemical additives, optimizing the mode of reagent addition, or improving thickener design. Advanced design tools, such as computational fluid dynamics, are also recommended as a means of developing a better understanding of how thickeners operate and how performance may be improved. Future work needs to include fundamental studies on the effect of surface chemistry and water chemistry on thickener performance.

Considerable interest is also growing in the application of technologies such as deep-cone thickeners, which can produce a paste of 45 to 55 percent solids as underflow in waste coal applications (Parekh et al., 2006). Ideally, the paste can be discarded as a stacked pile, thereby avoiding the need for impoundments to handle waste slurry. This approach has already been implemented as demonstration projects at two mining sites in the eastern United States (Bethell et al., 2008). Further studies in this area, and utilization of the new technology to eliminate fine coal impoundments (discussed later), is of great interest to those working in the coal preparation industry.

4.3.2 ENVIRONMENTAL ISSUES

Effective environmental controls are essential to the long-term success of any coal mining operation. Although environmental issues and controls are discussed in greater detail elsewhere in this study, several of them are very specific to preparation plant operation and have been highlighted in this chapter. Potential environmental issues associated with coal processing projects have been classified by the World Bank to include air emissions, wastewater, hazardous materials, solid wastes, and noise (IFC, 2007). Subsets of these of particular concern to U.S. operators are described in greater detail in the following sections.

a) Coarse Waste Disposal

Of the various challenges facing the coal preparation industry, perhaps none are as significant as those which relate to waste handling and disposal. This importance can be attributed to the fact that coal cleaning operations produce large volumes of waste that must be discarded into refuse piles or impoundments. Refuse piles are designed to receive coarse particles of waste rock that can be easily dewatered. This material is relatively easy to handle and can be safely transported by truck or belt haulage systems to the disposal area with little or no potential for environmental damage. On the other hand, the waste contains solid and liquid components that may present long-term disposal problems depending on the sizes, types, and quantities of minerals present and the conditions under which the wastes are stored (e.g., dry vs. wet, loose vs. compacted). These factors play a key role in establishing the structural integrity (e.g., slope stability, surface water runoff, sediment containment, and seepage) and chemical nature (e.g., acid generation and metal dissolution) of the wastes. Solid sediments and dissolved ions may be transported by rainwater where they can pollute streams or groundwater. Many of these issues can be effectively managed via proper disposal practices and monitoring programs. On the other hand, uncertainties related to the intricate biochemistry and complex hydrology of the waste warrant continued investigation to fully assess the potential for negative effects associated with long-term disposal of coarse waste. Overall, improved waste characterization, including better methods to define the nature of wastes from coal preparation operations, is considered by many to be a high-priority need for the coal industry.

b) Slurry Handling and Disposal

The handling and disposal of fine slurry waste is widely considered to be one of the most difficult challenges facing the coal preparation industry. Fine wastes have historically been discarded into earthen impoundments for permanent disposal. An impoundment is an engineered structure consisting of a large-volume settling basin formed behind a manmade dam or embankment. The waste, which is difficult to dewater, is normally pumped from the preparation plant thickener to the impoundment as slurry. The slurry contains water, coal fines, silt, clay, and other fine mineral particulates from the processing plant. In most cases, the slurry is retained behind a manmade embankment (earthen dam) constructed from compacted refuse material. The impoundment is designed to have a volume that is sufficiently large to ensure that fine particles settle by gravity before the clear water at the surface is recycled back to the plant for reuse. In some cases, chemical additives may be used to promote settling and control pH. According to the National Research Council (NRC, 2002a), the coal industry discards 70 to 90 million tons of fine wastes each year into existing impoundments. In 2001, the Mine Safety and Health Administration (MSHA) reported that there were 713 active impoundments and ponds, most of which are located in central Appalachia (NRC, 2002a). Impoundments, like any body of water contained behind a dam, can pose safety and environmental risks if not properly constructed, monitored, and maintained. Potential problems include structural failures, seepage/piping, overtopping, acid drainage, and accidental discharges of process water containing particulates. Since the well-known Buffalo Creek dam failure in 1972, strict engineering standards have been mandated by government agencies to regulate the design and operation of impoundments. EPA (1994b) published a detailed report on the design and evaluation of impoundments for the mining industry. No failures of impoundment dams or overspills have occurred since this legislation was enacted. However, several breakthroughs of slurry into old mine workings beneath impoundments have occurred. The most notable was the Martin County incident, which released about 309 million gallons of slurry into streams and rivers in late 2000. A number of accidental releases of slurry have also been reported at various plant sites. A listing of slurry release incidents from coal preparation facilities and impoundments is maintained the on the Web by the Coal Impoundment Location and Information System (www.coalimpoundment.org). More than 90 percent of the volume of slurry accidentally released can be attributed to five spill events (Figure 4.31).

Several alternatives to impoundments have been employed by the coal industry in an attempt to avoid any future potential for environmental damage. Gardner et al. (2003) extensively examined these alternatives. For example, some mines use new modes of slurry disposal such as slurry cells and underground injection wells. Slurry cells have been used successfully in some cases (albeit at higher cost), but limitations associated with maintaining less than 20 acre-feet of settling area make this alternative difficult to apply in all cases. Likewise, the use of injection wells has raised public concerns about groundwater contamination and well water quality (Breen, 2007; Wilcox, 2007). To overcome these problems, various types of mechanical solid-liquid separators have been investigated as a means of more fully dewatering the fine solids prior to disposal. Notable examples include paste thickeners and different types of filters (pressure, vacuum, belt press, and plate-and-frame). Unfortunately, these systems have specific problems, such as high costs, large chemical demand, poor performance, high energy consumption, and safety concerns. Consequently, it is not surprising that the Committee on Coal Waste Impoundments that recently examined the

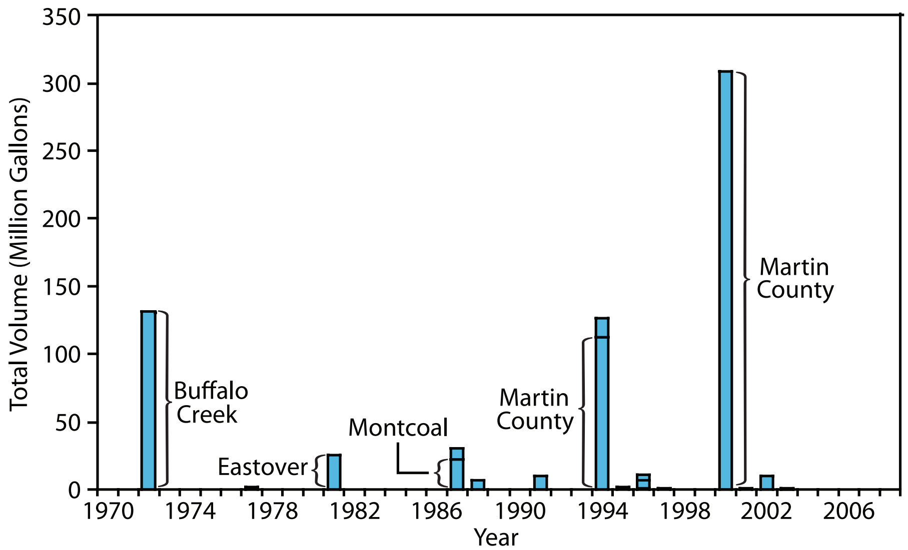


FIGURE 4.31 Accidental Releases from Coal Slurry Impoundments.
SOURCE: www. coalimpoundment.org.

issue of slurry disposal concluded that, "although there are alternatives to disposing of coal waste in impoundments, no specific alternative can be recommended in all cases." Therefore, in the absence of a preferred disposal method, continued development of new and improved processes and practices for slurry disposal is critically needed in the coal preparation industry.

c) Process Water Quality

The overwhelming majority of cleaning processes used in coal preparation require large amounts of process water. Nearly all of the process water is supplied by thickening units, which settle out ultrafine suspended solids and recycle clarified water back into the plant. A small amount of fresh make-up water from an external source is usually required to satisfy the balance between moisture contents of solids entering and exiting with the plant. The clarification and recycling of process water provides an effective means of reducing fresh water demands and lowing environmental impacts. On the other hand, plant operators are faced with the difficulty of avoiding the buildup of suspended solids and dissolved substances in the process water. The effects of these components on separating performance and plant maintenance (e.g., rusting and scaling) are not well understood. Deterioration of process water quality is known to reduce sizing efficiency, lower flotation recovery, and increase magnetite losses (Osborne, 1988). Evidence also suggests that dissolved ions adversely impact the performance of dewatering processes (Yoon et al., 2007). Detailed studies are needed to better understand these problems so that effective solutions can be identified and implemented before they impede preparation plant operations.

d) Residual Processing Chemicals

There are growing concerns by the public that chemicals used in coal processing may be harmful to the environment. The vast majority of coal is upgraded without being in contact with any chemical additives using density-based separation processes. On the other hand, fine coal particles (typically less than 0.2 mm) are processed using froth flotation circuits, which require small dosages of reagents known as collectors and frothers. Collectors consist of oily hydrocarbons, such as diesel fuel, kerosene, and fuel oil, which are insoluble in water and coat fine coal particles. If required, dosages are typically less than 0.3–2 pounds of collector per ton of fine coal processed. Likewise, frothers are added to all flotation systems to promote the formation of small air bubbles and to create a stable froth. Frothers are typically various types of alcohol and polyglycol surfactants

(Laskowski, 2001). Addition rates for frothers are typically less than 10–15 parts per million (ppm) in the process water. In addition, plants add water treatment chemicals into their thickening circuits to enhance settling rates and improve water clarity. These reagents commonly include various types of natural and synthetic coagulants and flocculants. Polymer flocculants, which are added in very small amounts, are diluted in strength to 0.01–0.05 percent solutions with water to improve performance. These chemical are also widely employed in the purification of drinking water and food as well as in the treatment of sewage, paper-making, oil recovery, storm water runoff, and many other types of industrial wastewater (Gregory and Bolto, 2007). Finally, coal operations may occasionally use small amounts of dust suppressants or freeze inhibitors to address seasonal problems that may arise at the plant site.

Several studies have been carried out in recent years to assess the ecotoxicological effects of chemicals used by processing plants. Although most of these studies have demonstrated that current disposal practices are not harmful and pose no risk to the public or environment, some studies have raised concerns that seepage from impoundments containing mine-influenced waters (e.g., residual chemicals, particulates, and acid drainage) may be impacting the population of freshwater mussels/mollusks in tributaries around coal mining and processing facilities (B. Beaty, The Nature Conservancy Clinch Valley Program, *pers. comm.*, 2007). Many of these issues were addressed in a recent symposium on the coexistence of coal mining and healthy aquatic ecosystems (Nature Conservancy, 2007). On the other hand, another recent study commissioned by the New Zealand Auckland Regional Council (ARC) examined the effects of residual coagulants and flocculants on natural waters (ARC, 2004). The study concluded that the negative impacts of these chemicals were "low level and not likely to be significant in relation to other factors which govern the health of aquatic communities. The benefit of reduced sediment levels in discharges is considered to outweigh the risk of any low level impacts attributable to residual flocculants." However, the study notes that improper application, such as misusage or overdosing, may create an environmental risk. Therefore, the development of new technologies that eliminate or significantly reduce the additions of process reagents is recommended as a way to address any potential concerns by the public. In the near-term, it is recommended that chemical manufacturers continue to develop "green" reagents for use in coal preparation facilities. Many plants that dispose of waste slurry via underground injection have successfully switched to natural flotation collectors, such as blends of canola oil, vegetable oil, and soybean oil, as environmentally friendly replacements for petroleum-based hydrocarbon collectors (Skiles, 2003).

e) Air Quality and Dust

EPA promulgated standards of performance for air quality for all new and modified coal preparation plants under the 1976 Clean Air Act. These New Source Performance Standards (NSPS) address all types of particulate emissions, including fugitive dust, which may result from producing, handling, transporting, and storing coal. Operations impacted by this regulation include crushers and breakers, sizing equipment, cleaning systems, thermal dryers, conveying systems, coal storage areas, and coal transfer/loading systems that are part of the coal preparation facility. For some processes, such as thermal dryers, opacity less than 20 percent must be maintained (Stationary Sources Branch, 1998). Dusting problems are not uncommon around material handling transfer points where ultrafine particles have the opportunity to become airborne. These locations may include truck and railcar load-outs as well as conveyor and chute transfer points in and around the preparation plant. Many operations use water trucks and water sprays with additions of various chemical and crusting agents to lower dusting problems. In addition, some operations make use of enclosures, such as silos and bins, to avoid exposure of coal to the environment. The use of inflatable structures over coal storage piles have also been attempted with limited success (Bowling, 2003). Despite these efforts, fugitive dust still seems to be an issue for many plant sites, often leading to disputes with the public and creating concerns for worker health. Therefore, work is needed to develop better practices and control technologies for reducing dust emissions. The reconstitution of fines via agglomeration and briquetting technologies can substantially reduce dust emissions, but these processes are currently too expensive to be practical in the coal industry. Additional R&D in this area is warranted to ensure that this environmental issue does not become a barrier to coal storage and production.

f) Permitting of New Facilities

Environmental compliance in the U.S. coal mining industry is strictly controlled by government regulations. History has proven that these regulations were necessary in many cases to ensure uniform environmental stewardship across the industry as a whole. Many mining companies now accept these environmental standards as good business practice and, in some cases, may go beyond simple compliance to promote goodwill and to set an example for others. On the other hand, many in the industry believe that regulatory constraints that act as barriers to the introduction of new technologies and practices into the industry need to be reexamined. For example, the additional liability associated with reclamation of abandoned coal waste piles and impoundments is constraining the extent of remining activity that the industry is willing to pursue. The application of new coal processing technologies has the potential to provide a financial return on remining operations, while simultaneously reducing the waste load in the environment. This win-win situation may be promoted by initiating demonstration projects for various stakeholder groups to prove the applicability of new technologies and practices. The knowledge base can be used to better inform decision-makers and enable them to reinterpret regulations that may be preventing remining/reprocessing operations for the cleanup of waste piles and impoundments. In addition, research and demonstration projects focused on new ways to process materials from remining should be pursued. The development of new equipment to allow remining of tailings and piles will increase the amount of materials that can potentially be remined. Technologies from other industries that can be used in remining for extraction and processing should be explored.

4.4 Future Considerations

4.4.1 CONVERSION PROCESSES

Coal preparation activities have traditionally been limited to those processes that involve physical separations. These processes include unit operations for particle sizing, concentration of organic matter, and dewatering/disposal of plant products. These processes are generally considered to be inherently benign because they do not alter the chemical structure of the individual particles contained in the coal. Conversion processes, which include carbonization, gasification, and liquefaction operations, are by this definition not considered to be part of the coal preparation industry. However, a new generation of coal preparation technology is being developed and commercialized that bridges the gap between traditional coal cleaning and coal conversion processes. These gateway technologies have the potential to reduce transportation costs and improve utilization properties for many of the low-rank coals located in PRB. Under this expanded definition, conversion processes that are geared to the production of enhanced solid fuels may also be included as coal preparation. The best known of these processes includes the K-Fuel process (Collins, 2007), Encoal process (Federick and Knottnerus, 1997), and SynCoal process (Sheldon, 1997). Some of these solid fuel production facilities may also produce gaseous or liquid byproducts that are of value in the synthetic fuel market. The upgrading of low-rank coals, which are abundant in the United States, is believed to be an attractive means of producing low-emission coals capable of meeting the 2010 Clean Air Interstate Rule (CAIR) standards. This approach is particularly attractive if the process simultaneously produces syncrude oil as a byproduct (Skov et al., 2007).

a) K-Fuel Process

One of the most widely publicized methods for upgrading low-rank coal is the K-Fuel process (Alderman, 2004). This technology is a decarboxylation process that uses heat and pressure to modify the structure of subbituminous coals. By driving off moisture and oxygen, the process has been shown to be capable of reducing emissions of nitrous oxides by 10 to 20 percent, carbon dioxide by eight to 12 percent, and mercury by as much as 70 percent (Wingfield, 2007). A commercial-size demonstration plant owned by Evergreen Energy is currently being operated in Gillette, Wyoming. Specific concerns associated with this technology include the high cost of thermal processing and problems related to disposal of process wastewater and spontaneous combustion of the treated products.

b) Encoal Process

The Encoal process was developed by SMC Mining Company and SGI International. The technology uses a two-step thermal treatment process to produce an enhanced solid coal fuel (char) as well as some derived liquid fuel. In the first processing step, the low-rank feed coal is heated until a completely dry solid is produced. The temperature is then increased in a second processing step to promote decomposition and drive off gases via mild gasification. According to published reports (e.g., DOE, 2003), the Encoal process generates about one-half ton of solid fuel and one-half barrel of condensed liquids from each ton of feed coal supplied to the thermal reactor. The products, as alternatives to existing fuel sources, are capable of lowering sulfur emissions in coal-fired boilers nationwide (DOE, 2002). The gaseous products that are not condensed into useful liquid are burned to supply thermal energy for the process. A 1000-ton-per-day demonstration plant was successfully operated between 1992 and 1998 under DOE sponsorship near Gillette, Wyoming. A commercial-scale plant is now under contract for design and construction. Concerns associated with this process include high treatment costs, excess fines production, dusting problems, wastewater generation, and the need for coal-char stabilization (to prevent spontaneous combustion).

d) SynCoal Process

SynCoal technology couples thermal upgrading with physical cleaning to upgrade low-rank coals into high-quality coal products. In this process, high-moisture coal is processed through vibrating fluidized bed reactors in three sequential stages—two heating stages followed by an inert cooling stage. These reactors remove chemically bound water, carboxyl groups, and volatile sulfur compounds. After thermal upgrading, the coal is put through a deep bed stratifier cleaning process to separate the pyrite-rich ash from the coal. When fed a typical low-rank western coal, the SynCoal process can provide a product with a heating value of up to 12,000 BTU/lb with moisture and ash contents as low as one percent and 0.3 percent, respectively (DOE, 1997). A demonstration plant (45 ton per hour) was successfully operated near Western Energy Company`s Rosebud coal mine near Colstrip, Montana. Although the plant closed in 2001, the facility generated more than two million tons of products during its lifespan (DOE, 2006a). Similar to the other mild conversion technologies, concerns associated with this process include high treatment costs, dusting problems, and product instability.

4.4.2 HUMAN RESOURCE SHORTAGES

Another looming issue for the coal preparation industry is the shortage of skilled labor—trained technicians and graduate engineers. As in other sectors of the mining community, human resource managers are finding it increasingly difficult to hire suitable replacements for their rapidly aging workforce. The severity of this problem can be demonstrated by examining workforce statistics compiled in this study from major coal producers in the Appalachian coalfields. These data indicate that the average age of employees who manage, operate, and maintain the preparation plant is 52 years. Of these, more than half will have 30 years of service and may be eligible to retire in the next two to five years. Although specific details were not available on the types of positions occupied by these employees, it was generally believed that highly skilled personnel, such as electricians, make up a larger percentage of the aging workforce than general laborers. Fortunately, labor demands for the plant complex are low because productivity (tons per man-hour) for plant workers is an order of magnitude greater than for underground miners (Carty, 2007) because of the high capacity and extensive automation of processing systems. On the other hand, the sophistication associated with processing equipment often requires a higher level of technical skill than can be filled by high school graduates.

As recommended by Watzman (2004), new partnerships in education and training need to be undertaken between government and industry to help supply skilled workers and engineers to an industry transformed by technology and mechanization. Support of programs in higher education is also essential to ensure a supply of well-trained engineers that are needed to address new technical issues that face the industry. It is this group that often brings new technology to the forefront. As pointed out by the Western Australia Technology & Industry Council (2004), "While R&D is a major factor producing new knowledge, a knowledge hub requires a strong university sector to complement these investments by transferring the knowledge to students. These sorts of complementary functions create a highly skilled environment for transferring knowledge between the university and business." Moreover, this new generation of engineers must have a broad interdisciplinary education in order to tackle the wide range of technical issues facing the mining industry. Instruction is needed in both basic and applied studies that span several disciplines in engineering and science.

4.4.3 RESEARCH AND DEVELOPMENT

Coal mining is often perceived by outsiders as a mature industry that can offer only small returns on investments in basic research and technology development (NRC, 1995). Consequently, only 0.2 percent of the $538 million spent in 2005 by the federal government on coal-related R&D was dedicated to coal mining and processing (NRC, 2007a). For coal preparation, this widespread belief stems from the misconception that the benefits of new technology can only be measured by increased coal production or reduced environmental impact. This viewpoint fails to account for the large financial effect of new processing technology on economically recoverable coal reserves. A recent study (Luttrell, 2004) demonstrated that many R&D projects in coal preparation have payback periods of less than a few months, and some less than a few weeks. A single percentage point improvement in plant efficiency can often provide double digit or greater improvement in profitability. The increased margins resulting from the adoption of new technology makes it possible to extend the reserve base of economically recoverable coal. This broader viewpoint suggests that continued coal processing R&D efforts are justified, particularly when environment and utilization benefits of cleaner coal fuels are also considered. One such example would be to develop technologies for recovering ultrafine particles, which are currently discarded as waste by many modern coal preparation facilities (Bethell and Lutrell, 2005).

5. CONCLUSIONS

There are several barriers associated with coal preparation that may limit future coal production in the United States. These barriers differ in the eastern and western states because of regional variations in the characteristics of the coal resources and industry activities in these regions.

TECHNOLOGICAL BARRIERS

The steady decline in the quality of U.S. coal reserves will require processing of feed coals with increasingly difficult washing characteristics. Therefore, continued development of improved solid-solid and solid-liquid separation technologies for coal preparation is needed to help offset the adverse effects of these changes to coal quality and recovery. The technological developments may require both incremental enhancements to existing processes as well as evolutionary technology that are more efficient, less costly, and environmentally attractive. Examples of incremental improvements may include the development of advanced processes for fine coal cleaning, dewatering, and reconstitution or the stepwise integration of some coal preparation functions within mine extraction operations (e.g., underground removal of coarse rock to minimize environmental footprint and reduce haulage costs). Potential examples of evolutionary technology may include the construction of small-scale gasifiers that obviate the need for dewatering by utilizing fine coal slurry at existing preparation plant sites as well as nontraditional processing strategies at end-user sites (e.g., dry removal of well-liberated impurities after pulverization at coal-fired utilities to reduce moisture, dusting, and waste disposal issues). A new generation of online systems for real-time characterization of coal size, density (washability), and quality will also be advantageous to deal with future declines in feedstock consistency.

Western coal operations face even greater challenges from a decline in reserve quality, because coals in this region have traditionally not required preparation other than size reduction. Increasingly stringent customer demands coupled with an overburdened railway infrastructure will pressure these operations to improve quality via the application of new coal processing technologies. Dry cleaning processes, such as pneumatic separators and electronic sorters, which can efficiently upgrade coals over a wide range of particle sizes, need to be developed for use in western states with scarce water resources. The remoteness of western resources may also dictate the need for next-generation upgrading facilities, such as mild conversion plants, which can reduce moisture and increase the heating value of low rank coal so the existing energy transportation system can be better utilized. Another option would be the construction of mine-mouth power plants close to coal production facilities, which would eliminate transportation barriers and improve the cost effectiveness of utilizing the large reserve base of low-sulfur western coals.

Unfortunately, most coal preparation technology now used in the United States is either adapted from other industries in a patchwork manner or produced by a relatively small group of manufacturers with very limited R&D resources. Moreover, coal producers are generally not capable of technology development because of the lack of internal technical personnel with the process engineering skills necessary for equipment development, testing, and manufacturing. Therefore, cost-shared government support for processing R&D, with industrial guidance and oversight, is recommended to ensure that the United States remains competitive in coal technology development.

ENVIRONMENTAL BARRIERS

Several environmental issues represent significant challenges to expanded utilization of U.S. coal preparation facilities. Although these impediments vary from state to state, the most significant challenge facing the industry is the management of coal wastes. The declining quality of reserves has contributed to the expansion of waste storage repositories such as slurry impoundments. Well-publicized events, such as impoundment failures, have raised serious questions as to whether new regulations, better practices, and improved technologies are needed to eliminate the possibility of future disasters. New methodologies need to be developed for dewatering, handling, and permanently disposing waste slurry. New techniques are also needed for locating and assessing the stability of impounded slurry over abandoned workings. In addition, the development of new processing technology that is specifically designed to re-treat and recover coal resources from existing or abandoned impoundment areas is an attractive approach for reducing waste.

Issues are also being raised regarding the environmental effects of chemical additives used in coal preparation. Although these reagents are safe when applied in accordance with manufacturer recommendations, proponents argue that the long-term effects and complex interactions that may occur when these chemicals are released to the environment are not well understood. To address these concerns, new processes or chemical additives need to be developed that minimize, and preferably eliminate, the use of processing reagents that have potential risk to the ecosystem.

FIRST STEPS IN REMOVING THE BARRIERS

The following are recommended as first steps in removing these barriers.

- ***Establish a national coal washability database.*** Detailed data related to the cleaning characteristics of much of the nation's coal resources do not currently exist; what does exist is not readily usable. Therefore, the establishment of a detailed database of coal washability information that fully defines the cleanability of U.S. coal reserves at different liberation sizes is recommended. In particular, detailed data regarding the potential removals of ash, sulfur, mercury, radionuclides, and other elements of environmental concern are needed. This information can provide the framework for developing effective and realistic policies for the optimum usage of the nation's valuable coal resources by producers, consumers, government agencies, and other interested stakeholders.

- ***Provide support for new and improved technologies for upgrading coal quality.*** The commitment by government and industry for cost-shared support of basic and applied R&D programs in areas related to coal preparation is recommended. Specific technical areas requiring additional R&D support include fine particle cleaning, fine particle dewatering, dry separation processes, advanced instrumentation, low-rank coal upgrading, particle reconstitution, and waste disposal and handling. Cross-cutting initiatives, which may combine the functions of coal extraction, processing, transportation and utilization, also warrant continued investigation as revolutionary approaches to enhancing the performance of coal-based energy systems.

- ***Address environmental issues associated with waste disposal.*** Environmental impacts associated with preparation wastes continue to be a source of concern for the environmental community. Therefore, continued support is recommended for environmental studies designed to quantify the long-term and complex effects of preparation operations on human health and the environment. In addition, the development of new technologies for remining and reprocessing valuable coal contained in existing and abandoned waste impoundments is recommended.

Chapter 5 Health and Safety Issues

1. SUMMARY

Every mining advance is an exploratory journey into new ground and new conditions. Although reasonably accurate predictions of what is expected can be made, occasionally unanticipated conditions are encountered and the challenge is to react quickly to establish control over health, safety, and productivity. Despite the portrayal of the mining industry by some as "dirty and dangerous," the industry has made technological innovations that have led to major improvements in mine safety and productivity. The goal of a completely safe mine continues to remain elusive; however, its pursuit is relentless.

The purposes of this chapter are to: (1) present an overview of the historical performance of the U.S. coal mining industry in the area of health and safety; (2) discuss current trends in coal mine safety, (3) discuss current trends in coal mine industrial health; (4) present a review of disasters in the coal mining industry in the past 25 years; (5) summarize legislative efforts concerning health and safety at the federal and state levels; (6) review modern safety management approaches and their adoption by the coal mining industry; (7) discuss and analyze major factors that are likely to affect coal mine health and safety in the future; and (8) provide suggestions for enhancing progress towards completely safe mines.

2. INTRODUCTION

Through the years, the U.S. mining industry has made significant progress in mine health and safety by developing and incorporating major advances in mining technology, equipment, processes, and procedures. Increased attention to mine planning and engineering, mining operations, worker selection and training, and safety equipment and practices, all aided by more effective laws and regulations, have made mines safer to work in than ever before.

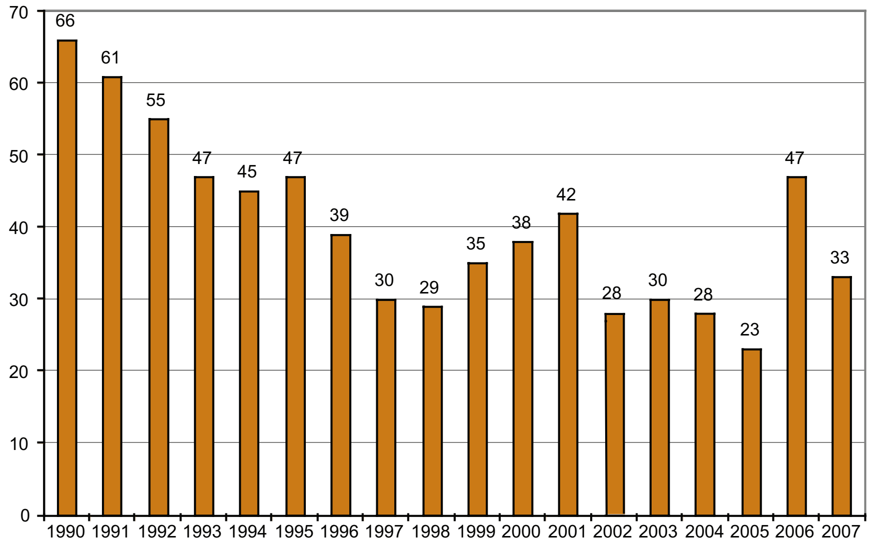


FIGURE 5.1 Coal fatalities, 1990 to 2007. SOURCE: Mine Health and Safety Administration data, 2008, http://www.msha.gov/stats/centurystats/coalstats.asp.

The number of fatalities and the fatality rate (per 200,000 man-hours) in coal mining generally has been decreasing since 1990, reaching a low of 23 and 0.02, respectively, in 2005 (Figure 5.1 and Table 5.2). Using the available data for coal operator employees, the number of injuries and injury rates in lost work days also decreased, reaching a low of 3,062 and 3.51, respectively, in 2005. This trend was interrupted by recent disasters, which increased fatalities in the nation's coal mines to 47 in 2006 and 33 in 2007.

It is important to note that this overall decrease in fatalities and fatality rates occurred as coal production levels increased. According to the Mine Health and Safety Administration (MSHA, 2008), in the period 1970 to 2006, fatalities decreased by 81 percent and the fatality rate declined by 33 percent, while coal production increased by 89 percent. Substantial progress over the last 30 years in problematic areas such as roof falls, traumatic injuries, and airborne respirable dust control played an important role in this improvement. The coal industry, however, still has fatality and injury rates that are significant when compared with other industries.

Health and safety statistics and data collected by the Bureau of Labor Statistics for all industrial sectors and occupations indicate that coal mining fatalities represent only a small fraction of total work-related fatalities (~ 0.08 percent). However, the fatality and injury rate of the coal industry is significantly higher when compared with the other industries. According to the Centers for Disease Control, "coal mining exceeds all other industries with the highest percentage of lost work days resulting from nonfatal injuries. Of ongoing concern is the mortality associated with black lung disease, or coal workers' pneumoconiosis, which is estimated at over 1,000 deaths per year among U.S. coal miners. Approximately 25 percent of these deaths are due to silicosis. Another important issue for miners is the prevention of hearing loss. Nearly

70 percent of miners experience occupational hearing loss by the time they retire" (NIH, 2008).

The recent spate of disasters, such as those in Jim Walters in Alabama, Sago and Alma in West Virginia, and Crandall Canyon in Utah, and the continuing occurrences of fatalities, injuries, and illness, have focused attention once again on safety and health issues in the coal industry. A direct consequence has been major changes in state and federal legislation, including the enactment of the Mine Improvement and New Emergency Response Act of 2006 (or MINER Act) at the federal level. There is continuing impetus for additional legislative action although many of the new statutes require further research, development, and demonstration. Additional health and safety requirements in the enacted and proposed laws and regulations are likely to impact mine investment, mine production, productivity, and costs in current and future mines.

3. HISTORICAL MINE HEALTH AND SAFETY PERFORMANCE

The story of mine health and safety during the twentieth century is one of sustained attack on the causes of mine deaths and disasters, with major successes along the way. The significant historical progress of the U.S. mining industry in reducing injury and illness rates is a matter of record. At the beginning of the century, more than 2,500 coal miners and 1,000 metal and nonmetal miners were being killed in mine accidents each year. Mine fires and explosions were common in the coal industry. A dozen coal mine explosions occurred on average each year during the first decade of the century. As shown in Figures 5.2 and 5.3, over the course of the twentieth century, significant progress has been made in reducing fatalities in the mining industry, particularly in coal mining. The reductions have been incremental, revealing the importance of advances in technology and extraction methods, safer

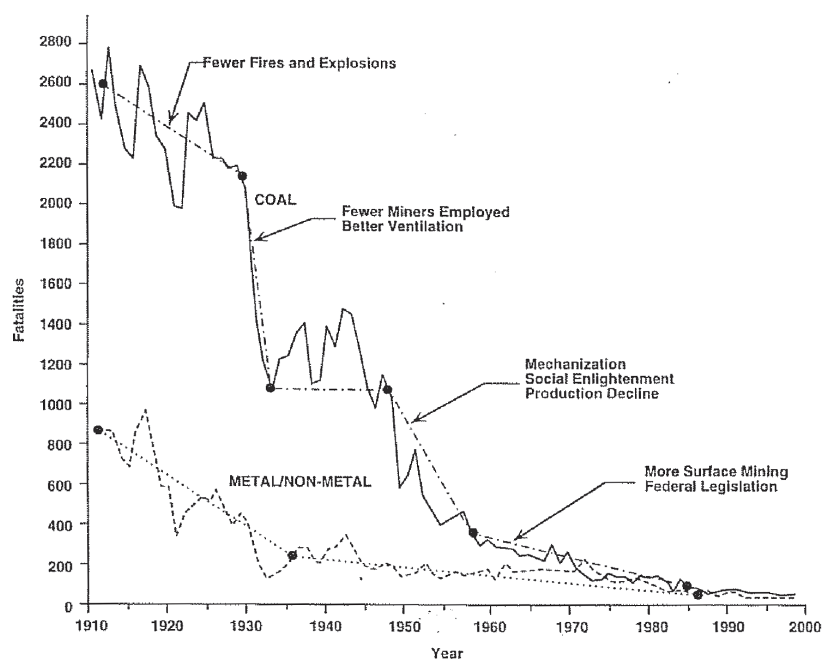


FIGURE 5.2 The number of fatalities in the U.S. mining industry (1910–2000). SOURCE: Ramani and Mutmansky, 1999.

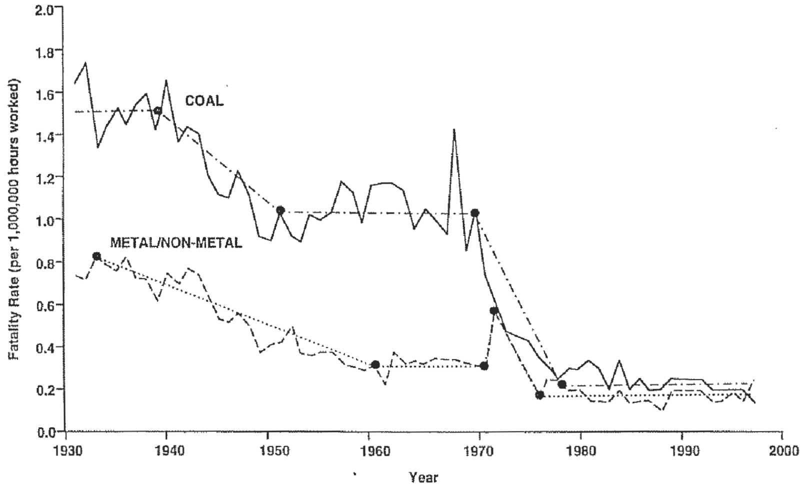


FIGURE 5.3 Fatality rate per million man-hours worked in the U.S. mining industry (1930–2000). SOURCE: Ramani and Mutmansky, 1999.

operating practices, increased mechanization, new federal legislation, and increased surface extraction (Ramani and Mutmansky, 1999).

Several types of illnesses are associated with working in a mining environment. The most common causes for these illnesses are ***airborne particulate matter*** (coal dust, silica dust, metal mine dust, and diesel exhaust particulate matter), which can lead to a number of respiratory diseases such as coal workers' pneumoconiosis (CWP) and silicosis; ***noise***, which can lead to hearing impairment; ***machine design and posture***, which can lead to a number of musculoskeletal disorders; and ***unsanitary conditions***, which can lead to skin diseases. Exposure to ***extreme heat***, which occurs in surface coal mines in Texas, or to ***extreme cold***, which occurs in surface coal mines in Wyoming, can result in heat stroke or freezing, respectively. Through improved equipment design and operating practices that reduce or eliminate exposure to harmful agents in the environment, considerable progress has been made in the control of health hazards from the most common causes of occupational illness. A major attack on the control and elimination of CWP was mounted with the enactment of the 1969 Coal Mine Health and Safety Act. This act directs the National Institute for Occupational Safety and Health (NIOSH) to study the causes and consequences of coal-related respiratory disease and, in cooperation with MSHA, to carry out a program for early detection and prevention of CWP. Figures 5.4 and 5.5 show that by the end of the century, the concentration of respirable airborne coal mine dust in continuous miner and longwall sections in underground coal mines and the mortality rate due to CWP also decreased. As the twenty-first century approached, the industry made good progress towards eliminating health and safety threats to its miners.

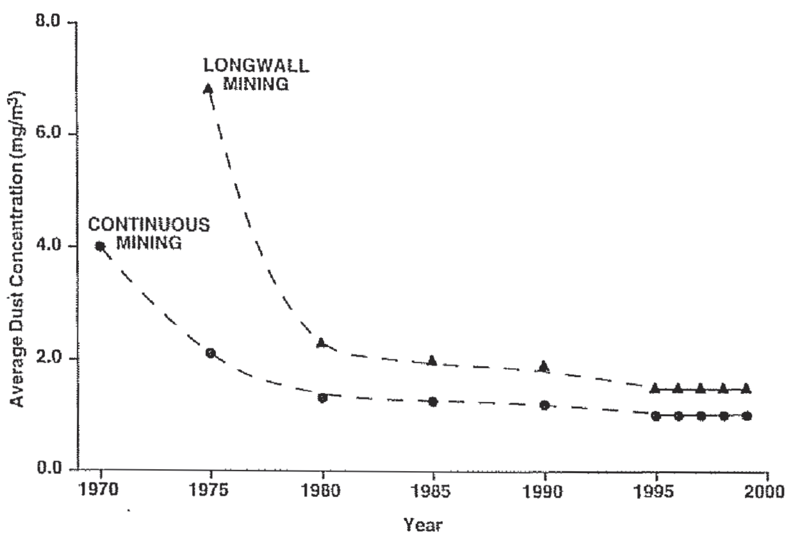


FIGURE 5.4 Average airborne respirable dust concentration in underground continuous and longwall mining sections in the United States. SOURCE: Ramani and Mutmansky, 1999.

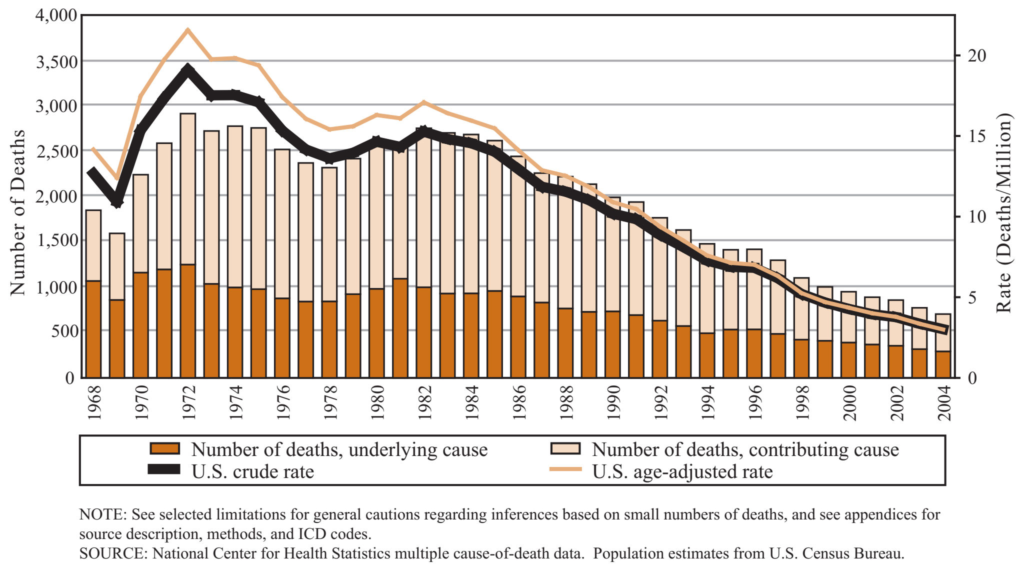


FIGURE 5.5 Number of deaths and mortality rates for U.S. residents age 15 or older with CWP recorded as an underlying or contributing cause on the death certificate, 1968–2004. SOURCE: http://www2a.cdc.gov/drds/WorldReportData/FigureTableDetails.asp?FigureTableID=509&GroupRefNumber=F02-01.

Mine safety statistics from MSHA for the entire mining industry for the last seven years (Table 5.1) reveal that the decrease in fatality and injury rates is not as rapid as in the previous decade. In fact, the number of fatalities has increased in 2006 and 2007 as compared to previous years because of the disasters in the Sago, Alma, and Crandall Canyon coal mines. In the latter decades of the twentieth century, noise, diesel emissions, and musculoskeletal disorders emerged as major issues for worker health. As chemical use in mining increased, threats from chemical hazards are also recognized.

Progress in mine health and safety in the United States is tied inextricably to efforts of the U.S. Bureau of Mines (USBM), which was created in 1910 to investigate mining methods, including mine safety and accident prevention. The USBM was closed by congressional order in 1995 and its health and safety program was transferred to NIOSH in 1997. As a point of reference, the NIOSH budget for mine health and safety research in 2005 was approximately $30 million, which represented a decrease of $12 million in nominal dollars from that of the 1995 USBM budget. Two recent reports from the National Research Council (NRC), one on the evaluation of mine health and safety research at NIOSH (NRC, 2007b) and another on coal research and development needs (NRC, 2007a) are relevant to any discussion of health and safety in the coal mining industry.

TABLE 5.1 All mine safety statistics (2001–2007).

	2001	2002	2003	2004	2005	2006	2007
Number of mines	14,623	14,520	14,391	14,478	14,666	14,885	14,786
Number of miners	347,228	329,114	320,149	329,008	344,837	363,497	376,386
Fatalities	72	70	56	55	58	73	64
Fatal injury rate[1]	.0232	.0240	.0197	.0184	.0183	.0220	.0192
All Injury rate[1]	4.75	4.60	4.23	4.05	3.92	3.64	3.42

[1] Reported injuries per 200,000 hours worked
SOURCE: http://www.msha.gov/MSHAINFO/FactSheets/MSHAFCT10.HTM, MSHA, 2008.

4. CURRENT TRENDS IN COAL MINE SAFETY

Table 5.2 shows mine safety statistics for the coal mining segment of the mining sector for the years 2001 to 2007. A number of disastrous events in underground coal mining in 2006 and 2007 reversed the declining trend in both number of fatalities and the fatal injury rate. These events have also had a profound impact on the perception of safety in coal mines. The impacts of the explosions of gas and fire in 2006 at Sago and Darby and the massive strata failure in 2007 in Crandall Canyon on the future design and operations of the mining industry are yet to be fully assessed.

A more detailed data analysis indicates that there were 161 fatalities in the coal sector for the period 2003–2007 (Table 5.3). In general, the surface segment (S), which produces nearly twice as much coal as the underground segment (UG), accounted for less than 40 percent of fatalities. Annually, the surface segment experienced fatalities ranging from a low of nine in 2005 to a high of 15 in 2003 and 2007. The major contributors to fatalities in surface mining are powered haulage (23), machinery (14), electrical (6), and fall of highwall (4).

Underground mining is generally regarded as more dangerous than surface mining because of its unique environment, with features such as geologic enclosure of the workings and the ambient mine atmosphere. Both of these factors have been associated with sudden, catastrophic, and horrific consequences. Besides disasters, roof and rib falls and powered machinery are major sources of hazards underground. The fatality data in Table 5.3 reflect this. For example, the underground segment accounted for 98 fatalities from 2003 through 2007.

Falls of roof and back are major contributors to fatalities in underground mining (24), as are ignitions or explosions of gas and dust (20), powered haulage (18), fall of face and rib (14), and machinery (10). The explosions and fires at Sago and Darby and the strata failure in Crandall Canyon accounted for the most fatalities in 2006 and 2007, respectively, and deserve critical evaluation of the causes of these disasters.

The large number of fatalities caused by roof falls reveals the risks involved in working underground, where the local geological conditions are not very accurately predictable; this uncertainty calls for improved methods of roof strata assessment and support determination. Fatalities associated with powered haulage and machinery also reveal the need to critically evaluate the visibility, clearance, and warning requirements for miners to work

TABLE 5.2 Coal mine safety statistics (2001–2007).

	2001	2002	2003	2004	2005	2006	2007
Number of coal mines	2,144	2,065	1,972	2,011	2,063	2,113	2,013
Number of miners	114,458	110,966	104,824	108,734	116,436	122,975	122,328
Fatalities	42	28	30	28	23	47	33
Fatal injury rate[1]	.0402	.0279	.0312	.0273	.0205	.0400	.0287
All Injury rate[1]	6.03	6.03	5.38	5.00	4.62	4.46	4.19

[1] Reported injuries per 200,000 hours worked

SOURCE: http://www.msha.gov/MSHAINFO/FactSheets/MSHAFCT10.HTM, MSHA, 2008.

TABLE 5.3 Distribution of coal fatalities (2003–2007).

Fatalities chargeable to the coal mining industry	2003		2004		2005		2006		2007		TOTAL	
	UG	S	UG	S	UG	S	UG	S	UG	S	UG	S
Electrical	3	1	2	2	0	1	0	2	0	0	5	6
Exp vessels under pressure	0	1	0	0	0	0	0	1	0	0	0	2
Exp & breaking agents	1	0	0	0	0	0	1	0	0	1	2	1
Fall/slide material	0	0	0	1	0	0	0	0	1	0	1	1
Fall of face/rib/highwall	1	0	1	1	0	0	3	1	9	2	14	4
Fall of roof or back	2	0	3	0	9	0	7	0	3	0	24	0
Fire	0	0	0	0	0	0	2	1	0	0	2	1
Handling material	0	0	0	0	0	0	0	0	1	0	1	0
Hand tools	0	0	0	0	0	0	0	0	0	0	0	0
Non-powered haulage	0	0	0	0	0	0	0	0	0	0	0	0
Powered haulage	2	7	4	5	5	5	6	3	1	3	18	23
Hoisting	0	0	0	0	0	0	0	0	0	0	0	0
Ignition/explosion of gas/dust	3	1	0	0	0	0	17	0	0	0	20	1
Inundation	0	0	0	0	0	0	0	0	0	0	0	0
Machinery	3	4	4	5	0	1	1	2	2	2	10	14
Slip/fall of person	0	1	0	0	0	2	0	0	0	7	0	10
Step/kneel on object	0	0	0	0	0	0	0	0	1	0	1	0
Striking or bumping	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	15	14	14	14	9	37	10	18	15	98	63
END OF YEAR TOTAL	**30**		**28**		**23**		**47**		**33**			

SOURCE: http://www.msha.gov/stats/charts/coal2007yearend.asp.

safely around moving equipment underground. Because powered haulage and machinery are also major contributors to fatalities in surface coal mining, the issue of safety around large-scale equipment is common to both surface and underground segments.

5. INTERNATIONAL SAFETY PERFORMANCE COMPARISON

International comparisons of safety performance of the mining industry can be valuable for developing recommendations, strategies, and best practices to improve the safety and health performance of the sector in all coal-producing countries. However, comparing the safety performances of mining industries across countries is complex and difficult, even after data on incidence and severity have been normalized to allow comparisons. Available data are limited, inconsistent, and often suspect. Data on fatalities are usually sparse. Further, data for nonfatal injuries are often presented using different criteria and are collected under different regulatory reporting requirements. For example, some countries/regions (e.g., Queensland, Australia) only collect injury data resulting in lost time from work. In South Africa, injuries are reported if more than 14 days are lost. As a result, focusing only on comparisons involving incidents of lost time at work between the countries is extremely limiting for valid comparisons. Also, it is difficult to discern trends in the short term, as there is considerable variability in the data from year to year. To make meaningful comparisons, it is necessary to recognize the major differences in factors that are likely to affect both the numerators and denominators of the rate statistics and to consider a sufficiently long interval of time to capture the temporal variations.

Beyond issues of accident injury definitions, reporting requirements, data collection, and management, it is very difficult to draw meaningful comparisons and conclusions because of the differences in technical and cultural factors in different coal-producing countries, such as geological settings, mining methods, mining technology, production and productivity, number and size of mines, age of mines, training requirements, laws, regulations, and oversight. This is true of the top five coal producers of the world that produced in 2006: China (2620 million tons), United States (1163 million tons), India (497 million tons), Australia (420 million tons), and South Africa (269 million tons) (http://www.eia.doe.gov/emeu/aer/txt/ptb1114.html).

The Australian Minerals Council in the Annual Safety Performance Report (Minerals Council of Australia, 2007) includes a section on international comparisons for both the entire mining industry, as well as the coal sector. The report also highlights some of the difficulties in developing meaningful conclusions on the basis of the comparisons. In the case of coal mining, the annual report provides some basic comparisons between the United States and Australian coal sectors, with some information also on the South African coal industry.

The Australian coal sector is closest to the U.S. sector in terms of technology employed in underground and surface mines. Several coal companies have extensive mining operations in both Australia and the United States. Therefore, it may be useful to look at the coal mining safety records of these two countries, recognizing their limitations. No attempt is made to look into occupational illness data, as they are not readily available. Further, only publicly available data were used from the Australian Coal Association (http://www.australiancoal.com.au/), Minerals Council of Australia (http://www.minerals.org.au/), U.S. Mine Safety and Health Administration, and several company websites.

As noted above, U.S. coal production is over three times the production of Australia. Almost all the coal mined in the United States is domestically consumed, whereas more than 75 percent of the coal mined in Australia is exported. The split in production between underground and surface mines is comparable between the two countries; in the United States, in 2006, it was 30/70 where as in Australia, it was 25/75. However, U.S. underground coal production is nearly equal to total Australian coal production. In 2006, there were 118 operating coal mines in Australia, of which 44 were underground mines. The number of total coal mines in the United States is about 18 times the number in Australia, and the number of underground mines is about 15 times. A greater proportion of the U.S. coal mining workforce is employed in underground coal mines. Specifically, there are about 30,000 persons employed in the Australian coal mining sector, with underground mines accounting for about 9,000 of them. Comparative figures for the United States (2006 data) are, respectively, 85,000 and 43,000 (exclusive of contractor employees and surface workers in underground coal mines). There are a large number of comparatively small surface and underground coal mines in the United States; however, there are several very large operations as well. For example, three U.S. coal producers (Peabody Energy, Arch Coal, and CONSOL Energy) produce around 350 million tons annually, based on their annual reports. Production comes from about 60 mines around the United States; 60 percent of them are underground mines. These three companies employ approximately 21,000 people.

The safety statistics of the Australian and U.S. coal industries are presented in the latest Australian Minerals Council Annual Safety Performance Report, 2005–2006 (Minerals Council of Australia, 2007). For comparisons, rates have been normalized for million man-hours. The report clearly indicates that coal mining in Australia and the United States has experienced significant health and safety improvements over the 10-year period, 1995/6 to 2005/6 (for the United States, the figure corresponds to end of 2005 data), as demonstrated in the number of fatalities, fatality rate, number of lost time injuries, and lost time injury frequency rate.

For the 10-year period 1995/6 to 2005/6, there were 145 fatalities in the Australian minerals sector. The annual number of fatalities varied from a low of seven to a high of 33, averaging more than 14 fatalities per year. There were no fatalities in the coal sector for the last two years of the period. The average fatality injury frequency rate (defined as the number of fatalities per million man-hours worked) for this 10-year period for the coal sector was 0.06, with 0.13 in underground coal mining and 0.02 for surface coal mining.

The total number of fatalities in the U.S. mining sector was 742, corresponding to 321 for coal and 421 for all other mining. The average annual employment during this period was 345,000, with coal sector employment at 115,000 and all other mining at 230,000. The annual number of fatalities varied from a low of 55 in 2004 to a high of 91 in 1997 for an annual average of 74. The number of fatalities in coal mining varied from a high of 42 to a low of 23. The underground coal mining sector had a high of 32 fatalities and a low of 14, whereas the surface mining sector had a high of 10 fatalities and a low of two. During this decade, the methane gas explosion at Jim Walter Resources No. 5 mine in Alabama claimed the lives of 13 miners. The average fatality rates for the coal mining sector for the 10-year period, 1995/6 to 2005/6, is 0.17 for underground coal mining and 0.08 for surface coal mining.

The lost time injury frequency rates from the same Australian report (Minerals Council of Australia, 2007) for Australia and the United States are presented in Figure 5.6. An injury that results in at least a full shift absence is defined as a lost time injury, and the lost time injury frequency rate is the number of injuries per million man-hours worked.

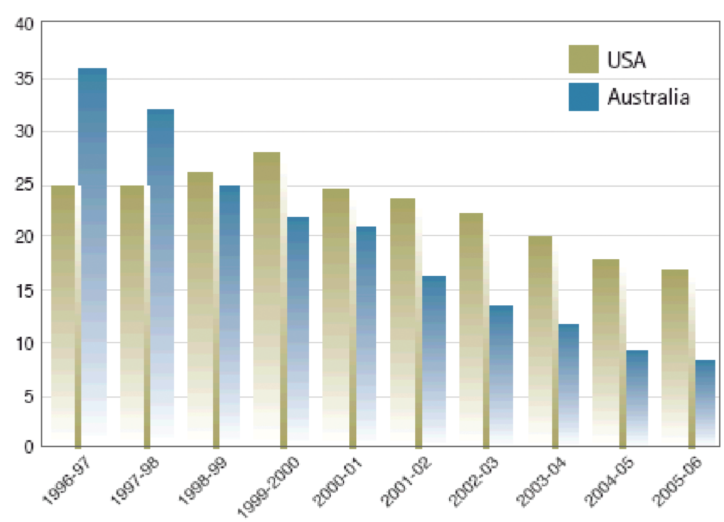


FIGURE 5.6 International coal mining lost time injury rates. Source: Minerals Council of Australia, 2007.

The Australian data show progress from an average rate of 19 over the 10-year period to eight in 2005/6. The underground coal lost time injury frequency rate was 19, and the surface four, for the last recorded year, 2005/6. The U.S. data also showed a decline from an average of 22 over the 10-year period to 17. The underground coal lost time injury frequency rate was about 26 and the surface rate was 8 for 2005. The latest available data from the United States (2006) indicate an overall lost time injury rate per million man-hours of 16, with a rate of 25 for underground mines and seven for surface mines. As noted earlier, these data may still include inconsistencies for proper comparisons, as some MSHA reported incidents (e.g., accidents in office, surface plants) may not be included in the Australian database used in developing Figure 5.6.

One of the major conclusions of this analysis is that the Australian and U.S. coal industries have been improving in their safety performances and that, at least in the nonfatal injury frequency rates, the performances are fairly comparable. To search for greater significance in these statistics would be rather meaningless due to the data limitations, including data quality and mining and structural differences of the sector in the two countries. Moreover, it would be inappropriate to draw conclusions, using such benchmarks, on the effectiveness of the regulatory regimes in the two countries. It is, however, clear that to achieve the goal of totally safe mines, much work needs to be done in design and operation of mines to eliminate root causes of disasters and accidents in mining.

6. CURRENT TRENDS IN COAL MINE HEALTH

As new technologies for monitoring and analysis were introduced, the ability to identify occurrences of health impairment and new sources of occupational illness increased. The ability to identify health improvements can be expected to continue, as there are also advances being made in the physical and biological sciences and in the field of industrial instrumentation. Reference has already been made to the occurrence of several occupational illnesses resulting from working in mines, particularly CWP.

Table 5.4 summarizes the distribution of cases of occupational illness in coal mining, other mining, and both combined for 2005. Data indicate that the coal sector accounted for over 50 percent of cases of occupational illness in that year. Within the coal sector, hearing loss, CWP, and musculoskeletal effects account for over 80 percent of illnesses.

6.1 Respiratory Diseases

The control of respiratory diseases continues to be important in view of the potential for increased generation and entrainment of particulate matter caused by increased production and productivity in mines. In particular, equipment design, operating practices, monitoring and control techniques, and new standards are continuing to be explored to control exposures to coal and silica dust and diesel particulate matter.

TABLE 5.4 Distribution of cases of occupational illness in mining, 2005.

TYPE OF ILLNESS	COAL	NON-COAL	TOTAL
Hearing loss or impairment	37	32	**69**
Joint, tendon, muscle inflammation or irritation	76	69	**145**
Black lung (CWP)	32	0	**32**
All other occupational illnesses	34	62	**96**
All occupational illness	179	163	**342**

SOURCE: Summarized from http://www.cdc.gov/niosh/mining/statistics/illness.htm.

CWP rates have decreased by more than 70 percent in U.S. coal mines during the last 35 years, from about 11 percent in 1970 to 2.6 percent in 2003 to 2005 (Pon et al., 2003). CWP continues to affect the nation's coal miners, though (Table 5.4). In particular, there has recently been an increase in CWP in workers in some coal mines in Virginia and West Virginia. Further, CWP rates for the nation's underground coal miners have doubled since 1967 among those working 25 years or more in the mines. The rate was four percent a decade ago, compared to nine percent of lung abnormalities shown in X-ray data from 2005 and 2006 (CDC, 2007). The complete elimination of CWP in the mining population is a goal that should be pursued vigorously.

6.2 Noise

According to the recent NRC report on mining health and safety (NRC, 2007b), occupational hearing loss continues to be one of the most pervasive problems facing today's miners. In the mining industry, hearing loss is the second most commonly reported injury, representing nearly 21 percent of diseases newly reported to MSHA. Further, 25 percent of the mining population is reported to be exposed to noise levels exceeding the permissible exposure limit of 90 dBA.

6.3 Musculoskeletal Injuries

Several unique factors are recognized as having the potential to cause severe ergonomic stress in mining tasks in the mine environment: working in confined places; carrying out tasks that involve heavy and repetitive jarring and jolting motions; and environmental factors such as limited visibility, dust, noise, and temperature. According to the NRC (2007b), for the period 1993 to 2002, repeated trauma disorders accounted for a majority of illness (3,314 cases out of a total of 6,419 cases). Efforts to enhance the design of mining equipment to incorporate ergonomic features and training miners to reduce ergonomic stress need to continue.

Health hazards such as those posed by gases, dusts, chemicals, noise, and extreme temperatures have long been apparent to miners and are increasingly controlled through improved monitoring, assessment, and scientific, engineering, and medical techniques. The monitoring and control functions of the mining industry and government, such as those at MSHA, are carried out through adherence to occupational health standards prescribed by mine health and safety laws. Research to improve existing methods of monitoring and controlling known hazards and to identify new sources of hazards is a major component of current research by NIOSH.

7. COAL MINE DISASTERS: 1980–2007

There is no commonly accepted definition of what constitutes a disaster. In the past, accidents were considered disasters if they involved five or more fatalities; later, this definition was changed to three or more. According to a dictionary of terms used in the safety profession (Lack, 2000), a disaster is a sudden and often unforeseen natural or human-caused occurrence that results in multiple injuries and deaths and/or major property destruction. "Sudden and unforeseen" are important qualifiers of disasters for the purposes of this study. If potential disaster can be foreseen, then there is an opportunity to prevent it, or at least, to reduce the number of injuries and fatalities and mitigate property damage. In the mining industry, events such as fires, ignitions of gas or coal dust, explosions of gas and dust, inundations (sudden inflow) of gas and liquids into the work environment, and major and long power failures are potential disasters, as these events can severely threaten the health and safety of the miners and mines.

Figure 5.7 shows the number of coal mine disasters and the number of fatalities from 1900 to 2007. The last disasters indicated are the two massive ground failure events that occurred at the Crandall Canyon Mine on August 6 and 16, 2007. The drop in number of disasters and the number of fatalities from 1900 onwards is remarkable. Furthermore, the data show a relatively disaster-free period in the last decade of the twentieth century.

After 1980, disaster occurrences are less frequent, with a relatively lower number of fatalities compared to earlier periods. These improvements can be attributed to enhanced health and safety provisions in the major federal mine safety legislation of 1969 and 1977, the introduction of more productive and safer mining technologies involving ventilation and electrical power, more effective isolation of the disastrous event from other parts of the mine, and enhanced health and safety training provided to miners.

The U.S. Mine Rescue Association (2008) lists mine disasters that have occurred in underground coal mines since 1980. This list includes mine incidents and accidents that have resulted in one or more fatalities. Since 1980, 32 incidents are classified as disasters, resulting in 197 fatalities; the number of fatalities per event varies from one to 27 miners. The distribution of these disasters is: Kentucky, nine; West Virginia, eight; Virginia, four; Pennsylvania and Utah, three each; Illinois, two; and Colorado, Tennessee, and Alabama, one

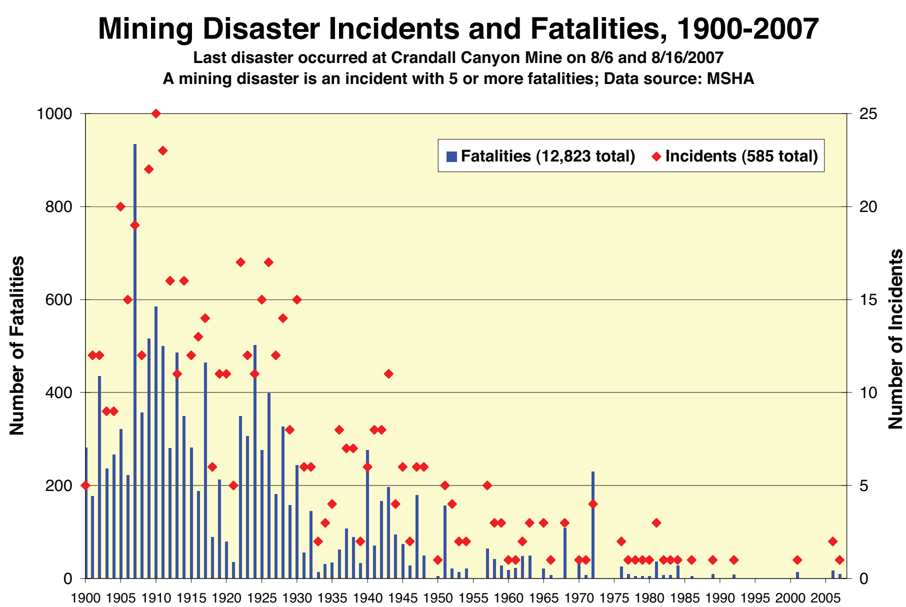


FIGURE 5.7 Mining disaster incidents and fatalities, 1900–2007. A mining disaster here is an incident with five or more fatalities. SOURCE: http://www.cdc.gov/niosh/mining/statistics/disall.pdf.

each. Kentucky, West Virginia, and Virginia have a large number of small operations and account for a significant fraction of their production from underground coal mines.

Table 5.5 shows the classification of the 32 disasters by type since 1980. Methane gas and coal dust explosions and mine fires have a high potential for miners to be trapped or exposed to toxic atmospheres. Consequently, there is a high potential for loss of lives as well as loss of property. Although the number of miners who would normally be affected by roof or ground collapse is likely to be small, in some cases, when the collapse is massive and affects a large working area, a large number of miners may be killed, as was the case at Crandall Canyon. In addition to the tragic loss of lives, these disasters are accompanied by extensive property damage and revenue losses.

Even when there is no loss of life, revenue losses can be quite high. For example, the Buchanan Mine roof fall that occurred on July 9, 2007, forced the mine to stop production; the mine was temporarily sealed when high levels of carbon monoxide were detected (an indication of heating). These actions adversely impacted net income of the company for the fourth quarter of 2007 by approximately $31 million (net of an initial insurance recovery payment of $25 million), including additional expenses incurred in managing and monitoring the underground mine atmosphere since the mine was idled, and reduced income from lost sales. The mine resumed full production in March 2008.

TABLE 5.5 Classification of mine disasters by type, since 1980.

TYPE OF DISASTER	EVENTS	FATALITIES
Methane Explosions	15	104
Roof and ground collapse	7	29
Mine fires	2	29
Coal dust explosions	2	15
Materials collapse	2	8
Explosives	2	6
Inundation	1	3
Gas poisoning	1	3
Total	32	197

SOURCE: U.S. Mine Rescue Association, 2008.

The potential for slipping and sliding of materials in stockpiles and impoundments on the surface, especially at elevated locations, must be recognized. When mine workings are near bodies of water or abandoned mines, accidental breach of the barrier can lead to a sudden in-rush of water or gas (e.g., blackdamp). It is indeed fortunate that the nonfatal Quecreek Mine inundation in 2002 only resulted in the entrapment of nine miners for over 77 hours. Under unfavorable conditions, this event had the potential for drowning the 18 miners who were working underground at the time of the breach.

In surface mines, the potential for disastrous events that can threaten life and property arise from different sources. Surface mines are associated with much higher-voltage electricity. The sheer scale of equipment can lead to problems of visibility, clearances, and stability of benches. Surface mining uses large amounts of explosives, creating a need for detailed attention to their handling and use. Ground control stability problems due to the highwalls and spoil piles can be exacerbated by weather conditions. Waste impoundments on the surface have been a constant source of concern ever since the disastrous impoundment failure at Buffalo Creek, West Virginia, in 1972, and more recently at Martin County, Kentucky, in 2000 (NRC, 2002a). Methane gas ignitions in preparation plants and mine fires in surface coal storage silos and slots also have the potential for disaster. Particular precautions are needed to avoid miners and others from working close to active coal stockpiles that are being recovered with reclaim conveyors under the piles.

TABLE 5.6 Coal events in underground and surface coal mines, 2003–2007.

ACCIDENT CLASSIFICATION/YEAR	2003		2004		2005		2006		2007		TOTAL		TOTAL
	UG	S	UG	S	UG	S	UG	S	UG	S	UG	S	
Gas/dust explosions or ignitions	59	03	49	06	36	09	57	01	63	05	264	24	**288**
Mine fires	07	12	13	19	07	24	08	29	15	22	50	106	**156**
Inundations	19	01	14	0	13	02	13	03	23	02	82	08	**90**
TOTAL	**85**	**16**	**76**	**25**	**56**	**35**	**78**	**33**	**101**	**29**	**396**	**138**	**534**
TOTALS	**101**		**101**		**91**		**111**		**130**		**534**		

SOURCE: MSHA, *pers. comm.*, 2008.

Events that can be classified as having disaster potential, such as ignitions of gas or dust, explosions, fires, and inundations, occur surprisingly frequently in coal mines. Table 5.6 shows that there were 534 such events in coal mines from 2003 to 2007. Of these, 138 events occurred in surface coal mines; a vast majority of them (106 events) were fires. It is quite common for low-rank coals to catch fire in the pit and stockpile. Of 396 events in underground coal mines, 264 resulted from ignitions or explosions of gas or dust (accounting for over 66 percent of the incidents), 82 resulted from inundations (over 20 percent), and 50 from mine fires (about 13 percent). It is indeed fortunate that all of these events did not grow into full-blown disasters (as occurred at the Sago and Alma mines) or entrap miners (as at the Quecreek mine).

The impact of mining on the health, safety, and general welfare of mining communities is not specifically addressed here. Careless mining in the past has resulted in environmental, economic, and cultural disasters that are still being remedied.

8. RECENT MINE HEALTH AND SAFETY LEGISLATION

Health and safety hazards in the mining industry have been recognized as early as the nineteenth century. Most mining countries, including the United States, responded with legislation specifically directed to mine design and operation. In the United States, legislation at the state level was enacted almost 150 years ago in West Virginia and Pennsylvania. The 1969 Coal Mine Health and Safety Act, enacted at the federal level, was pioneering in that several major provisions concerning ventilation, roof control, airborne dust, and electricity significantly affected the design and operation of mines. This act was updated in 1977 to include provisions for miner training.

The most recent addition to federal legislation is the MINER Act of 2006, an immediate result of 19 fatalities that occurred because of explosions and fires at Sago, Alma, and Darby. That act incorporates the use of new and additional health and safety equipment and procedures. The response of miners and mine rescue teams to recent disasters has exposed weaknesses in mine escape and rescue systems, including: (1) insufficient provisions for locating and communicating with trapped miners; (2) inadequate provisions to increase the chances of survival of miners when escape, evacuation, or rescue are unsuccessful; and (3) the significant lapse of time from knowledge of an emergency to the arrival of rescue teams. If the overall downward trend of disasters and fatality rates in mines is an indication of an increase in general health and safety, the tragic events in Sago, Alma, and Darby are an indication that improvements still need to be made, particularly with regard to sealing abandoned areas, locating miners, and revamping communication systems, emergency preparedness, escape, evacuation, survival, rescue, and training in emergency procedures and safety standards.

At present, new legislation, the S-MINER Act of 2007, has passed the House of Representatives but has an uncertain future because of a threatened presidential veto. In addition, several coal-producing states, such as West Virginia, Kentucky, Pennsylvania, and Utah, are examining this legislation to assess its adequacy for dealing with a number of issues raised by the disasters in Sago, Alma, and Crandall Canyon.

9. MODERN MINE SAFETY MANAGEMENT APPROACHES

It is well known throughout the coal industry that safety performance varies by company; some have excellent records and others do not. Many companies have operated for long time periods without any incidents that mar their safety record. Clearly, these differences can be reduced not only among the companies but within the same company. Safety management is an area that has been extensively studied to understand these differences and how to eliminate them.

There are five elements in a mining production system: (1) miners; (2) materials, including machines and supplies; (3) media, which refers to the environments in which mining takes place; (4) management personnel; and (5) the mission of the organization. Management's role is critical in that it has the authority and ability to select, organize, train, use, and maintain all resources including coal seams, methods of mining, machines, materials, and miners. Management's most important purpose is to achieve the mission of the organization as set out by the owners. Enlightened mine management has always recognized that a *safe mine* is the most *productive mine*.

Accident prevention has many facets. It involves (1) meticulous selection, training, organizing, and leadership; (2) exercising proper scientific and engineering controls during the planning, designing, and operating phases of the mine to eliminate or decrease the impact of hazards; and (3) the correct selection, arrangement, application, and maintenance of equipment and supplies. Essentially, accident prevention involves accurate data collection about mining seams and conditions, correct assessment of issues and problems that are encountered during mining, and appropriate selection of strategies for addressing the problems and preventing them from becoming serious threats to the health and safety of miners and property. The continually improving record of the mining industry gives reason to believe that in most cases, the industry is performing well in the above areas.

In the past, the principal approaches to enhance safety of industrial operations generally have been based on incorporating advances in science and engineering to engineer safety into the system. All of these approaches traditionally have been identified under the three headings: (1) engineering, (2) education and training, and (3) enforcement of government and company rules and regulations. These are the "three E's of safety." The role of human interaction and reactions has always been considered important, and constitutes a part of education and training.

In this study, accidents are defined as unexpected events that have the potential to cause injury, death, or loss of property or production. Thus, accidents do not have to cause actual deaths, injuries, or monetary loss, but merely have the potential to do so. Thus, the goal of the mining industry is (or should be) to have no accidents, not just no fatalities, injuries, or monetary loss. "Near misses" or "close calls," under this definition, are accidents, and are to be avoided. The goal of the industry is not just to "get lucky" in achieving a perfect record on health and safety in terms of injury reduction, but to eliminate potential causes of those injuries as well. The mining industry can benefit from increased application of the tools and techniques of risk analysis and risk management to the health and safety functions of hazard identification, accident potential reduction, and accident avoidance.

Management must take an active approach to accident avoidance by being involved in a zero-tolerance accident prevention program. An accident prevention program should seek to integrate research on the "science of safety," including recent work in the area of human-machine interaction, with a "culture of safety," including human reactions in the workplace. According to Harvey (2007), the culture of safety "involves engaging the mind of every employee." The science of safety is "technology driven," whereas the culture of safety must be "people driven"; it must be emphasized by management every day, at every meeting, and on every shift. When these two merge, a new approach to safety will evolve.

The root causes of major recent disasters in several sectors, such as commercial transportation, nuclear and chemical industries, and space agencies, have been attributed to organizational factors that affect safety and performance. These organizational cultures have been studied using a variety of tools, techniques, models, and methodologies, such as behavior modification, with a goal of inculcating safe behaviors. Still, the goal of developing and encouraging desired behaviors is not without controversy. It is well known that accidents have multiple causes and unsafe behavior can be one of them. Nevertheless, the coal industry should examine the various methodologies used to study organizational cultures and adopt the best ones for a new approach to managing mine safety.

Some mining companies have set new goals for health and safety performance measurement and have instituted new procedures for worker and management training. According to one of the companies that has introduced safety culture in its mines, the critical elements in the success of its program are (Pick, 2003):

- Emphasizing the difference between safety as a value and safety as a priority
- Leading by clearly communicating the safety philosophy of the company and believing that operations can be injury-free
- Implementing written safe work and safe operating procedures that have been developed and updated in cooperation with the workers
- Demonstrating that safety will not be compromised for production
- Developing clear safety rules
- Understanding that working safely is a condition of employment
- Anchoring safety programs in quality training of workers and management
- Allowing enough lead time to develop safety programs that incorporate worker involvement and feedback
- Tracking, investigating, reporting, and communicating every first aid and near miss accident to workers
- Making sure every employee knows and understands the safety expectations of the company
- Making safety performance a large part of each employee's annual performance evaluation
- Having a goal of zero hazards and violations for all safety observations
- Communicating and correcting unsafe actions and unsafe conditions immediately
- Highlighting, acknowledging, and rewarding safe performance

10. MAJOR FACTORS IMPACTING HEALTH AND SAFETY

The passage of new mine and health laws at the state and federal levels is the most important factor that has an immediate effect on the coal mining industry. Other factors are the introduction of new equipment and systems in the workplace, the infusion of new workers into the industry, and the changing physical conditions of mining. These factors are also likely to affect the production and productivity of the coal industry, thereby affecting the cost of mining and the relative competitiveness of coal in the energy scenario.

10.1 Emerging Legislative Environment

The MINER Act of 2006 mandates that the coal mining industry incorporate new and additional health and safety equipment and procedures. The implementation of the provisions of the MINER Act includes several actions by MSHA (Stickler, 2008), such as policies on immediate notification of accidents, minimum penalties, flagrant violations provisions, and civil monetary penalties. Other provisions include promulgation of rules on emergency mine evacuation, new and additional requirements for self-contained self-rescuers (SCSR), new and additional requirements for emergency training, and issuance of guidelines for acceptable air quantities and delivery methods for breathable air underground. Emergency response plans are required to address the provisions of the act with regard to breathable air, post-accident tracking and communication, lifelines, training, and local coordination. Emergency temporary standards were issued regarding seals used in sealing abandoned areas and for sampling and controlling the atmosphere behind the seals.

The direction that mine safety regulations will take in the future is not easy to predict. As experience is gained with the provisions of the MINER Act of 2006 and as technology is developed to address those provisions, it is quite likely that more appropriate regulations may be developed. If S-MINER is any indication of the direction of Congress, it is clear that issues such as an airborne respirable coal dust standard, use of belt air in coal faces, and enhanced personnel exposure monitoring are likely to be priorities for legislative action.

10.2 New Technology

Reference has already been made to major technological changes that have taken place in coal mining in the last three decades and the trend towards larger underground and surface mines. According to a RAND study (RAND, 2001) specifically conducted for the U.S. mining industry and commissioned by NIOSH with additional funding from the Department of Energy (DOE), there are four major technological trends on the horizon: (1) increased use of information and communication technologies; (2) increased use of remote control and automation; (3) greater attention to operations and maintenance to improve the performance and availability of equipment; and (4) development of new technologies for unit operations, such as size of buckets and truck capacities in hauling and loading. In a study conducted for DOE and NIOSH, the NRC (2002b) looked at future technological developments in mining and found that new technologies, including computer-based monitoring and control, have the potential for improving health and safety. The NRC study, however, cautioned that these same technologies may result in unforeseen hazards, especially if used inappropriately.

Newer equipment for underground and surface mining incorporate enhanced features for noise and vibration reduction, as well as enhanced ergonomic features such as more comfortable seats and better controls and visibility. Equipment advances can enhance health, safety, and productivity, such as increased use of automation and remote controls in dangerous tasks, for example, working near a highwall or on badly fractured ground. Thinner and deeper seams present significant challenges with regard to health and safety. These difficulties are associated with ground control, ventilation, and ergonomic conditions. Increased use of automatic and remote control will reduce some of the problems but has the potential to introduce new health and safety hazards.

The sweeping changes called for in the MINER Act of 2006 and in some state legislation cannot be implemented without additional research, development, and demonstration of new equipment and systems. Congress provided emergency supplemental funding to NIOSH to develop and diffuse new knowledge and technology to the industry in a timely manner. NIOSH efforts are focused on the following areas (Kohler, 2007): (1) disaster prevention, including understanding of ignition mechanisms, seals, and ventilation; (2) escape, with emphasis on communications and tracking, refuge chambers, escape training, and oxygen supply; and (3) rescue and response, with emphasis on fire fighting and rescue technology. Development in these areas should effectively address some of the issues raised after the Sago, Alma, and Darby disasters. The events at Crandall Canyon are likely to result in increased research and development efforts to understand mine strata control issues and increased monitoring and control of strata movements during mining. The increased use of atmospheric monitoring and control systems is also likely. The report of a technical study panel appointed under the MINER Act of 2006 on the use of belt air contains a number of specific recommendations concerning ventilation, belt materials, belt approval testing, atmospheric monitoring system, and training (MSHA, 2007).

It is clear that implementing all the provisions of the Miner Act will take some time. Evidence of this is available from recent reports from MSHA and NIOSH with regard to the availability of SCSR and refuge chambers, respectively. Fortunately, Congress has made funds available to both MSHA and NIOSH to ensure that research, development, demonstration, and diffusion of new knowledge are pursued in a diligent manner. Recent Brookwood Sago training grants from MSHA and NIOSH contracts and grants for technology demonstration should accelerate the availability of new training materials and critical technology for the mining industry.

10.3 Corporate Health and Safety

Whether the mining operation or corporation is big or small, there is need to develop improved methods of safety management. Because legislative reactions to deaths and disasters in mines are mostly technical, they can rarely address management issues in sufficient detail. Legislative prescriptions to enhance health and safety are only a minimum requirement for improving conditions in mines. Enhanced penalties are aimed at increasing costs for operating in an unsafe manner.

Several important requirements for incorporating a culture of safety are outlined in Section 8, on modern mine safety management approaches. Redefining what an accident is, setting a goal of zero accidents, analyzing health and safety aspects of equipment and systems using concepts from risk analysis, training managers and workers to understand how the mining process works, and developing monitoring and control systems to ensure that systems work appropriately (such as equipment, materials, personnel, processes, and procedures) are all important for achieving the integration of the science of safety with the culture of safety.

10.4 Changing Mining Conditions

Mining conditions in the future will differ from those encountered in present operations. Changes will include geographical location, geologic aspects, mine size, technology, workforce, and organization. Underground mines are likely to be in deeper and gassier seams. In the east, coal seams are likely to be thinner and often under previously mined-out areas. Problems of gas and strata control increase with depth. Reserves that are overlain by old workings may be affected by the presence of water or gas. The amount of pre-mining exploration that has to be carried out to document actual physical conditions and to enable mine planning and design to avoid hazards can be extensive. Large blocks of coal, which support development of very large underground mines, will become scarce and it may be necessary to develop mine complexes incorporating several mines. Coal quality is likely to be poorer and mining itself can lead to increased dilution. Increase in stripping ratios in surface mining can create problems of slope stability in spoils and highwalls. Increased scale of equipment in surface mining and increased use of remote control and automation are likely to create new hazards. The need for a relatively large number of new miners and the changing nature of work organization are also likely to be major sources of concern for health and safety. It is safe to say that adequate engineering controls and a knowledgeable workforce will continue to be prime prerequisites for a safe work environment.

10.5 Changing Workforce

Employment in the coal mining industry has been declining for over 20 years because of increased mechanization, increased contribution from surface mining, and increased productivity from

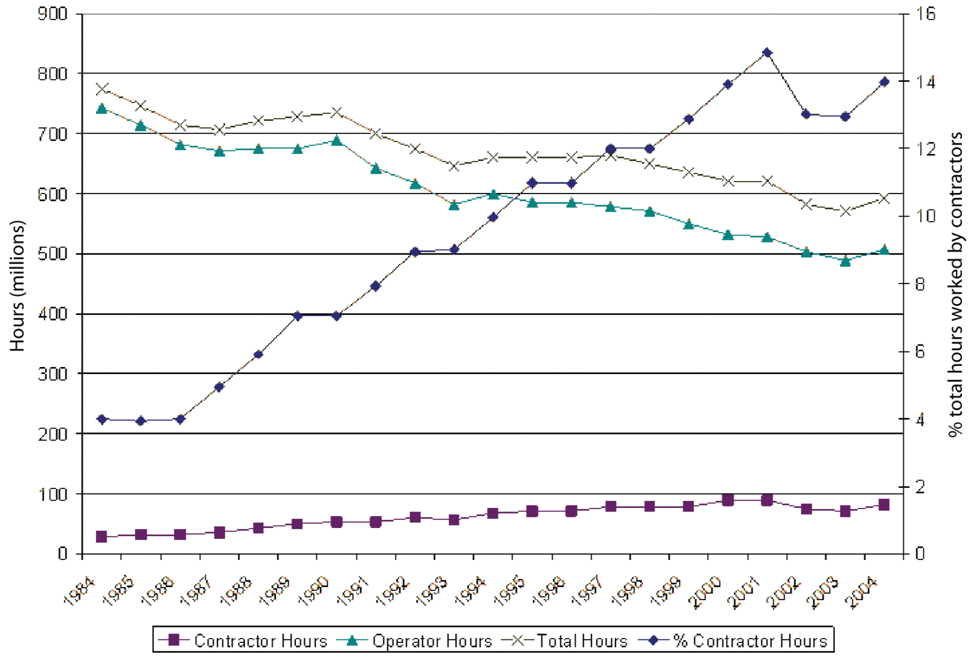


FIGURE 5.8 Number of hours worked by operators and contract workers in the mining industry from 1984 to 2004. Total hours is the sum of operator and contractor hours. SOURCE: NRC, 2007b.

operations. The median and average ages of the current mining workforce are quite high, creating concern for the future. The trends toward larger mines and consolidation of companies in the mining industry have enabled consolidation of engineering, research, and other services. An unexpected and unfortunate consequence of these trends is a serious decrease in the availability of technically trained personnel for not only the mining companies but also research laboratories, universities, consulting companies, and manufacturers.

Furthermore, there has been an increase in the number of contractors and contractor hours employed by the mining industry (Figure 5.8). Contract workers are assuming an increasingly important role in smaller surface mining companies for drilling, blasting, servicing, and repair. Contract workers represent a subpopulation of the mining workforce whose health and safety training and requirements may require special consideration (NRC, 2007b).

The need for addressing the number and quality gap that is likely to develop in both mine worker and mine technical personnel areas is immediate. The tasks of replacing experienced retiring workers, attracting additional miners for new mines that are needed to meet projected production increases, and creating a larger pool of technically trained personnel require immediate attention from all stakeholders.

11. CONCLUSIONS

The enhancement of mining workplace safety and health requires recognition that mining is a hazardous occupation and that vigilance in addressing hazards can never be relaxed. As this study has shown, notwithstanding the impressive progress that has been made in mine health and safety, illnesses and injuries and deaths and disasters continue to occur, revealing the need to accelerate the processes of identification and elimination of the root causes of mine health and safety incidents. Coal mining in the coming years will experience several changes arising from:

- Mining conditions
- Mine health and safety laws
- New technology
- Younger workforce
- Innovative work schedules
- Societal demands for greater health and safety

In the recommendations below, specific technical mining topics are avoided. Two recent NRC reports (NRC, 2007a, 2007b) have extensive discussions and provide the rationale and recommendations for research and development in specific mining technical areas. The recommendations made in Chapter 3, on mining technology and resource optimization— reducing the uncertainties associated with mining conditions, developing new mining equipment and technology, and enhancing mine health and safety research—are equally applicable here.

- ***Enhance and accelerate recruitment and induction strategies for new workers into coal mining.*** Experience has repeatedly shown that outstanding engineering controls and a knowledgeable workforce are the two prime requisites for a safe system. Given the impending critical shortage of qualified mining personnel at all levels (see Chapter 7 for details), there is an immediate need to recruit qualified personnel for the industry. New workers must not only be recruited in sufficient numbers, but they must be developed into a knowledgeable workforce in a short time so as to not compromise health and safety advances. Each miner already performs a variety of tasks, and is likely to perform even more in the future. As the level of mechanization and the scale of equipment and operations increase, the importance of the human element in the system will increase as well. The miners of the coming decades must have increased multidisciplinary and critical thinking skills to enhance the health, safety, and productivity of their operations.

- ***Enhance the application of systems safety methods for safety evaluation of mining systems.*** Repeated occurrences of injuries, illnesses, deaths, and disasters in mining point to the continued existence of root causes of these incidents. Unless the root causes are eliminated, the hazards in the system remain undetected and may manifest themselves at some other time, possibly with disastrous consequences. Even with increased remote or autonomous control, if the root causes are not eliminated, property damage or production loss cannot be ruled out. In the past, unfortunately, injuries have been the most frequent indicator of hazard detection and avoidance. The need to increase the application of proactive approaches that examine systems critically for either component or systemic weaknesses, using tools and techniques from risk and reliability analyses and techniques, has never been more apparent. Past experience has shown that changes in conditions, practices, and procedures all have potential to create a more hazardous environment. Proactive assessment of the health and safety impacts of the above changes (e.g., on existing and emerging hazards) is essential to ensure that the changes warranted or otherwise implemented make mines safer than before.

- ***Evaluate and develop more effective systems for management and control of the safety function in organizations.*** The importance of organizational factors, including the goals, objectives, and means of managing safety issues, has been growing in the industry. Although not widespread, some companies in the mining industry set their goal as zero accidents and have developed training programs for managers and workers that go beyond the minimum mandated requirements. There is growing recognition in the mining industry that there is need to examine current safety approaches to identify their shortcomings and improve on them. The introduction of modern safety management techniques in mining requires a detailed evaluation of current practices in other industries and adapting the applicable ones to the mining environment.

- ***Expand the funding and scope of mine health and safety research.*** Ever since the closure of the U.S. Bureau of Mines in 1995, funding for mine health and safety research at the federal level has remained fairly constant at about $30 million, $12 million less than that in 1995. In addition, in 1995, a $10 million annual research effort on advanced mining technology was eliminated. In recent years, Congress has made additional one-time funds for research available for specific projects, such as void detection (after Quecreek) or communications and miner location (after Sago). There is need to increase health and safety funding on a more permanent basis and for a more encompassing base of health and safety problems. At present, most research is performed in government labs with very little funding for extramural research. Further, with limited funds, there is little opportunity to expand the research base into new areas. To make substantial and sustained progress in mine health and safety, vibrant research initiatives involving government, industry, universities, and manufacturers are needed. There is a need to increase funding to expand the scope of mine health and safety research.

Chapter 6 Environmental Protection, Practices, and Standards

1. SUMMARY

Environmental protection, practices, and standards have influenced the coal industry over the past 30 years. Federal and state regulatory authority overseeing coal mining and reclamation has been introduced, local communities and concerned citizens have become involved, and the coal industry has become increasingly aware of, and has participated in, environmental stewardship. Coal mining activities inevitably disturb land, air, and water resources, as well as aquatic and terrestrial habitats, to varying extents. Environmental consequences caused by these disturbances also vary throughout the United States; however, within particular coal regions, there are similar characteristics that must be addressed through proper planning, permitting, and mining practices to minimize or prevent impacts to the environment and natural resources. Specific environmental concerns that are a focus of this chapter include mountaintop mining (MTM) and associated valley fills (VFs); acid mine drainage (AMD); impacts to important resources such as threatened and endangered species and unique habitats; revegetation and post- mining land use; slurry impoundments; subsidence; prime farmlands; air and water quality; and bond release. Additionally, legacy issues, current production, and future coal activities must be considered in the context of environment and natural resources protection, with both federal and state regulations designed to protect the public and the nation's natural resources while meeting ever-increasing energy needs.

This chapter presents a discussion and recommendations for minimizing environmental impacts from historic, current, and future coal activities. Because coal production has increased significantly since the enactment of several landmark federal and state laws, it is anticipated that future coal production will be challenged by issues related to MTM, VF, AMD, air quality, subsidence, and protection of unique resources in the various coalfields. Several initiatives are underway by various federal and state agencies, citizen groups, and industry to address environmental issues involving reforestation, AMD, and species protection, which are expected to provide information for addressing improved stewardship for future coal mine activities.

2. INTRODUCTION

The mining, transportation, and utilization of coal can result in a variety of environmental consequences with coal combustion and emission of carbon dioxide (CO_2), a greenhouse gas, receiving most of the attention in recent years (EPA, 2007a; Kavalov and Peteves, 2007; MIT, 2007; NRC, 2007a). In addition to CO_2, coal combustion also results in emissions of the criteria pollutants sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2), particulates ($PM_{2.5}$ and PM_{10}), and mercury (Hg) (EPA, 2007a–2007g) (see Chapter 2). For the purpose of this study, however, only the upstream impacts of coal production are considered (see Chapter 1) and, therefore, this chapter focuses on the environmental issues directly related to the mining and processing of coal.

Environmental protection begins with careful consideration of mining practices, compliance with federal and state regulations, and community involvement. Consideration of these factors should occur prior to permitting a coal mine, should address sustained stewardship associated with active mine operations, and should be followed by the necessary reclamation and restoration activities during mining and at mine closure. Environmental effects of mining can include surface habitat disturbances, water and air quality issues, production of mine wastes, and the release of methane (CH_4), a greenhouse gas entrained in coal (EPA, 1999, 2007a).

In order for coal to remain a viable part of the U.S. energy mix, there will continue to be a need to mitigate potential adverse environmental consequences associated with past, present, and future coal mining and processing (see several chapters in Barnhisel et al., 2000, that are associated with coal mine land reclamation; Epstein et al., 2007; Lashof et al., 2007; NRC, 2007a). Future coal production will undoubtedly encounter new environmental challenges because more complex coal reserves will be mined. In general, easily accessed coal seams are being depleted and the newer mines will likely require more complex mining and may produce poorer quality materials that require increased processing.

The expansion of environmental protection related to coal production will require reclamation of abandoned mine lands, incorporation of environmental stewardship in current coal mining practices, and the use of standards in new coal operations that minimize environmental impacts and preserve ecosystems.

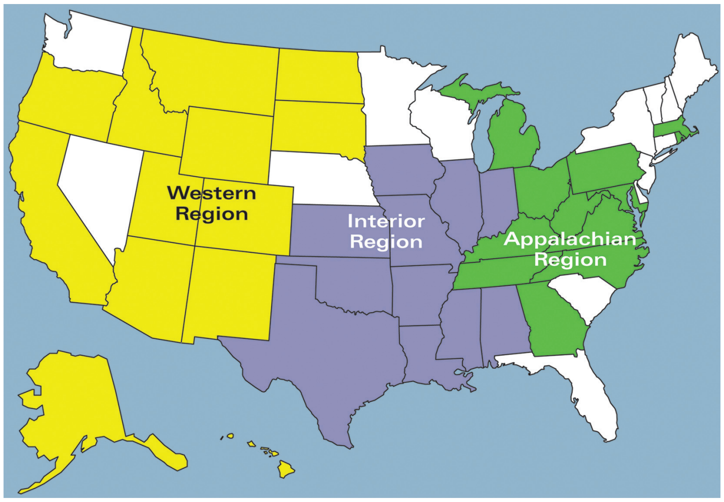


FIGURE 6.1 Three coal regions in the United States, delineated by the Office of Surface Mining.

Coal is mined from several coalfields located throughout the United States (see Chapter 1). The Office of Surface Mining (OSM) has differentiated three regions, based on states within similar geographic areas (Figure 6.1). Mitigation of the effects of past mining practices, particularly AMD from abandoned mine lands in the Appalachian region, subsidence on prime farm lands in the Interior region, and landscapes associated with spoil piles and mine safety issues in abandoned surface mines of the Western region coalfields, has been a priority of both federal and state agencies for several decades (OSM, 2008b).

2.1 Environmental Regulation of Coal Mining

Prior to the enactment of key federal legislation in the 1970s, minimal attention was given to environmental impacts of coal mining. The Surface Mining Control and Reclamation Act (SMCRA) of 1977 was the primary federal law enacted to regulate and enforce environmental requirements for coal mining activities. In addition to SMCRA, numerous federal agencies enforce environmental compliance requirements from a variety of federal regulatory programs that apply to coal mining activities (Table 6.1). A significant number of these laws were passed from the mid-1960s to the later 1970s, resulting in a body of important coal mining operation regulations and the development of technical guidance that has benefitted the industry, communities, and society.

Although coal mining is heavily regulated, local communities, environmental groups, and concerned citizens often provide additional oversight of activities associated with the coal mining industry to ensure their operations and practices are in compliance with federal and state regulations (Squillace, 1990; Fitzgerald, 2005, 2007; Epstein et al., 2007; Lashof et al., 2007). Numerous federal and state environmental laws govern coal operations, including laws enacted to clean up and protect the nation's air (Clean Air Act, or CAA) and water (Clean Water Act, or CWA) resources, protect aquatic and wildlife habitats (National Environmental Policy Act, or NEPA), and those that address protection of cultural and historic resources (National Historic Preservation Act, or NHPA). Great strides have been made in adopting practices that reduce environmental problems associated with the legacy of past coal mining activities. Additionally, the last 30 years have resulted in tremendous successes in the reclamation of abandoned and active mined lands, even as coal production has increased dramatically. However, remaining legacy problems from past mining activities must be addressed through programs that result in the reclamation and restoration of these sites. Coal mining must follow regulations and guidelines that emphasize the protection of public and environmental resources to prevent degradation or result in improvement. In addition, all coal mining must continue to be conducted in a manner that is safe for humans and the environment.

Table 6.1 Federal legislation (other than SMCRA) that may potentially impact environmental compliance at coal mining operations.

LEGISLATION (ACT)	AGENCY	DATE OF ENACTMENT
Rivers and Harbors Act	COE	1899
Antiquities Act	NPS	1906
Migratory Bird Treaty Act	FWS	1918
Fish and Wildlife Coordination Act	FWS	1934
Federal Insecticide, Fungicide and Rodenticide Act	EPA	1947
Multiple Use-Sustained Yield Act	FS	1960
Wilderness Act	FWS	1964
Historic Preservation Act	NPS	1966
Natural Gas Pipeline Safety Act	DOT	1968
National Trails System Act	NPS	1968
Wild and Scenic Rivers Act	NPS	1968
Bald Eagle Protection Act	FWS	1969
National Environmental Policy Act	Several	1969
Clean Air Act	EPA	1970
Mining and Minerals Policy Act	BLM	1970
Endangered Species Act	FWS	1973
Archaeological and Historical Protection Act	DOT	1974
Forest and Rangeland Resources Planning Act	FS	1974
Safe Drinking Water Act	EPA	1974
Hazardous Materials Transportation Act	DOT	1975
Federal Land Policy and Management Act	BLM	1976
Resource Conservation and Recovery Act	EPA	1976
Solid Waste Disposal Act	OSHA	1976
Toxic Substances Control Act	EPA	1976
National Forests Management Act	FS	1976
Clean Water Act (formerly Federal Water Pollution Control Act of 1948)	EPA	1977
Soil and Water Resources Conservation Act	NRCS	1977
American Indian Religious Freedom Act	BIA	1978
Emergency Planning and Community Right-to-Know Act	EPA	1986
Transportation Act	DOT	1998
Homeland Security/Safe Explosives Act	DHS	2002

ABBREVIATIONS: COE, Corps of Engineers; NPS, National Park Service; FWS, Fish and Wildlife; EPA, Environmental Protection Agency; FS, Forest Service; DOT, Department of Transportation; BLM, Bureau of Land Management; OSHA, Occupational Safety and Health Administration; OSM, Office of Surface Mining; NRCS, Natural Resources Conservation Service; BIA, Bureau of Indian Affairs; DHS, Department of Homeland Security. SOURCE: Primarily from Ashcroft, 2007.

2.1.1 FEDERAL AND STATE REGULATORY AGENCIES

2.1.1.1 Office of Surface Mining

SMCRA (30 U.S.C 1201 et seq.) was signed into law on August 3, 1977, as the primary legislation that regulates the environmental impacts of coal mining activities nationwide. The law was enacted to ensure that coal mine activities are performed in a manner that protects citizens and the environment during mining, to assure that affected land is restored to beneficial use following mining, and to mitigate the effects of past mining by aggressively pursuing the reclamation of abandoned coal mines. Another objective of SMCRA is to "provide for the cooperation between the Secretary of the Interior and the States with respect to the regulation of surface coal mining operations" (Preamble to P.L. 95-87). This objective is accomplished by the "state primacy" process, whereby states can assume authority for regulation of coal mining activities in their states if they develop laws and regulations that are "no less effective" than federal requirements. SMCRA is based on the Congressional determination that, although coal mining is an essential part of the nation's energy needs, it is also important to protect society and the environment from adverse effects of coal mining operations (30 U.S.C. 1202). OSM, officially named the Office of Surface Mining Reclamation and Enforcement, was created in the Department of the Interior to manage and direct the requirements of SMCRA, which include the promulgation of regulations, funding of state regulatory and reclamation efforts, and oversight of state regulatory programs (Box 6.1). Regulations of past and present surface mining activities were also legislated in SMCRA (30 U.S.C. 1202).

SMCRA mandates the regulation of active coal mines, which is carried out by OSM and 23 states through individual programs. SMCRA also provides for programs for the reclamation of abandoned mine lands (AML), which are administered by OSM, 23 states, and three Indian tribes. Like most other federal environmental regulatory statutes, SMCRA establishes a system of cooperative federalism that grants states with approved programs the responsibility for regulating coal mining operations within their boundaries, while OSM oversees state accountability (30 U.S.C. §1253). Under SMCRA, OSM can approve a state's authority to regulate mining operations if the state demonstrates that it has both the appropriate laws and regulatory capacity. Currently, most coal mining states have approved programs and are able to issue permits, inspect mines, and take enforcement action if necessary. States without approved programs and Indian tribal lands are administered by OSM. An AML fund was also created by SMCRA to assist in the cleanup of mine lands abandoned prior to 1977; in addition, SMCRA was amended in 1990 to fund reclamation of some mines abandoned after 1977.

2.1.1.2 Environmental Protection Agency

The Environmental Protection Agency (EPA) also regulates coal mining through an assortment of laws, such as the CWA, CAA, and Resource Conservation and Recovery Act (RCRA), as well as under a variety of other statutes shown in Table 6.1. However, the primary regulatory focuses of EPA that impact coal mining operations are related to protection of water and air.

The CWA and CWA Amendments of 1977 were enacted to control water pollution and serve as the cornerstone of surface water quality protection in the United States. The statute was designed to reduce direct pollutant discharges into waterways and manage polluted runoff to achieve the goals of restoring and maintaining the chemical, physical, and biological integrity of the nation's waterways so that they can support "the protection and propagation of a balanced population of shellfish,

BOX 6.1 SMCRA REGULATIONS

SMCRA contains five main regulatory provisions that together form the basis for protecting the environment during coal mining and ensuring prompt restoration of the land following mining.

Permits are required before a coal operator is allowed to develop a surface or underground coal mine. Applications for a permit must contain details of the proposed mining and reclamation plans. Information must be provided that describes environmental conditions before mining begins; how the land is currently being used; how the land will be mined and reclaimed; how performance standards will be met; and how land will be used following mining.

Performance Standards (Box 6.2) are intended to ensure that all coal mining is done in ways that protect the environment and the public and that mined land is properly reclaimed.

Reclamation Bonds must be posted by the operator before a permit is issued. The bond is intended to cover the cost of reclaiming the site if the operator fails to complete the reclamation process. Operators can recover portions of the bond as phases of reclamation are completed. However, the bond cannot be fully released until all performance standards have been met and the land has been successfully reclaimed. Mine sites are not considered to be reclaimed successfully until five years have passed in the East and Midwest and 10 years have passed in the West from the end of mining.

Inspections and Enforcement are carried out by inspectors who visit mine sites (usually at least monthly) and have the authority to issues violations if they determine an operator is not meeting their performance standards. The problem must then be corrected by the operator, who may also have to pay a fine for the violation. If the operator fails to correct the problem, inspectors can issue a cessation order stopping all mining until the problem is corrected. If a violation is found that creates an imminent danger to the public or causes significant environmental harm, an inspector will immediately issue a cessation order.

Lands Unsuitable for Mining are protected by SMCRA. The Act prohibits mining within national parks, national forests, wildlife refuges, trails, and wild and scenic rivers. Mining is also prohibited in places where it would adversely affect sites listed on the National Register of Historic Places and within restricted distances of homes, public roads, buildings, schools, parks, churches, and cemeteries. The Act also allows anyone to petition to have specific lands designated unsuitable for surface coal mining.

fish, and wildlife, and recreation, in and on the water" (33 U.S.C. §1251 et seq). The requirements developed by EPA are based on the application of process or treatment technologies to control pollutant discharges.

The CWA was designed to prohibit the discharge of pollutants into U.S. waters except when in compliance with permits issued under programs established by the CWA. Section 404, which is jointly administered by EPA and the Army Corps of Engineers (COE), covers fill material discharges that may impact surface waters. This section of the CWA applies to many aspects of coal mining operations conducted in or near the "waters of the United States." The application of section 404 to coal mining operations is discussed in more detail later in this chapter.

The National Pollutant Discharge Elimination System (NPDES) was developed under the CWA and authorizes states to implement a permit program for controlling and eliminating water pollution from point sources. EPA also regulates wastewater using the Coal Mining Point Source Category (40 CFR Part 434) under NPDES and is considering rules that will cover pre-existing discharges at coal remining operations. Coal mining operations must obtain permits for effluent discharges, stormwater discharges, and other non-point source discharges under the CWA.

The Safe Drinking Water Act (SDWA), enacted in 1974 and amended in 1996, developed enforcement standards and identified minimum treatments to improve water quality. Maximum contaminant levels of waters have been developed under SDWA to protect against pollution of drinking water supplies that would be unsafe for human consumption.

EPA also administers the CAA, which regulates the nation's air quality. Portions of CAA that relate to coal mining include air pollution prevention and control from stationary sources, emission standards for moving sources, and the establishment of state permitting programs. CAA requires EPA to promulgate national ambient air quality standards (NAAQS) for certain pollutants. Several criteria pollutants regulated under NAAQS include particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and lead (Pb) (EPA, 2008a). Individual states are required to develop a State Implementation Plan (SIP) (CAA, Section 110) for implementing, maintaining, and enforcing compliance for emission limitations, schedules, and timetables for air pollution sources as defined by NAAQS. Regulations apply to major stationary or existing sources that emit, or have the potential to emit, levels greater than amounts allowed for a designated pollutant within an air quality control region. Each plan needs to include source-specific emission limitations and measures required to ensure attainment and maintenance of CAA primary or secondary standards. Although each SIP must be approved by EPA, a state has the flexibility of determining what emission controls are needed to meet NAAQS. Non-NAAQS pollutant emissions that can cause an increase in serious illnesses or death are regulated under the National Emissions Standards for Hazardous Air Pollutants (NESHAP) (CAA, Section 112).

2.1.1.3 Army Corps of Engineers (COE)

The COE, along with EPA, is responsible for issuing permits under CWA to regulate stream disturbances and VFs. Section 301(a) of CWA prohibits a "discharge of a pollutant" unless one has obtained and complied with a permit issued under CWA. Section 404 of CWA specifically authorizes the issuance of permits for the placement of material at "specified disposal sites" and outlines explicit and coordinated responsibilities for EPA and COE. Under Section 404, COE has the authority to grant either site-specific or nationwide permits for surface water discharges resulting in minimal adverse impacts. Coal mining operations are required to obtain an approved COE permit to discharge fill material into surface waters. In addition, states require mitigation of any stream or wetland loss caused by mining, and that certification must accompany any 404 permit. Finally, EPA may raise objections to the issuance of Section 404 permits and may also veto a COE permit on the grounds that the activity will have an unacceptable adverse effect on downstream aquatic resources.

COE regulates the "discharge of dredged or fill material" under section 404 and EPA or state authority regulate "all other pollutants," such as effluent standards, under section 402. Surface coal mining related activities conducted in and around streams and wetlands typically result in addition of dredged or fill material to the streams or wetlands. For example, placement of excess spoil in VFs, and construction of slurry impoundments, sediment ponds, roads, and other stream crossings discharges fill material into U.S. waters and, therefore, requires permits under section 404. Mountaintop removal mining often necessitates applying for a COE permit to allow creation of VFs from the excess overburden (i.e., spoil) of the surface mining operation. The COE permitting process was established to regulate the discharge of all materials into U.S. waters, and is thus applied to the placement of spoil materials from MTM operations into stream channels for construction of VFs as well as coal refuse disposal sites that are common in the Appalachian coalfield region.

2.1.1.4 Other Federal Agencies

The U.S. Fish and Wildlife Service (FWS) and appropriate state fish and wildlife agencies are also required to review mining permit applications to determine whether important fish or wildlife habitats and threatened and endangered species will be negatively impacted. Because coal mining results in the disturbance of various natural resources, alternative designs may be required to reduce habitat impacts or, if endangered species may be at great risk, the mining may not be authorized.

The Bureau of Land Management (BLM) is required by the 1976 Federal Coal Leasing Amendments Act and the Mineral Leasing Act of 1920 as amended to competitively lease coal reserves on all eligible public lands following identification of federal lands that are acceptable for coal leasing and development during the land use planning process (43 CFR 3420.1-4). Coal lease applications accepted by BLM require that an environmental assessment (EA) be conducted and/or an environmental impact statement (EIS) prepared under the provisions of NEPA. After developing a draft EA or EIS, BLM seeks public comment on the proposed lease sale. BLM also consults other appropriate federal, state, and tribal agencies that may be involved in conducting EA or EIS assessments.

Other federal agencies with specific responsibilities for the environmental regulation of coal mining activities include the U.S. Forest Service, where mining activities take place on Forest Service lands, and the Bureau of Indian Affairs, when mining will occur on Native American lands. Interagency coordination is required to manage the permit review process, for approval of mining plans, and for the release of bonds upon successful reclamation.

2.1.1.5 State Agencies

West Virginia (1939), Indiana (1941), Illinois (1943), and Pennsylvania (1945) enacted laws regulating coal mining prior to SMCRA. As coal production increased rapidly during the 1940s and 1950s, states with regulatory programs often required mining permits or reclamation bonds. Surface coal mining also became more common in the 1960s and 1970s, and even states with regulations were ineffective in controlling the number of land disturbances that resulted. Under SMCRA, if a state has not been granted primacy by OSM, OSM assumes regulatory control of the state's coal mining operations, as it does on federal and Native American lands. OSM is required to monitor and evaluate the enforcement and administration programs of primacy states regularly.

A coal mine application must meet all requirements of SMCRA, other applicable federal and state laws, and the applicable state regulatory program, including a demonstration that reclamation required by the program can be achieved (Box 6.2).

BOX 6.2 ENVIRONMENTAL PROTECTION PERFORMANCE STANDARDS

Once a coal mine permit has been approved and issued, an operator is required to meet specific performance standards that ensure that the public and the environment are protected. Some of the more specific requirements associated with performance standards include:

- Salvaging, properly storing, and replacing all topsoil on the reclaimed mine surface
- Protecting the hydrologic balance by monitoring, protecting, and restoring pre-mine capacity and quality of ground and surface water resources
- Replacing any water rights adversely affected by mining
- Implementing sediment control measures that prevent additional contributions of sediment off the permit area
- Properly designing, maintaining, and removing all structures such as ponds, embankments, berms, and diversions
- Protecting stream buffer zones (typically 100 feet from a stream)
- Implementing blasting standards that include a pre-blast survey of all structures within one-half mile of the mine; blasting schedules with public notice; blast warning signals; and a blast control plan for airblast, flyrock, and ground vibration
- Meeting standards to ensure the safe disposal of all excess spoil, including plans for handling mine waste and refuse piles
- Developing erosion control standards
- Meeting standards for the protection of fish, wildlife, and related environmental values
- Meeting performance standards for achieving contemporaneous reclamation
- Meeting standards for meeting slope and stability requirements on all regarded spoil
- Reestablishing a diverse, effective, and permanent vegetative cover
- Developing criteria for meeting revegetation success and post-mining land use
- Meeting standards for design, maintenance, and reclamation of all mine roads

2.2 Environmental Resources Issues

Several environmental issues arise from past, present, and future activities associated with the mining and processing of natural resources. Because of the extensive use of coal for electricity production, it is not surprising that there are many questions related to environmental issues associated with the coal industry (Fitzgerald 2005, 2007; Epstein et al., 2007; Lashof et al., 2007)). Addressing and mitigating the effects of past mining practices in order to improve the image of coal mining and to restore the environment are important. Current and future coal mining operations must continue to follow environmental compliance with responsible, sustainable, and systematic approaches.

As mentioned above, states play an integral role in developing and administering regulatory programs to implement SMCRA. Both the U.S. coal industry and SMCRA regulatory programs have evolved together over the past 30 years. The SMCRA program has undergone a successful maturation process that weathered initial periods of conflict, controversy, and litigation to become a stable regulatory framework that is widely accepted as working well, though not without some imperfections. In the midst of this regulatory transition, the coal industry experienced significant structural changes as a result of a combination of factors, including market forces and regulatory requirements. In fact, the coal mining industry has demonstrated innovative reclamation enhancements, beyond compliance environmental stewardship, and has received a number of best practices awards from OSM and state agencies (Figure 6.2). Actions by industry suggest there has been significant success in protecting environmental quality even as coal production has increased significantly over the years.

FIGURE 6.2 North Antelope Rochelle Mine has been recognized by the Wyoming Wildlife Federation for its voluntary research projects on sage grouse that have included programs to identify habitat preferences using 50 sage grouse with radio-collar transmitters. SOURCE: Yingling, 2007.

3. DATA COLLECTION ISSUES

In evaluating the past and current environmental performance of the coal mining sector, it is appropriate to look at various types of data and information to determine the environmental impacts of coal mining and the effectiveness of coal mine reclamation in restoring the environment. However, a number of difficulties arise when attempting to make such an analysis. A major challenge in addressing environmental issues related to the expansion of coal production is the lack of complete, readily available data in a format that permits meaningful analysis. For example, no readily available data exist on the number of acres disturbed and reclaimed at coal mining operations in any given year. Indeed, discrepancies in how information is gathered, assembled, and reported have created data that are of limited value when trying to quantify relationships. In addition, collection of sufficient data to demonstrate any options or the feasibility of different strategies requires the use of predictions, extrapolations, expectations, and planning options, realizing that assumptions and models beyond 10 or 15 years may need to be revisited.

This is not to say that significant amounts of data are not available. Several studies have been conducted on the impacts of MTM and VFs, the reclamation of prime farm lands, reclamation and revegetation of disturbed coal mine lands, and the prevention of off-site problems caused by coal mining operations. A coordinated effort by several federal and state agencies resulted in a Programmatic EIS (PEIS) related to mountaintop mining in Appalachia and the accompanying fills in adjacent valleys (for the final PEIS and public comments, go to http://www.epa.gov/region3/mtntop/). Environmental impact information was also reviewed by the BLM for the Powder River Basin (PRB), which was targeted by this agency for potential coal production (BLM, 2005). The review evaluated both current and cumulative air and water quality, social and economic conditions, and environmental circumstances (BLM, 2005, 2006a, 2006b, 2008). In addition, past, present, and possible future development activities were presented for the years of 2010, 2015, and 2020 (BLM, 2005).

Among the other challenges associated with the review of data from federal and state agencies is that published data are not always in the same format, do not cover the same geographic areas or use the same scales, do not use the same definitions in the same manner over time, and do not use information in a way that permits analysis using multiple data sources. These problems often result in criticisms by citizen and environmental groups and organizations, as in the recent report by the Natural Resources Defense Council (Epstein et al., 2007) on 30 years of SMCRA.

Federal and state agencies often make data available online in electronic format, or in reports that are produced on an annual basis. Information related to coal mining activities is available from several federal agencies (e.g., OSM, EPA, COE, BLM, FWS, U.S. Department of Energy's Energy Information Agency [EIA], U.S. Geological Survey [USGS], and the Minerals Management Service [MMS]). However, data collection methods, analysis, and reporting are not consistent among agencies, making it difficult to integrate the information. The Government Performance and Results Act requires that federal agencies develop specific measures of programmatic success, which, depending upon the agency, may define or constrain what data are collected and reported.

In addition to the data published by federal agencies, various state agencies with responsibility for resources associated with coal mining and reclamation also collect, publish, and analyze a host of data. Much of this information is used by and reported to the federal agencies, and may be the basis for the reports that those federal entities produce. The introduction of methodological differences among states and state agencies adds additional difficulties in collecting or analyzing environmental data related to coal mining and reclamation. Many of the federal agencies must conduct detailed "data scrubbing" exercises to ensure that all the data that are reported to them by the states has the same definition prior to being used, and often the reports of the federal agencies differ greatly from the raw data obtained from the states as a result of these processes. There are also differences in federal and state reporting periods, fiscal years, and other information that may introduce differences that must be reconciled.

Many publicly available data sources lack long-term consistency in the type of data, accuracy of data, or sources of data, making the development of trends and time-based comparisons very difficult. Depending upon the federal agency, regional data may be available for water, air, or land resources that are specific to a region. In various states, some agencies collect and maintain information on specific resources, but may or may not make it available to the public in a useful format. Information was available through scoping meetings for this project that allowed suggestions and concerns from public and industry to be heard.

In the case of data obtained from mining companies, there is a great deal of variability. This variance results from differences in data collected by various mining companies and at different operations, and in the willingness or ability of companies to release those data. In some situations, whether or not the company is publicly traded will affect how much and what type of data will be released. Thus, while company-provided data may have some utility, the lack of a comprehensive source for data and the variability in the quality, quantity, and specificity of the data make its usefulness for statewide, regional, or national analysis difficult.

4. ENVIRONMENTAL ISSUES

One approach to studying environmental concerns associated with coal mining is to evaluate past AML problems and their solutions. Data associated with AML in OSM Annual Reports (1978–2006) indicate there are thousands of AML sites throughout the country (OSM, 2008b). Figure 6.3 shows many areas that have been mined in the past are located in areas important for current and expected coal production. With the legacy of past mining, improvement in perceptions will play an important role in the acceptance of future coal mining activities. Although the AML reclamation program has been responsible for the reclamation of a significant number of problem areas (almost 240,000 acres of high-priority, coal-related problems) at a cost of $1.7 billion according to the 2006 OSM Annual Report (OSM, 2008b), there are many reclamation projects that have yet to be funded. In addition, new problems arise when events such as the following occur: land subsidence; unattended degradation of air and water resources; erosion of mine spoil material that can potential impact homes, roads, railroads and streams; mine fires that emerge at the land surface; and development expanding into past coal mining areas. OSM has suggested that it could cost more than $11.4 billion to address unreclaimed legacy problem areas. Although the 2006 amendments to SMCRA will result in millions of additional dollars in funding provided to states to address sites where the problems exist, many sites will remain unreclaimed when the program expires in 2021 (OSM, 2006).

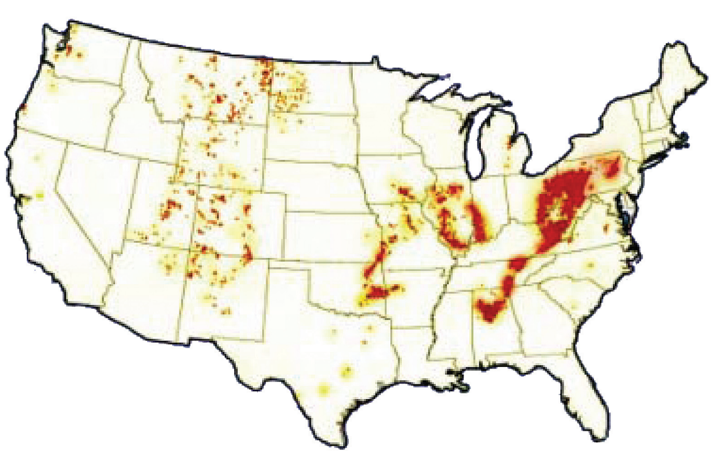


FIGURE 6.3 Distribution of abandoned mine land problem areas. SOURCE: 2006 OSM Annual Report (OSM, 2008b).

4.1 Regional Issues

Coal resources and reserves located in the three primary coal regions vary in quality, quantity, accessibility, economic value, and potential environmental impact. Approximately half of U.S. coal resources consist of subbituminous and lignite coals located primarily in the Western coal region. Bituminous coals are mined in Appalachian and Interior regions and anthracite coal is mined primarily in northeastern Pennsylvania. Generally, subbituminous and lignite coals are not processed before use, thus eliminating potential waste management issues. However, these coals contain higher oxygen and moisture contents compared to bituminous and anthracite coals, and thus have lower energy values, higher transportation costs on an energy value basis, and lower thermal efficiency for power generation. The differences in moisture content and energy value can also result in an increase in CO_2 emissions upon combustion (Winschel, 1990; Quick and Glick, 2000).

4.1.1 APPALACHIAN REGION

4.1.1.1 Mountaintop Mining

In central Appalachia, coal is mined by MTM methods (Figure 6.4) in addition to other surface and underground mining techniques. As explained in Chapter 3, MTM generically includes coal mining that uses methods such as contour mining, area mining, and

FIGURE 6.4 Mountaintop mining with associated valley fills. Note the inclusion of areas with AOCs, VFs, and reclamation efforts. SOURCE: McAtee, 2007.

mountaintop removal mining in the steep terrain of the central Appalachian coal fields. Under SMCRA, mountaintop removal operations do not have to return the land to "approximate original contour" (AOC), in exchange for the establishment of post-mining land uses specified by law. MTM is highly controversial because it changes topography and impacts habitats, scenery, and streams.

Issues related to MTM arise for two main reasons. First, the overburden removed during mountaintop mining usually cannot be completely placed back into the pit following coal removal. Second, there are issues involving the restoration of AOC. Excess material is often disposed of in adjacent valleys, or VF. Depending on the topography and the material properties of the mined spoil, MTM can produce significant amounts of spoil (e.g., unwanted overburden) material. Further, many object to MTM methods based on their broad impact on communities and traditional uses of the land. Much controversy has existed related to this type of mining for many decades, but recent litigation and media coverage have intensified public opposition and attention by regulatory agencies.

A common argument against MTM/VF involves the requirement to restore the AOC of the land that is part of the SMCRA regulations. As noted earlier, variances from the requirement to restore AOC have been provided for mountaintop removal mining in SMCRA (30 U.S.C.§ 1265(c)), as long as post-mining development of lands for industrial, commercial, residential, agricultural, or other public uses listed in SMCRA is established (Figure 6.5). Many MTM operations do not receive these variances, however, and are required to reclaim to AOC.

Because of intensive public outcry concerning MTM and VFs, and as a result of litigation, efforts were recently undertaken to evaluate the role of federal and state agencies in improving the MTM process, the impact of VFs, and opportunities

FIGURE 6.5 Buchanan County Industrial Development Authority Lover's Gap to Bull's Gap connector (Phase I). SOURCE: Quillen, 2007.

for better post-mining land uses. Individuals, organizations, and industry are concerned about MTM/VF. Positions range from total opposition to the MTM/VF process because of its environmental impact, to support for the mining practice because it represents the livelihood of many people in a community.

This controversy led several agencies involved in the MTM/VF EIS process to prepare an EIS to assess ways to improve agency programs under CWA, SMCRA, and the ESA, and to reduce adverse environmental impacts from MTM/VFs (EPA, 2005a). After many years, a final PEIS was released that included information related to historical data, alternative options, and results from scientific and technical studies. The PEIS synthesized information from more than 30 studies that identified impacts or potential impacts related to MTM/VFs. These studies indicated that much of the focus of past MTM reclamation was on erosion prevention and backfill stability. Soils in the reclaimed areas were often compacted, hindering tree establishment and growth, which is commonly the preferred post-mining land use in the Appalachian Mountains. Another problem originated from the planting of grasses that often kept tree seedlings from establishing, thus slowing reforestation of the reclaimed mined land.

Although the number of MTM operations may decrease in the future, public concerns and issues raised will affect all coal mining activity in the Appalachian region for many years to come. Concerns over adverse impacts on the landscape, streams, and habitats that have been raised in the MTM controversy will assuredly be raised in relationship to other mining operations. In addition, the MTM controversy has resulted in involvement of citizens and environmental groups in coal mining permitting and regulation to a greater degree over the past decade, and that involvement is likely to continue and increase.

4.1.1.2 Valley Fills

Other types of surface and underground coal mining in the steep topography of Appalachia also result in excess spoil and the need for VFs. In these cases as well, the process of disposing of excess spoil and coal preparation wastes in VFs has been widely criticized because of adverse impacts on terrestrial and aquatic environments (Fitzgerald, 2005, 2006; Lashof et al., 2007). VFs can bury the headwaters of streams (or ephemeral streams) (Figure 6.6), which in the eastern United States support diverse and unique habitats that regulate water quality and flow quantity, sediment retention, nutrient uptake and cycling, and organic matter processes. The elimination of headwaters potentially has far-reaching impacts on downstream ecosystems. Additionally, some large VFs can affect intermittent and perennial portions of some streams, resulting in added environmental impacts. Recent regulatory changes contemplated

FIGURE 6.6 Downstream view from a valley fill. SOURCE: OSM, 2008d.

by OSM, EPA, and COE have resulted in limits on those impacts, but not all communities are satisfied that those limits are sufficient.

Particular concerns about VFs involve issues related to both CWA and SMCRA. CWA issues focus on streams, such as when disposal of spoils bury headwaters. SMCRA deals with the stability of VFs, placement of excess spoil into streams, impacts downstream from the sites, and post-mining land use. SMCRA also covers cases where lack of AOC is allowed at the permitting and reclamation stage of mine operations. Although concerns about stability are often raised, evidence shows that VFs are generally stable, with fewer than 20 reported slope movements out of more than 6,800 fills constructed since 1985 (EPA, 2005a).

Recently, OSM has proposed to develop rules to address environmental concerns related to disposal of excess mine spoil and coal preparation waste outside the mine area. Additionally, OSM is revising requirements for mining in and around streams. Because requirements related to VFs and stream buffer zones have not always been interpreted consistently, there is need for science-based, technologically feasible guidance to maintain effective environmental protection through long-term regulatory stability of MTM/VFs.

Improved multi-agency coordination, evaluation, and oversight can result in better permitting decisions that can minimize the adverse effects of VFs. Better understanding of environmental impacts in the selection, implementation, and monitoring of projects that fall under SMCRA and CWA is particularly needed. According to the EPA (2005b), the primary goal of the MTM/VF EIS is to establish an integrated surface coal mining regulatory program to minimize environmental impacts from MTM/VF that will include "detailed mine planning and reclamation; clear and common regulatory definitions; development of impact thresholds where feasible; guidance on best management practices; comprehensive baseline data collection; careful predictive impact and alternative analyses, including avoidance and minimization; and appropriate mitigation to offset unavoidable aquatic impacts." Continued evaluation of the progress and mitigation of impacts associated with VFs will be critical for MTM to gain acceptance. Thus, mining activity in Appalachia may be significantly limited by regulatory constraints and public acceptance of VF and associated mining activities. Impacts on streams are often viewed as the most significant by citizens and environmental groups.

4.1.1.3 Water Resources and Quality

Long-term mining in the Appalachian region has caused surface and groundwater problems associated with AMD and mine pools, with more recent water resource impacts caused by MTM/VFs (Ziemkiewicz, 2008). EPA (2005a) estimates indicate that from 1985 to 2001, more than 700 miles (1.2 percent) of stream resources have been directly affected by construction of VFs, with approximately 1,200 miles (two percent of stream resources) directly affected by MTM/VF operations from 1992 to 2002. Streams affected by coal mining operations often contain higher amounts of total dissolved solids (TDS), have lower biodiversity, and generally have more macro-invertebrates and fish species that are tolerant of pollution. However, some streams affected by mining have shown biological communities and water properties of good quality when compared to reference streams (EPA, 2005a). Greater base flow occurs downstream from VFs and tends to be more persistent than comparable unmined watersheds. This results in streams that are less prone to higher runoff than unmined areas during low-frequency storm events, although this trend reverses during larger rainfall events. Wetlands are formed in areas containing erosion and sediment control structures, as well as in unintended areas, with both types of wetlands generally of low-quality aquatic function. Improvements in designs for VFs to increase downstream function are currently an area of intense research (Warner, 2008; Ziemkiewicz, 2008).

AMD from past coal mining activities contributes to severe water-quality problems in the Appalachian region. AMD continues to be a concern because of twentieth century mining practices that resulted in sites susceptible to leaching and unreclaimed areas with acid-producing overburden. In both underground and surface mining, strata containing sulfur-bearing minerals are brought up to the surface. When these minerals come in contact with oxygen and water, a leachate forms, with acidity derived from iron and sulfur oxidation-reduction reactions that decrease pH and increase heavy metal and trace element contents in streams or groundwaters (Figure 6.7). AMD can contain increased levels of TDS, iron, calcium, magnesium, sodium, manganese, selenium, and acidity that result in higher electrical conductivities (EPA, 1994a). Surface waters impacted by AMD may have reduced or eliminated aquatic organisms and provide limited recreational opportunities, with added acidity also enhancing the corrosion of structures such as culverts and bridges (EPA, 2005a). Acid mine drainage has impacted approximately 10,475 miles of rivers and streams in the Appalachian region with 5,115 miles identified as impaired fish habitats in a five-state region that includes Maryland, Ohio, Pennsylvania, Virginia, and West Virginia (EPA, 1995).

FIGURE 6.7 Example of acid mine drainage. SOURCE: Jeff Skousen, West Virginia University.

Estimates are that 80 to 90 percent of AMD in the Appalachian coal region comes from abandoned mines or poor-quality waste drainage, for which there are no legally responsible parties. Streams are often impaired by AMD until either a federal or state agency or a watershed organization takes measures to improve water quality. Although federal and state agencies may not be able to support long-term chemical treatment of AMD, passive treatment systems and land reclamation activities have been used to reduce the acidity and metal load into streams from abandoned and active surface or underground mines. Improvements in water quality at mine sites have been accomplished using passive systems, including wetlands, anoxic limestone drains, vertical flow wetlands, and open limestone channels. Constructed on site, these systems have successfully demonstrated measurable decreases in acid load to streams. These systems are also low maintenance and do not require the continual addition of chemicals; they remove metals from AMD by oxidation and precipitation processes, microbial reduction reactions, and adsorption-exchange reactions. Longevity of system effectiveness is not entirely known for all systems, but passive treatment is an option for many stream restoration projects and can be used on active mines to control off-site contamination.

Significant reductions in acid loads to streams have been achieved after AMLs are reclaimed, due to reduced water flows and acid concentration in the waters from the mine sites. Remining areas can eliminate the AMD source. For example, ten remining sites in Pennsylvania and West Virginia demonstrated that if reclaimed to current standards by eliminating mine portals and previously constructed highwalls, covering refuse, and revegetation of the entire area, water quality improves and, in some cases, on-site AMD is completely eliminated. One surface remining operation of an underground mine in Preston County, West Virginia, used alkaline overburden from an adjacent surface mine to neutralize acid materials on the remined site (approximately 6,000 to 7,000 tons per acre). At another site, water quality from an acid-producing deep mine had an average pH of 3.7, but after remining and reclamation, the pH was greater than 7.0 (Skousen and Ziemkiewicz, 1996).

Current coal mine operators must take action to prevent the production of AMD. If AMD is produced during or after mining, they must develop a system for treating the affected water to comply with water quality discharge limits. Despite better predictive methodologies, federal and state regulators acknowledge that AMD still occasionally occurs at active coal mines. Once created, AMD may be difficult to treat and may require long-term, if not perpetual, treatment to prevent off-site impacts to receiving waters. In the Appalachian coal region, regulatory requirements and recommended procedures include segregating and placing acid-producing materials above the water table and, to reduce the potential for AMD development, treating, compacting, and isolating the materials to reduce surface water infiltration. The effects of AMD can also be diminished through addition of alkaline substances such as limestone, soda ash, quicklime, and hydrated lime to the reclaimed site to neutralize the acid that may be generated. AMD has been and will continue to be costly to mitigate, with millions of dollars spent annually to reduce AMD impacts.

Recently, there have been increased concerns with streams in mining regions that contain trace elements such as selenium and arsenic at levels above criteria contaminant limits (CCL) (EPA, 2005a). Trace elements can be aquatic health concerns because of bioaccumulation in fish and other organisms. Concentrations of some trace elements above CCL have been found in adjacent streams, groundwaters, and runoff from ash disposal sites (Hansen and Christ, 2005). These sites are high-priority concerns in the Appalachian region because they have the potential for causing stream and groundwater contamination, and have only recently gained attention.

Both the legacy of water-quality issues and emerging water-quality concerns related to effects of coal mining operations have heightened public and regulatory agency awareness and scrutiny. The multiple law suits that have arisen related to water issues are expected to continue and may impact current and future coal production in the Appalachian region.

4.1.1.4 Coal Preparation Plants and Slurry Impoundments

Coal preparation plants produce large volumes of waste comprised of mixtures of shale, clay, coal, low-grade shaley coal, and preparation chemicals (NRC, 2002a). A significant amount of raw coal processed through preparation plants is discharged to waste ponds or slurry impoundments as "refuse." Nationally, there are over 700 active slurry impoundments, with a majority located in the Appalachian region states of West Virginia, Kentucky, Virginia, and Pennsylvania (see Chapter 4); an estimated 240 slurry impoundments exist above abandoned mines. The pre-SMCRA abandoned impoundments are being identified and reclaimed as part of the AML program funded under SMCRA; however, many of these slurry impoundments may be unstable

BOX 6.3 IMPOUNDMENT FAILURES

Human and environmental disasters associated with some slurry impoundments have raised concerns about their safety. The failure of a 72-acre surface impoundment of liquid waste on October 11, 2000, which released approximately 250 million gallons of the slurry into an underground coal mine, was the focus of a study by a specially constituted committee of the National Academy of Sciences (NRC, 2002a). One of the three tasks of the study was to evaluate the accuracy of mine maps and to explore ways and means to improve surveying and mapping of underground mines to delineate more accurately how underground mines relate to current or planned slurry impoundment. The NRC study recognized that maps of mines operating since the 1970s are likely to be more suitable for impoundment design, maps of older mines may not be suitable, and mine maps may be inaccurate because of unrecorded final cuts. In these cases, the study stated that additional investigation to locate the underground workings is warranted, and that invasive drilling programs can provide the necessary information. Noting both cost and environmental issues involved in intensive drilling programs, the study suggested that well-planned and appropriate use of geophysical techniques can help minimize the amount of drilling required to detect mine voids. The NRC Committee, however, cautioned that no geophysical technique is capable of performing optimally under all geological and topographic conditions and that multiple geophysical techniques may be necessary to reduce the probability for error to an acceptable level. Further, the Committee noted that while the geophysical methods have proved successful in some cases, drilling is still necessary to confirm interpretations of the geophysical and remote-sensing data. The majority of these types of accidents involve failure in the basin area. Inaccurate mine maps and inadequate characterization of the basin area most likely contributed to at least some of these incidents. See Chapter 4—Coal Processing Technologies for more information on slurry impoundments.

and could be hazardous to humans, wildlife, and the environment. Impoundment structures are known to fail, which is why waste disposal areas are regulated (Box 6.3). Future mining operations should develop better processing methods that minimize refuse to reduce disposal area needs, while maximizing the amount of material that can be used for energy production. In addition, it is important to locate coal refuse disposal facilities to minimize potential for embankment or impoundment failure. Certain coal mining activities can produce significant amounts of spoil that may be used to construct dams in valleys adjacent to the mine. In preparing and processing coal, liquid and solid wastes are produced that are disposed in impoundments, where significant amounts can accumulate over time. Although MSHA and OSM have regulations concerning impoundments, there have not been explicit regulations for evaluation of the breakthrough potential of impoundments (NRC, 2002a). If an impoundment leaks, contaminants and slurry may end up polluting streams or groundwater.

The history of impoundment breakthroughs into underground mines and associated environmental and safety impacts have resulted in long-existing concerns about impoundment stability. Coal waste facilities have been involved in some well-known accidents. One of the most famous was the 1972 Buffalo Creek incident, where a coal waste impounding structure collapsed, killing 125 people, injuring 1,100, and leaving more than 4,000 homeless.

The Buffalo Creek tragedy was one of the drivers for the passage of SMCRA, and no failures of that magnitude have occurred since. However, in 2000, a failure of a coal slurry impoundment in Martin County, Kentucky, led to the contamination of over 100 miles of streams. These types of accidents will likely result in continued public and regulatory concerns about the environmental impacts of coal waste disposal and can impact permitting of additional coal processing and associated waste facilities.

4.1.1.5 High-Quality Streams/Aquatic Resources

Another important environmental issue related to coal mining in Appalachia results from the presence of high-quality streams in areas with mining. Following a national review of rivers, The Nature Conservancy named the Clinch River in the Appalachian Mountains of Southwest Virginia as the most biologically rich river in the country. The Clinch River is home to 31 rare mussel species and 17 rare fish species, many found nowhere else in the world. The Clinch River has been recognized as a river of global significance, though its water quality is impacted by a variety of human activity in the area, including coal mining.

The Clinch and Powell rivers are the only ecologically intact (undammed) headwaters of the Tennessee River system. The Clinch River watershed has more imperiled aquatic species than any other watershed in the nation. Combined with the rare plants, mammals, birds, and insects that live in the watershed, the Clinch Valley and its rivers support 30 federally listed threatened or endangered species.

Land use around the main stem of the Clinch River is predominantly agricultural, but there has been a significant amount of historical impact contributed by coal mining, especially prior to 1977. Even today, the harmful effects of past coal mining still linger. Erosion from abandoned mine lands, AMD, and inadequate sewage disposal from former coal mining communities contribute toxic and persistent pollution to the waterway.

Concerns over these impacts may limit expansion of coal production in these watersheds. However, it should be noted that the remaining economically viable reserves in this area are declining, thus they will not significantly impact future coal production in the region.

4.1.2 INTERIOR REGION

4.1.2.1 Subsidence

Underground coal mining can cause surface subsidence either during active mining or following the completion of a mine (Figure 6.8). In conventional room-and-pillar mining, pillars of coal are left in place while the mine is active to protect against roof falls, but over time these supports tend to fail, resulting in subsidence at the land surface. Subsidence associated with room-and-pillar

FIGURE 6.8 Water ponding and tension cracks around the edge of the depression due to a sag subsidence event. SOURCE: Bauer, 2006.

mining may occur months, years, or even decades after mining ceases. In longwall mining, no pillars are left in place over the primary mining area, and the overburden is allowed to collapse as the longwall section advances forward. Because longwall mining results in extensive area collapse in mined-out panels, surface subsidence is expected, and occurs coincident with mining. Subsidence may cause flooding of low-lying areas, destruction of buildings, roads, and other structures, and disturbance of underground water tables from caving of the overlying strata. Generally, subsidence from longwall mining is more uniform than room-and-pillar mining, making surface impacts more predictable.

Subsidence from underground mining has caused widespread problems for homeowners and local communities throughout the United States. Although some subsidence problems may be relatively limited and manageable, large subsidence events can result in major structural damage to homes (Figure 6.9), buildings, and roads (i.e., sinkholes or uneven surfaces) that can be dangerous and costly. Subsurface strata also have different leaching and permeability characteristics compared to pre-mining conditions. Collapse of strata above a coal seam in underground mine areas can lead to surface and subsurface impacts that can modify hydrologic properties on and off site. Subsidence may also disrupt the natural flow of water into wells, streams, and aquifers.

Coal mine subsidence is primarily regulated under SMCRA, which prohibits mining beneath impoundments, aquifers that provide water supplies, and public buildings unless the regulatory authority determines that such mining will not cause subsidence damage to such sites. SMCRA also requires coal operators to "promptly repair, or compensate for, material damage resulting from subsidence caused to any occupied residential dwelling and structures related thereto, or

FIGURE 6.9 Impact due to land subsidence. Freeburg, IL. SOURCE: Illinois Department of Natural Resources, 2008. http://dnr.state.il.us/mines/aml/gallery/freeburgc.html.

non-commercial building due to underground coal mining operations," and to "promptly replace any drinking, domestic, or residential water supply from a well or spring in existence prior to the application for a surface coal mining and reclamation permit, which has been affected by contamination, diminution, or interruption resulting from underground coal mining operations." Some states have additional requirements related to subsidence that exceed those contained in SMCRA.

Subsidence can be a problem particularly where water tables are near the surface and the landscape is of low relief. Under these conditions, ponds can form in the subsided areas. Research has shown that subsidence mitigation, properly applied, can restore agricultural productivity to undermined areas in most cases (Darmondy, 2000).

Continued or expanded public opposition to subsidence and the costs of mitigation of subsidence damage may result in limitations on coal production from underground methods. This is particularly true of areas with prime farmland (discussed below) or where subsidence may impact surface water resources.

4.1.2.2 Prime Farmland

The Interior coal region has significant coal resources that underlie areas that are classified as prime farmlands. Surface mining of these areas causes significant changes to the soils after the areas have been mined and reclaimed (Dunker et al., 2008). Underground mining can also alter the surface of prime farmland areas, resulting in a reduction in agricultural productivity. Because both coal mining and the production of food and fiber are essential industries, a balance is needed between coal mining and farming. As underground coal production increases in parts of the Interior region, areas of prime farmland require greater attention so that surface subsidence can be managed and lands used for agricultural production are minimally impacted.

Whereas SMCRA addresses subsidence mitigation, states are given the authority to oversee and enforce the types of surface subsidence impacts created by underground mining. SMCRA also requires that this enforcement include requiring coal operations to restore prime farmlands affected by subsidence to their pre-mined land use capability. Prime farmland requirements are intended to ensure that restoration results in as good or better productivity of the soil after mining. Included in the process of protecting and restoring farmlands is an initial survey of the soils to determine the location of prime farmlands. For surface mining operations, soil surface layers important to crop production must be separated, stored, and protected from wind and water erosion or chemical contamination. After coal is mined in a particular area, the soils are replaced during reclamation in order to create a root zone of comparable depth and quality as the pre-mined or natural soils of the area.

Coal mine operators have overcome many past prime farmland problems and are successfully achieving revegetation goals and obtaining final bond release. In fact, in some parts of various coal regions (such as Kentucky, Kansas, and North Dakota) reclamation practices have actually created prime farmland soils. The long-term impacts of surface mine reclamation on potential agricultural productivity of reconstructed soils is being addressed by the Natural Resources Conservation Service (NRCS), in part because concerns associated with projecting actual crop yields based on the measurement of existing soil qualities still exist. The NRCS has initiated programs that will produce detailed guidance on the reconstruction of prime farmland soils. Continued evaluation of the reconstructed soils requires area-wide mapping and reassessment of reconstructed prime farmland soils to determine if they have obtained comparable agricultural productivity to pre-mined soils. Reclamation of prime farmland areas is important in determining land values, crop production capabilities, and tax assessments. The decrease of surface coal mining in the Interior region has reduced the amount prime farmland disturbance; however, increased underground mining has resulted in greater potential impacts on prime farmland through subsidence.

The protection and development of prime farmlands impacted by coal mining have undergone many changes over the years, but based on a forum on the topic (Hooks et al., 1998) there is still much to be done. An emphasis should be placed on region-specific guidance for post-reclamation management that includes a soil-based productivity model (e.g., soil parameters important for plant growth) that would substitute for actual crop production. More science-based information can also be obtained by soil penetrometer systems, development of GPS-based reclaimed prime farmland databases, and use of long-term prime farmland performance based on soils and crop yields (Dunker et al., 2008).

Reclamation of prime farmlands does not appear to cause significant problems in maintaining or expanding coal production in this region; however, the coal industry and regulatory authorities must continue to address issues related to subsidence impacts and measures of restoration.

4.1.3 WESTERN REGION

4.1.3.1 Importance and Impacts

The mid-1970s to 1980s brought significant attention to Western region coal fields, particularly those in the PRB of Wyoming and Montana. CAA requirements for reduction in SO_2 emissions from coal combustion increased interest by power plant operations in using low-sulfur, less-expensive coals from the PRB to meet air quality compliance instead of installing sulfur-related emissions scrubbers. The restriction on SO_2 emissions is a primary reason why the low-sulfur coal from the PRB has far outpaced the rate of growth for higher sulfur, more expensive coal from the Appalachian and Interior regions. Nevertheless, as surface mining in the Western region proceeds, it is likely that the deeper coal reserves that will be mined will cost more to produce, reducing the economic advantage over coal from other regions.

Subbituminous coals of the PRB are not processed because of their low ash and low sulfur content, although they do contain a significant amount of moisture (~30 percent). The high moisture content, lower energy value, and distance to markets increase transportation costs and the potential for environmental impacts. One way to partially offset these disadvantages is to remove excess water from, or "dewater," PRB coal by heat processing to increase the coal's energy value and reduce transportation costs. The few coal preparation plants in the Western region, however, are located at bituminous coal mines.

Relatively small populations near these mining operations and the economic benefits of resource extraction to neighboring communities have traditionally limited the opposition to coal mining operations in the Western region. As the population near mining activities and the size and scope of operations increase , there may be increasing opposition to the environmental impacts of PRB coal operations. Additionally, many national environmental groups have expressed opposition to coal leasing, mining, and power generation in the region over the past decade.

4.1.3.2 Reclamation and Revegetation

Replacing topsoils is an important reclamation practice and enhances revegetation potential following the reclamation of mine topography. Topsoils increase the potential for successful revegetation that can control erosion and improve water use and management. Alternative reclamation approaches suggested for future consideration include reducing grading, which results in lower fuel consumption, less compaction, increased water retention, better water recharge, greater plant root penetration, and greater crop productivity. Topsoil depth requirements that specify amounts that have to be uniformly applied across a mine have been questioned because research shows greater plant diversity with variable topsoil depths (Schladweiler et al., 2004; Bowen et al., 2005).

Land reclamation in the Western coal region can be challenging because of arid climate and often poor soil quality conditions, although innovative techniques have been developed (Munshower, 1994; Ferris et al., 1996). Reclamation of surface mined areas must produce viable post-mining land uses, with final bond release requiring successful revegetation of reclaimed mine areas.

Under SMCRA, areas of annual average precipitation below 26 inches require a 10-year minimum period of revegetation success, whereas areas of annual average precipitation above 26 inches require a minimum period of five years. The arid and semi-arid climates of Western region coal fields are given a longer liability period to assure revegetation success.

Revegetation of the arid and semi-arid Western region coal fields that contain high levels of water-soluble salts (i.e., have a high salinity level) and contain high levels of soluble sodium (i.e., have a high sodicity level) can be vastly different from revegetation of humid climate areas in Appalachian and Interior region coal fields. Arid and semi-arid climates present unique and sometimes adverse conditions for reestablishing vegetation. However, even in humid climates, revegetation may be unsuccessful if plant roots are restricted by dense, compacted topsoils or spoils, or by acid and toxic materials. In fact, several AML sites across the nation have remained sparsely vegetated because of acidic, saline, or toxic condition of the abandoned spoil material.

Although public and environmental group issues related to reclamation and revegetation continue to increase in number and importance, it is highly unlikely that these concerns will detrimentally affect the ability to maintain or increase coal production from this region. It will become more incumbent upon regulatory agencies and the mining industry to address these concerns adequately to maintain the level of public support that the coal industry generally enjoys in this region.

4.2 National Concerns

Whereas many concerns related to coal mining are of particular interest in the three major production regions, some issues are more national in scope. Coal mined from both surface and underground mining operations results in terrestrial modifications related to redistribution of strata, hydrologic changes, alterations in topography, and landscape disturbances that have a direct bearing on plant ecology and wildlife habitats. Coal mining operations affect terrestrial ecosystems; mining techniques, locations, geological properties, and habitats all influence environmental change. Subsidence, VFs, reclamation/revegetation, and post-mining land use are some of the important national terrestrial issues.

4.2.1 WATER QUALITY

Coal production can affect the chemical and physical properties of surface water and groundwater and the biological suitability of those waters. Water chemistry can be affected by leachates from abandoned and active mine sites; sediments affect the chemical and physical properties of water and aquatic habitats. Water discharges associated with coal mining operations are regulated by CWA and administered by federal or state programs. Permits that set specific effluent discharge levels for different chemical and physical water quality characteristics must be in compliance with CWA. Water resources that must be protected from degradation include surface waters (i.e., AMD, sediments, trace elements, and stream loss, such as impacts from VFs) and groundwater systems (i.e., hydrology and drinking water standards). Additionally, mine site restoration involves water resources (e.g., wetlands and stream reconstruction). SMCRA requires prevention of material damage to the hydrologic balance off the mine site and minimization of impacts in the permitted area.

4.2.1.1 Surface Water

The Fish and Wildlife Coordination Act (FWCA) recognizes the importance of fish and wildlife resources. Specific actions that are regulated by FWS and COE according to FWCA (16 USC

661) and the Rivers and Harbor Act (Section 10) include discharge of pollutants and their consequences resulting from the diversion, control, or modification of streams and other water bodies. FWCA specifies that fish and wildlife conservation must be carefully considered and coordinated in permitting programs and proposals that involve water resource development. Both FWS and state conservation agencies must be notified by an agency considering actions that fall under FWCA. FWS and state recommendations that address fish and wildlife protection must be incorporated into project plans, although the final wildlife mitigation measures are determined by the permitting agency. In addition, many streams contain threatened or endangered species that require additional consideration of habitat and species protection.

Surface water impacts from AMD, sediments, trace elements and compounds, or other forms of contamination during coal mining are regulated primarily by federal and state agencies, including EPA. Mine operations must meet federal and state standards for protecting surface waters and groundwaters from contamination to meet compliance standards, which are often based on water quality testing programs. The effectiveness of surface water protection has been questioned as a result of a number of issues that have arisen related to coal mining, including the widespread construction of VFs in the Appalachian region. Accordingly, OSM is developing "stream buffer zone" rules that will apply to intermittent and perennial streams, and will also include lakes, ponds, and wetlands affected by mining nationwide (OSM, 2007b). The inclusion of lakes, ponds, and wetlands in the new rule recognizes the importance of aquatic organisms and other beneficial environmental resources that need to be protected. The new rules will limit dumping mine spoil outside of mining areas and reduce environmental impact from VF and disposal of coal processing waste. Although both SMCRA and CWA contain language that directly or indirectly addresses the need to protect water flow in perennial streams and establish buffer zones with setback distances, the new rules are intended to identify mining activities associated with these requirements and define the circumstances under which these activities may be allowed within 100 feet of a body of water. Coal operators will be required to demonstrate how this standard will be met throughout the life of the operation before receiving a state or federal permit to mine.

Waters that are acidic usually contain high metal and trace element concentrations and can increase the dissolution of other minerals. As previously discussed, reducing AMD on a mine site often requires isolation of acid-generating spoil materials (Figure 6.10). Technologies such as diversion systems, containment ponds, groundwater pumping systems, subsurface drainage systems, and subsurface barriers can be used to control water

FIGURE 6.10 Spoil impacts to stream waters. Note the AMD (brown iron oxide deposits) along the stream banks. Source: Jeff Skousen, West Virginia University.

flow at a mine site. Treatment of AMD requires neutralization of acidity and reduction of metal concentrations. OSM has expended considerable efforts to reduce or eliminate AMD from AML sites (OSM, 2008b).

Adjacent watersheds and streams may also be affected during and after mining. Excess mine spoil can affect aquatic habitats that are altered during coal mining operations, causing the loss of integrity in effected watersheds and downstream environments. Subsidence from underground mining can also impact surface water bodies and groundwater hydrology. Stream pollution is highly controversial and continues to play a major role in the conflict between increasing coal production and protecting the environment.

4.2.1.2 Groundwater

Site hydrology is altered when surface and rock strata are modified during mining. Alteration in hydrology can impact surrounding environments and damage water sources used for drinking water supplies or for irrigation. As surface mining in semi-arid Western regions increases, there are concerns that groundwater quantities and qualities will be affected. Groundwater recharge is also expected to be affected by coal mining operations in the Appalachian region. Post-mining discharges from flooded underground mines have resulted in impacts to surface and groundwaters and, according to state and federal agencies, appear to be more likely in the future.

Currently, mines that have post-mining discharge potentials are required to develop plans for funding and treating the discharges. Coal seams that are likely to develop post-mining discharge pollution are not permitted unless the coal mining operations are capable of preventing the discharge from occurring.

4.2.1.3 Underground Mine Pools

Encountering water in underground coal mines is not unusual because underground mine openings can intercept and convey surface water and groundwater. When excavated below the water table, mine voids often serve as low-pressure sinks, inducing groundwater to move to the openings from the surrounding saturated rock. The result is the dewatering of nearby rock units via drainage of fractures and water-bearing strata in contact with mine workings. Provisions for handling normal water inflow in mines by collecting it in sumps and pumping it outside are standard procedures in the mining industry. However, the sudden influx of large quantities of water into a mine is a dangerous event. When this influx is unexpected, the lives of miners and the safety of a mine are threatened. Inundations of coal mines have occurred from surface waters, nearby aquifers, and from waterlogged mine workings in the same mines or in adjacent mines (Box 6.4).

In the past, some underground coal mines were operated so as to allow mine water to discharge to the surface when the mines were closed and abandoned. Although this type of mining is no longer allowed under SMCRA and state regulations, the legacy of these past mining practices is a current environmental issue. Where flooded and abandoned underground coal mines have the potential to discharge polluted water to the surface, federal and state laws now require coal operators to maintain pool levels with a "pump and treat" process. Although these approaches can be very effective in preventing discharge, the process can be very expensive because it is likely that the pumping will continue forever. For example, in Pennsylvania in 2003, as many as 140 mine operators actively treat water on 270 mine sites using 376 separate treatment facilities. If they cease operation, there may not be enough incentive to stop them from abandoning their environmental obligations at

BOX 6.4 FAIRMONT MINE POOL

Near Fairmont, West Virginia, there is an underground network of abandoned mine workings covering more than 27,000 acres of tunnels and shafts. Historically, groundwater and surface water have drained into these workings, creating a huge underground pool, known as the Fairmont Mine pool. Water in the pool is contaminated with iron and acid from former coal mining operations. If the level of the pool were to rise high enough, it could overflow, heavily contaminating nearby streams. A former coal operator is currently pumping and treating water from the mine pool in an effort to reduce the likelihood of seepage or potential blowouts. Similar mine pools cause serious environmental concerns in Pennsylvania, Maryland, and West Virginia. The National Mine Land Reclamation Center at West Virginia University recently completed a multi-year study on mine pools, "EPA Region III Mine Pool Project," that analyzed flooding and water chemistry in the Pittsburgh coal seam in northern West Virginia and southwestern Pennsylvania (http://www.ri.nrcce.wvu.edu/).

262 mines and coal waste piles across the state. Together, those sites generate an estimated 28 billion gallons of AMD annually.

If states have to assume this liability, the cost could be astronomical. If treatment is stopped, the impacts to the environment and to quality of life will also be significant, and will imperil abatement efforts that are already underway. Available funds are limited, but the costs of perpetual treatment and the environmental cost of not treating these discharges are enormous. As a result, many states are attempting to devise new ideas for establishing funding mechanisms such as trust funds to deal with orphan mine discharges, as well as creative technical solutions to use the water as a resource in an effort to address both current industrial needs and the issue of mine water treatment.

4.2.2 AIR QUALITY

Air quality emissions are related to gases and PM. Emissions of PM and gases such as methane and nitrogen oxides are known to cause respiratory and human health problems (EPA, 2006a) and may contribute to other environmental issues, such as climate change. Mines generally have on-site equipment for hauling, processing, and loading coal onto rail cars, all of which can contribute to air emissions. Gases such as nitrogen oxides can be generated by blasting. Noise can also be an air quality concern, but careful conduct of blasting, selection of type and location of equipment, installation of insulation and sound enclosures around machinery, and development of vegetative buffers around equipment stations can reduce noise levels.

PM on mining sites can affect visibility near the mine and result in other air quality degradation. PM originates from several sources, including dust from haul trucks, blasting, mined coal, exhaust from mining equipment, coal crushing and processing, drilling operations, and, particularly in Western region surface coal fields, wind-blown dust from the mine-disturbed areas. Dust levels can be controlled by spraying water and other chemicals on roads, stockpiles, and conveyors, or by equipping drills with dust collection systems. Purchasing land surrounding the mine to act as a buffer zone and planting buffer zones with trees or shrubs may also reduce off-site migration of PM and provide a visual barrier of mining operations. Exposure to PM emissions can be a serious health threat that can cause significant respiratory damage.

Air quality regulation of coal preparation plants that process coal by breaking, crushing, screening, wet or dry cleaning, and thermal drying are legislated under the New Source Performance Standards and CAA. In addition, sources that emit pollutants in sufficient quantities may also be subject to CAA's prevention of significant deterioration (PSD) requirements for NAAQS attainment areas. If deemed critical to attainment area quality, requirements of best available control technology (BACT) may be imposed on new mine operation facilities or those undergoing major modifications.

Ambient air quality in Campbell County, Wyoming's leading coal producing county, exceeded air quality threshold limits in 2002. Air pollution in Campbell County almost earned non-attainment status, which could have prevented construction of power plants that, in the past, have been responsible in part for an increase in PRB coal production (BLM, 2005).

The greenhouse gases produced in coal mining consist primarily of methane, with other emissions, including carbon dioxide (from vehicles and fires) and nitrogen oxides (from blasting). Coal mine methane (CMM) is a byproduct of coal production that is released from coal and the surrounding rock strata. CMM can be recovered prior to, during, and after mining; coalbed methane (CBM) is generally produced independently of coal mining activities (Figure 6.11). Although all coal contains methane, the amount in a particular area depends on coal type and depth.

In abandoned and surface mines, CMM may be emitted into the atmosphere through natural fissures or cracks. Deep underground mines typical of the Interior and Appalachian regions, however, are the largest source of CMM (Figure 6.12). CMM is emitted from several sources including:

- Degasification or drainage systems at underground coal mines that employ vertical or horizontal wells to recover CMM prior to or after mining
- Ventilation air from underground mines that contains low levels of CMM
- Abandoned or closed mines where CMM seeps out of vent holes or cracks in the ground
- Surface mines where CMM is released from coal seams directly exposed to the atmosphere
- Fugitive CMM emissions from coal processing, coal storage, and transportation

In underground mines, CMM can be an explosive hazard. For both human health and explosive concerns, ventilation systems are installed in underground mine shafts and portals to remove the gas.

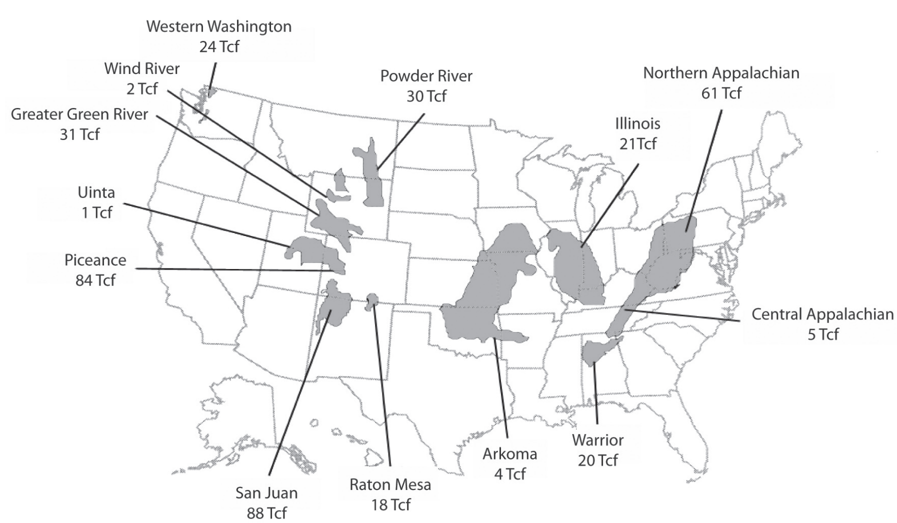


FIGURE 6.11 Coalbed methane (CBM) resources in U.S. coal basins (Tcf = 1012 cubic feet). SOURCE: EPA, 1999.

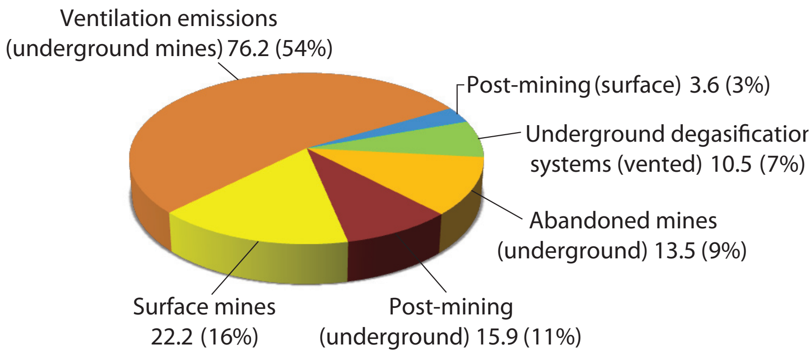


FIGURE 6.12 Source and amounts (billion cubic feet) of coal mine methane emissions during 2005. SOURCE: EPA, 2006b; U.S. Emissions Inventory, 1998–2006.

Prevention methods, such as methane draining, reduce CMM in underground mines (The Coal Authority, 2007).

Coal mines account for approximately 10 percent of all anthropogenic methane emissions in the United States (EPA, 2005c). Captured methane may be used as a fuel source at mine sites (Box 6.5) or transferred to a natural gas pipeline system. Benefits of capturing and using CMM include: reducing greenhouse gas emissions; conserving a local source of valuable, clean-burning energy; enhancing mine safety by reducing in-mine concentrations of methane; and increasing mine revenue. Where CMM is captured, it may be sold to natural gas pipeline systems or used for coal drying, as a heat source for mine ventilation air, as supplemental fuel for mine boilers, or as vehicle fuel as compressed or liquefied natural gas (LNG). The report, *Upgrading Drained Coal Mine Methane to Pipeline Quality*, by EPA's Coalbed Methane Outreach Program (CMOP) provides an overview of gas upgrading technologies that can be used to remove contaminants typically found in CMM (EPA, 2008b, 2008c). This report also provides several examples of successful technology installations in current operation in coal mines. One of the priorities of EPA's Office of Air and Radiation in 2008 is to promote the recovery and use of methane as a clean energy source (EPA, 2008d).

Mine discharges of methane increase the overall environmental impact of coal mining. Reducing greenhouse gas emissions, including CMM, in the upstream cycle is possible and should therefore be pursued. This reduction could be accomplished by developing low path emissions for coal, increasing efficiency of mining energy needs, using mining techniques that reduce materials movement, increasing the efficiency of energy-intensive activities, decreasing coal comminution processes,

BOX 6.5 MEGTEC'S VOCSIDIZER

EPA, DOE, and CONSOL Energy are collaborating on a project that will demonstrate thermal oxidation of ventilation air CMM using Megtec's Flow Reversal Reactor. The Megtec Vocsidizer uses up to 100 percent of the CMM released from mine ventilation shafts to generate heat that can be used for power production (EPA, 2003). SOURCE: http://www.megtec.com/documents/UK_Vocsidizer.pdf.

developing coal byproducts, or capturing and using CMM through methane-to-market programs.

4.2.3 PROTECTION OF PUBLIC PROPERTY AND SAFETY

Coal mining can provide economic benefits to communities both during the productive life of a mine and following mine closure by establishing beneficial post-mining land uses. However, coal mining can also have negative effects on nearby communities. Impacts can include noise, dust, and subsidence issues. Noise from blasting and trucks is a concern to individuals and communities near mine operations. Blasting and road dust can result in increased air pollution. In the PRB of Wyoming, air quality concerns have become important issues to the public and currently are considered one of the principal environmental issues in the area. Subsidence from underground mining can also cause structural damage to houses, roads, and bridges. It is important to involve local communities in mine activities so that they are more aware of coal operations and their potential effects. To maximize the protection of property and the safety of the people, mining operations must involve all stakeholders, including industry, regulatory agencies, and communities, in the comprehensive process of developing a coal mine.

Increasingly, coal producers must encourage community involvement. New and innovative technologies must be developed to address issues that are important to communities and provide them with confidence in the suitability of coal development activities. One example of how the industry is increasing public awareness is through the Coal Impoundment Location and Warning System (CILWS) project (http://www.coalimpoundment.com), which was initially developed in 2003, in part because of past impoundment failures. The system has been adapted by industry to provide local communities with knowledge of coal impoundments, operations, and the increased need for public safety in the case of a failure. Information on the CILWS website includes simple and detailed emergency plans and an interactive map showing evacuation routes, checkpoints, meeting places, and emergency contact phone numbers. Such approaches need to be developed to ensure that potential problems that confront communities are minimized or eliminated as coal production continues at currently levels or expands as projected in the future.

4.2.4 MINE WASTES

Mine waste management is an important environmental concern because of potential impacts associated with solid, liquid, and gaseous wastes. In the Appalachian region, coal preparation will unquestionably be more important in the future, with increased efficiency resulting in greater quantities of coal refuse and wastes. Another waste from coal mining is the solid waste rock left behind from tunneling or blasting, which can set off a number of previously discussed environmental impacts, including AMD. Potential future coal mine waste problems also include the legacy of AMLs.

4.2.5 PROTECTION OF SENSITIVE RESOURCES

4.2.5.1 Threatened and Endangered Species

Under the Endangered Species Act (16 USC 1531), all federal agencies are prohibited from authorizing, funding, or performing actions that could adversely modify habitats essential to the survival of species that are in danger of extinction or threatened with endangerment. Endangered and threatened species are protected from the impacts of surface coal mining operations by federal and state requirements as outlined in the 1996 programmatic biological opinion (BO) on surface coal mining and reclamation operations. A federal agency must consult with FWS when an action that might affect endangered species, such as when coal mine permit approval is being considered. In a similar manner, the state regulatory authority that issues coal mining permits must also be consulted when endangered or threatened species are concerned, as required by Section 7 of ESA. This rule was added after federal action was taken when OSM approved state programs that regulate coal mining. The 1996 BO is designed to reduce the potential for duplication of effort between federal and state regulatory agencies while maintaining the level of protection for listed species and their habitats as specified in ESA.

FIGURE 6.13 English bat cupola at an abandoned mine. SOURCE: OSM, 2007a.

For example, the Indiana bat (*Myostis sodalis*) is an endangered species listed by ESA that is found in many areas of the United States where coal is mined. The known range of the Indiana bat overlaps all or a portion of active coal mining areas in Alabama, Arkansas, Maryland, Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, Tennessee, Indiana, Illinois, Missouri, Iowa, and Oklahoma. In all of these states except Tennessee, coal mining is regulated by a state agency; coal mining in Tennessee is regulated by OSM under a federal regulatory program. All agencies and programs involved in the coal mining permitting process must consult with FWS under Section 7 of ESA to ensure Indiana bat survival.

Coal mining activities in the Interior and Appalachian regions can cause temporary and extensive disturbance to local environments, and in some cases have the potential to affect the summer and winter habitats of the Indiana bat. Specifically, coal mining activities such as blasting near winter hibernacula, such as caves or abandoned underground mines, can adversely affect local bat populations. Additionally, clearing of certain mature hardwood forest species during the initiation of mining activities can destroy summer habitat for roosting Indiana bats. Information provided by FWS shows a dramatic decline in the number of Indiana bats over the last 30 years nationwide (Pruitt and TeWinkel, 2007). However, bat populations are increasing in some coal-producing states and decreasing in others, with no consistent correlation between bat populations and changes in levels of coal mining activity, total coal production, or mining method. Use of cupolas is one option for preserving and protecting bat habitats (Figure 6.13).

4.2.5.2 Archeological, Historic, and Cultural Resources

Potential fragmentation of habitats in unique places, either through direct mining activities or from off-site degradation caused by runoff or air quality impairments, is a growing concern, particularly in the western United States. However, both SMCRA and BLM prohibit mining within specific areas of the different coal regions. For example, SMCRA restricts mining in national parks and wildlife refuges, around wild and scenic rivers, and in designated wilderness areas; around sites on the National Register of Historic Places; and in close proximity to roads, homes, schools, churches, and cemeteries. There is also a provision in SMCRA that allows any interested person to petition the state regulatory authority to designate a coal-bearing property as unsuitable for coal mining. If an area considered for mining would cause a significant or unavoidable impact to environmental resources or historic structures or if successful reclamation is not possible, the area may not be mined. The "designation of lands as unsuitable for coal mining" has been used to restrict thousands of acres to coal mining throughout the country, particularly during the late 1980s and early 1990s. BLM is responsible for managing the leasing and development of federal coal and also has discretionary authority for declaring lands unsuitable for ecological reasons. Areas that can be considered unsuitable may include bald and gold eagle nests and roosts, and essential habitats for specific types of plants, fish, and wildlife that are of special interest to the public.

Surface coal mining and reclamation on Native American lands is regulated by OSM under SMCRA (30 CFR Sec. 750). There are, however, several agencies involved in the administration of coal mining operations on Native American lands. In addition to OSM, the Bureau of Indian Affairs (BIA) and BLM also play vital roles in exercising the federal government's trust responsibilities towards Indians with regard to coal mining operations. Active coal mines currently exist on Navajo, Hopi, and Crow reservation lands. Energy resource extraction of oil, gas, and coal owned by Native American tribes, but managed by federal agencies, are of concern to Native tribal governments because of potential impacts on traditional beliefs and practices of their people. It is important that Native American tribal governments and land managing agencies work together to coordinate coal mining practices to mitigate their effects on sacred sites and areas that are traditionally used for gathering plant foods and materials (BLM, 1999).

4.2.5.3 Bond Release Concerns

Underground and surface coal mines present different environmental challenges following coal mining and reclamation. Mine reclamation, decommissioning, and closure are regulated by federal, state, and local governments. Reclamation of underground portals, surface facilities, and the surface mined area is necessary to obtain coal mine bond release. A mining plan that is integrated with a local community or regional master plan enhances post-mining land use options such as development of productive croplands, rangelands, and forests. Additional benefits can be realized by developing local, state, and federal recreational areas or industrial settings, although competing land uses—wildlife habitats, prime farmlands, and wetlands—may make balancing various regulatory requirements difficult.

Currently, coal mine companies are required to post bonds to ensure reclamation is completed as required by the permit, with bonds on some large Western region mines exceeding $100 million. When considering the cost of bonding, comparisons between states and regions are difficult because of differences in environmental conditions and state regulatory programs. Bond release criteria may, therefore, vary from state to state, so comparisons of reclamation efforts and activities can be difficult to determine.

4.3 Concerns of Public, Industry, and Interest Groups

As noted earlier, a dominant issue that affects the Appalachian coal region is that of past and future MTM/VF. Environmental issues related to MTM/VF have caused considerable concerns for the public and interest groups and have been outlined in the 2005 EPA Final MTM/VF EIS (EPA, 2005a). Concerns have been voiced by various groups on the effect restriction of coal mining would have on miners and local communities as well as the influence on native habitats such as agricultural lands, forests, and streams. Specific areas of concern outlined in the EIS were centered on aesthetics, effects on tourism/recreation, property values, property rights, timber values, and environmental justice. However, individuals were also concerned about issues associated with pay inequities, effects on existing jobs, loss of jobs from mechanization, the availability of jobs when the mine shuts down, and effects on issues such as the tax base, revenues, and worker benefits. Industry is also concerned about the future of coal mining, as indicated by increasing litigation, redundant and sometime ineffective regulatory processes, and the need to increase state primacy oversight (Quinn, 2007).

Another concern is focused on coal processing plant emissions of different gases such as carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxides, volatile organic compounds (VOC), and trace amounts of mercury, chromium, copper, and other hazardous air pollutants. These emissions, regulated under CAA, must be monitored and controlled for the protection of processing plant workers and local communities. Transporting coal on and off site releases particulate matter and gases into the atmosphere (USFHA, 2005; Hill, 2005, EPA, 2007d). Even the transportation of coal is a concern to communities where trucks move coal from the mine site to off-site locations. This may be the case where coal is delivered to coal processing or preparation plants prior to shipping. Local citizens and communities have expressed significant concerns about impacts resulting from large haul trucks traveling on residential and other public roads.

Since SMCRA was enacted, industry has been a key partner in developing new technologies that have transformed significant mining areas into restored ecosystems with productive land uses. Some have questioned the evolution of regulatory duplication and the efficiency of regulatory programs, and have suggested that greater reliance be placed on SMCRA as the mechanism to ensure environmental protection. Increasing state oversight of mining activities has also been suggested because of regional differences that may not be included in federal statutory goals.

5. DISCUSSION OF MAJOR ENVIRONMENTAL CHALLENGES

5.1 Increased Land Disturbance and Associated Impacts

In the Appalachian coal region, surface mining is highly controversial, in part as a result of concerns associated with the burial of headwaters that takes place with MTM/VFs, and which may result in loss of ecosystems that feed streams and disturbance or destruction of vegetation and wildlife habitats. However, as discussed in Chapter 3, MTM, although expected to continue, will play a smaller role in the future due to declining reserves amenable to that type of mining. Multi-agency coordinated program improvements related to MTM and VFs have included integration of applications for addressing CWA and SMCRA requirements, while enhancing environmental protection associated with these operations. Program improvements involve enhancing efforts toward detailed mine planning and reclamation; clear and common regulatory definitions; development of feasible impact thresholds; guidance on best management practices; comprehensive baseline data collection; predictive impacts and alternative analyses, including avoidance and minimization; and appropriate mitigation to offset unavoidable aquatic impacts. It is important to promulgate regulations and develop policies and guidance necessary to establish an integrated surface coal mining regulatory program that minimizes environmental impacts.

Continuation of comprehensive monitoring of coal mining activities is necessary to determine the effectiveness of enhanced multiagency coordination and to consider whether new efforts are warranted. Ongoing efforts to evaluate MTM and VF will assist in determining if the impact of size and number of VFs, land disturbance areas, slope stability, and water resource impacts can be reduced. Water quality and quantity and habitat displacement issues associated with VF in-stream impoundments and artificial wetlands should also be evaluated to determine if the "stream buffer zone" rule is effective in controlling or mitigating off-site problems.

Advanced hydrologic modeling will be needed for better detection of the extent to which coal mining has had an impact on underground aquifers and the stability of steep slopes. Innovative software applications are required to address critical problems associated with prediction and prevention of AMD, groundwater recharge, and the closure, dewatering, and reclamation of coal waste impoundments. Advanced technologies should be developed for creating reclaimed water features to support post-mining land uses. OSM, states, and industry should develop strategies to address current and potential mine pool discharges.

PM from coal operations in the Western region may increase with EPA's revisions to NAAQS that eliminate the annual standard for coarse PM (PM_{10}). The CBM industry has also had an impact on coal production in the PRB of Wyoming. Although coal would appear to be highly regulated based on federal and state laws, particularly SMCRA, the CBM industry is much less regulated. Appropriate application and rigorous enforcement of relevant standards will therefore be necessary to ensure adequate control of air emissions from all energy-related activities in PRB.

Air quality modeling efforts need to be upgraded to distinguish natural events—such as high winds, disturbances from other industries (e.g., CBM and oil), and disturbances caused by other activities, such as road dust and overgrazing—from disturbances that are caused by coal operations. Methane production and emissions from abandoned and active mines must be closely monitored with added emphasis placed on exploitation of CMM to reduce emissions to the atmosphere and for human safety reasons.

5.2 Reclamation Issues

Section 515 (b) (16) of SMCRA requires that "all reclamation efforts proceed in an environmentally sound manner and as contemporaneously as practicable with the surface coal mining operations." The regulations recognize three discrete phases of reclamation for purposes of bond release. Phase I includes backfilling, regrading, and drainage control. Phase II occurs after topsoil replacement and establishment of revegetation. Phase III requires meeting revegetation success standards and follows completion of the revegetation responsibility period, which is five years in the eastern and central parts of the United States and ten years in the arid West. Final bond release is contingent upon the site remaining in compliance with all other applicable reclamation requirements. This phased bonding approach is intended to ensure that reclamation will proceed toward completion contemporaneously as mining progresses.

Citizen groups have expressed concern that the contemporaneous reclamation requirements outlined in federal and state regulations are not being fully met by mining operations. They point to the fact that Phase III bond release acreage has not kept pace with acres disturbed by active mining. In other words, more land is being disturbed by mining than is being reclaimed each year, using Phase III bond release as the definition of reclamation. A review of the data presented in OSM annual reports suggests that this is true for some states (Epstein et al., 2007). However, Phase III bond release cannot be translated into a lack of coal mine reclamation since SMCRA does not provide statutory authority for OSM or states to require mine operations to apply for and receive final bond release. Therefore, many acres of reclaimed land appear to be unreclaimed because companies have not always applied for and received Phase III bond release. The reported figures may not provide an accurate reflection of contemporaneous reclamation or overall reclamation success and do not always support the actual practice or completion of reclamation activities.

A review of mining and reclamation activities in Wyoming provides insight on this issue. Wyoming is the nation's top coal-producing state, accounting for almost 450 million short tons of production annually, about 38 percent of national production. According to OSM annual evaluation reports, Wyoming currently has 25 active coal-producing mines, involving approximately 3,350 acres in 2007, with Phase III bond release obtained on 1,570 acres. Wyoming's PRB coal production has increased rapidly over the years, resulting in more land disturbance per year. With the minimum 10-year period required for obtaining Phase III bond release, there will be a gap between production and final reclamation and post-mining land-use activities. In addition, many of the large Western region mines have not actively pursued a Phase III bond release, which has led to misinterpretation of the status of reclamation success, for reasons such as that reclaimed lands are located within active permit boundaries. In total, there are 399,686 acres currently permitted in Wyoming of which 139,371 acres have been disturbed, with 50,517 acres receiving Phase I bond release and another 18,471 acres achieving Phase III bond release (http://www.osmre.gov/EvaluationInfo.htm). Data reported by the Wyoming Mining Association (WCIC, 2008) indicate that 68,330 acres, or 47 percent, of land disturbed by coal mining in Wyoming has been reclaimed at the Phase II level. If accurate, this means that about 50,000 acres of land have been reclaimed for which Phase III bond releases have not been sought. The fact that reclamation is taking place contemporaneously with active mining disturbance is also supported by the vigorous inspection and enforcement process undertaken by the Wyoming Land Quality Division, along with OSM's oversight inspections. These monthly inspections ensure that reclamation is occurring contemporaneously and violations are issued when reclamation standards have not been met. In general, contemporaneous reclamation violations have not been an issue in Wyoming. The more important issue is how reclamation success data are collected and reported. Therefore, greater federal, state, and industry efforts should be devoted to informing the public and interest groups on mining activities, such as number of acres mined and reclaimed annually.

"Beyond regulatory compliance" has also been a focus of some mine operations' reclamation programs, which have been noted in recognition and award programs. Examples of beyond compliance activities include reduction or improvements in AMD mitigation, wetland construction, habitat development, enhanced land stewardship, and hazardous and solid waste management. OSM Annual Reports provide information on Excellence in Mining Reclamation Awards given to coal companies throughout the country for their post-mining development of land, stream, and habitat resources associated with both AML and current operations. Coal operators have become better land stewards through projects that involve creation of critical elk winter habitat, establishment of mountain plover and sage grouse habitat, reestablishment of shrubs, development of topographic diversity designs, enhancement of steep slope topsoil salvage techniques, and management of grazing on reclaimed lands (Marshall, 2007).

5.3 Cumulative Impacts

The reclamation and restoration of disturbed environments (i.e., forest, rangeland, farmland, and wildlife habitats) are important to enhancing the quality of the natural environment, improving area aesthetic values, and potentially providing tourist destinations (i.e., recreational areas, parks, and wild lands). In the 2006 OSM Annual Report (OSM, 2008b), over 4,400,000 acres have been permitted for coal mining across the nation since 1977, with 191,638 acres permitted in the 2005–2006 reporting year. This acreage amounts to approximately 4.3 percent of total land since 1977 designated for future mining. Over the years, numerous AML, active, and decommissioned mine site acres have been reclaimed and restored, resulting in the rehabilitation of coal mines. OSM and some states have developed programs that reward companies for outstanding environmental stewardship. In the future, there will be higher expectations for reclamation of soil, water, and wildlife habitats.

Multi-agency (e.g., FWS, OSM, U.S. Forest Service, and state agencies) programs and guidelines for the protection of threatened and endangered plant, animal, and aquatic organisms need to be evaluated in the context of mining development impacts. Concerns associated with potential habitat fragmentation, breeding ground displacement, water resource needs for aquatic organisms, and loss of plant diversity must be addressed with new and expanding mining activities.

Reclamation and restoration of active mining operations must use best available technologies for site reconstruction, revegetation using native plants, and development of wildlife habitats so that post-mining land use can be realized in a timely manner. Reforestation, prime farmland, and rangeland issues related to post-mining reclamation should continue to be addressed as new technologies develop.

5.3.1 POWDER RIVER BASIN, WYOMING

The number of other extractive industries in the PRB in addition to coal mining, such as oil, gas, and CBM, is increasing, thus exacerbating air quality problems. Air quality has become a greater concern because of the rapid development of CBM infrastructure in the PRB (BLM, 2005). In addition to tens of thousands of drilled or permitted CBM wells, there are hundreds of diesel generator compressor stations and over 9,000 miles of new dirt roads that have been developed to access sites. BLM and EPA are active participants with state and interstate groups responsible for coordinating activities in the PRB. Studies conducted by the Wyoming Department of Environmental Quality are evaluating the ability to mitigate PM air quality concerns. Noteworthy is the fact that PRB, like much of the western United States has been experiencing a major drought, which has caused more frequent and intense forest and grassland fires. The persistent drought in the PRB has complicated strategies for dust control measures.

Because of the many activities taking place in PRB, EPA Region 8, which oversees PRB, is required to work with other federal agencies to support environmental stewardship and pollution prevention through the NEPA process. A major facet of the NEPA process in PRB, linked to EPA work with Wyoming and Montana environmental regulatory agencies and with Native American tribal partners, involves the development and implementation of mitigation strategies to reduce road dust and reduce emissions associated with increased industry activity in PRB. As these activities increase from current and predicted future rapid development of oil, natural gas (including CBM), power plants and refineries, and coal operations, NEPA assessments by EPA and other agencies will require additional evaluation of environmental impacts within the area. It will be important to increase the number of personnel responsible for conducting and coordinating the additional NEPA studies required as PRB energy industries continue to grow.

5.4 Disposal of CCBs

Coal combustion byproducts (CCBs), also known as coal combustion residues (CCRs), coal combustion wastes (CCWs), or coal utilization byproducts (CUBs), are the large-volume materials or residues produced from the combustion of coal and pollution control technologies that are used to clean combusted stack gases. CCBs include fly ash, bottom ash, boiler slag, fluidized bed combustion ash, and flue gas desulfurization material. There are many incentives for developing beneficial uses for these materials, including increased revenue, reduction in the use of other natural resources, and conserving landfill space. For example, the Clean Coal Technology Demonstration Program (CCTDP) is evaluating the use of CCBs as construction materials such as cement or wallboard (DOE, 2006b).

CCBs are often landfilled, placed in surface impoundments, or returned to the mine. In 2003, approximately 125 million tons of CCBs were produced, of which seven million tons, or six percent, was returned to the mines (ACAA, 2005a). There are many potential uses of CCB at coal mines, including prospective benefits for reclamation efforts of both abandoned and active mines. Examples of CCB uses include: application as an agricultural supplement or topsoil replacement material in areas where surface soil material is limited or potentially acidic; as a sealant to encase materials that may be acid producing (e.g., pyrite) or potentially problematic (e.g., arsenic, boron, selenium) in order to prevent the formation of acidic or toxic mine drainage; the construction of dams or other earth-like materials; as a fill to seal and stabilize underground mines to prevent subsidence, AMD, or to restrict mine pool flows; and as fill in spoil areas or as final pit material. Over time, CCBs have become increasingly sold or reused; more than 40 percent were sold or reused in 2004. Government agencies and other stakeholders have established a goal of 50 percent use by 2010; however, recognition of the impacts to aquatic environments and water resources from CCB must increase as government and industry initiatives are implemented (ACAA, 2005b).

An NRC (2006) report, *Managing Coal Combustion Residues in Mines*, described applications for using CCB materials. Even though there are efforts to increase CCB uses, there will probably continue to be controversy associated with use of CCBs at mine sites. As a result of concerns associated with CCBs, OSM, various universities, the National Energy Technology Laboratory (NETL), and industrial research organizations have been developing technologies related to the return and placement of CCBs at coal mines. Federal and state agencies should develop science-based, technologically feasible guidelines for CCB use at mines that include development of national standards for CCB placement site characterization, leaching tests, post-placement monitoring, and environmental performance standards.

5.5 Timelines for Leasing and Permitting New Coal Mines

BLM is responsible for coal leasing on 570 million acres of BLM, national forest, and other federal lands, as well as on private lands where the mineral rights have been retained by the federal government. These public lands are available for coal leasing, but only after they have been evaluated through the BLM's multiple-use planning process and deemed to be potential coal reserves. In areas where development of coal resources may conflict with environmental protection and management of other resources or public land uses, BLM may identify mitigating measures that may appear on leases as either stipulations for use or restrictions on operations.

The regional coal leasing process is initiated by application and involves the selection of potential coal leasing tracts based on multiple land use planning, expected coal demand, and potential environmental and economic impacts. Permitting issues can vary depending on mining method and resources. SMCRA requires maximized recovery of the coal, which differs with surface, room and pillar, longwall, highwall, and auger mining, and remining activities. Leasing by application begins with BLM review of an application to lease a coal tract to ensure that it conforms to existing land-use plans and contains sufficient geologic data to determine the "fair market value" of the coal. Upon review of the application and consideration of public comments, the BLM may reject, modify, or continue to process the application.

If an application is accepted, BLM must either conduct an EA or prepare an EIS. The draft EA or EIS must be submitted for public comment on the proposed lease sale, and appropriate state, federal, and tribal agencies must be consulted. If a coal lease is approved by BLM, additional permits and licenses required by BLM, OSM, and other pertinent state and local governments must be obtained.

About 40 percent of the nation's coal production comes from mines located on federal lands, with more than 70 percent of coal production in the western United States from mines on federal land. Nearly 50 percent of federal coal reserves are located in the PRB of Wyoming. A number of features of federal coal leasing and permitting programs present impediments to the efficient development of federal coal reserves. Coal operators believe changes are needed to allow more flexibility to coordinate Mine Leasing Act of 1920 mine plans dealing with coal resource recovery under the permit requirements of SMCRA. There also appear to be overlapping requirements in coal leasing and permitting processes specified by NEPA. Often, two EAs or EISs are prepared for leasing and permitting of the same area. Enhanced data use and processes are needed for mine permitting, monitoring, and reporting in order to provide accurate, consistent information with a reduction of redundant and overlapping processes that often create inefficiencies and result in significant time delays without obvious benefit to the public or the environment.

5.6 Increased Public Concerns

As noted previously, coal combustion is the largest source of carbon dioxide emissions into the atmosphere. Concerns about CO_2 have led to much research on ways to use coal while minimizing or eliminating CO_2 emissions with new technologies. Carbon capture and geological storage is one potential option, but alternative methods for processing coal into useful chemicals, for example, liquids or gases, may be used if economically viable and environmentally safe technologies become available (Tullo, 2008). Therefore, collaborative efforts among industry, federal and state agencies, and research institutions are needed to develop new clean coal technologies. Additionally, there is a need to enhance public awareness of issues associated with real and potential environmental sustainability of mining activities related to land disturbances, as well as opportunities that support future prospects of the community, both economically and environmentally.

5.7 Initiatives to Address or Reduce Environmental Impacts

Several initiatives have been developed to facilitate coordinated partnerships among federal, state, and tribal governments; academia; industry; and the public concerning the evaluation of coal mining impacts and development of solutions to minimize these impacts. Suggested solutions include cost-effective regulatory compliance and assistance in the development of self-sustaining post-mining landscapes. Various program initiatives have been instrumental in advancing scientific knowledge through application of technologies and cooperative solutions to better manage and restore wildlife habitat areas, yield more productive soils and streams, and identify and manage potential risks.

Solutions and applications are developed and advanced through participation in conferences, workshops, and forums where the exchange of information and experiences fosters an effective and efficient use of post-mining land uses and resources of those involved in mining applications. These program initiatives are a reflection of coordinated efforts to achieve long-term success through the evaluation and minimization of coal mining impacts. Balance between resource recovery and recognition of the importance of environmental stewardship must continue to be a primary focus in the coal industry.

5.7.1 ACID DRAINAGE TECHNOLOGY INITIATIVE

AMD is a long-term water pollution effect of coal and metal mining, especially in Appalachia (OSM, 2008a). To combat this problem, the Acid Drainage Technology Initiative (ADTI) was formed as a partnership of technical experts from industry, federal and state agencies, and academia joining together to combat and seek solutions to AMD and related water-quality problems from mining. ADTI provides a forum for collaboration and information exchange concerning the following goals:

- Development of innovative solutions to AMD and related water-quality problems
- Identification, evaluation, and development of "best science" practices to predict AMD prior to mining
- Recognition of successful remediation practices for existing sources of AMD and best technologies for AMD prevention
- Cooperation in the development of understanding and implementation of proven and innovative technologies for prediction, avoidance, monitoring, and remediation of mine drainage
- Promotion of transfer of information on mine drainage prediction, monitoring, avoidance, and remediation

A wide variety of coal mine drainage projects have been and are currently undertaken by ADTI members. West Virginia University and National Mine Land Reclamation Center (NMLRC) are studying flooded underground mine pools and their potential for contributing new sources of AMD. OSM-funded projects include assessments of abandoned coal mine drainage treatment sites; evaluation of selenium in coal mine overburden and surface and ground water; field verification of the acid-base accounting method to predict AMD; and development of standardized, lab-based kinetic test methods to evaluate AMD potential.

5.7.2 APPALACHIAN REGIONAL REFORESTATION INITIATIVE

The Appalachian Regional Reforestation Initiative (ARRI) is a cooperative effort among Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, OSM, industry, environmental organizations, academia, local, federal and state government agencies, and private landowners. ARRI advocates a technique known as the Forestry Reclamation Approach to plant trees on reclaimed lands (OSM, 2008c). Highly productive forestland can be created on reclaimed mine lands under existing laws and regulations by using the Forestry Reclamation Approach.

The goal of ARRI is to increase reforestation using high-value trees to improve survival and growth rates for the establishment of forest habitat through natural succession. ARRI seeks to reduce current cultural, technical, and regulatory barriers surrounding the forestry reclamation of coal mined lands. This activity would involve changing perceptions about what forestry reclamation can do for the environment. Although reforestation may be more expensive and have greater potential risks, reclaiming mine sites to preexisting habitats should be an important goal for post-mining land use. Another emphasis of ARRI is to provide better education on how to create an appropriate growth medium for forests, reduce surface compaction, reduce competition of ground cover, and reforest with high-value hardwood trees.

5.7.3 PRB COAL REVIEW

The PRB Coal Review was a regional technical study that BLM recently conducted to help evaluate the effects of coal development in that region (BLM, 2005). It consisted of three tasks. Task 1 was to identify current conditions in PRB and to update BLM's 1996 status check for coal development in PRB. Task 2 was to develop a forecast of reasonably foreseeable coal, coal-related, and other industrial development in PRB through 2020. Task 3 was to predict the cumulative effects that could be expected to occur to air, water, socioeconomic, and other resources if development occurs as projected. Task 3 databases and reports are available for use in evaluating cumulative impacts in future NEPA documents. The report found that approximately 1.5 percent of the federal mineral estate assessed in the PRB—or 82,000 out of 5.4 million acres—is available for coal mining under standard lease terms, or about 27 billion tons of federal coal that is available for mining. Nearly 88 percent of the federal mineral estate in PRB is available for coal mining with varying degrees of access restrictions. About 11 percent of federal acreage in the basin is prohibited from being leased by statute or because of land-use planning decisions.

5.8 Agency Coordination on Permitting and Regulatory Issues

Reducing duplicate reviews and permitting through better integration of both federal and state regulatory guidelines would result in a more efficient permitting process that allows for better decision-making and consideration of environmental concerns based on science. This coordination would be an important step in improving environmental stewardship in existing and new coal operations. Although there is a need for more flexible regulations to accommodate regional, geological, and economical differences that exist throughout the country, there must also be effective enforcement of environmental quality standards. Concerned citizens and groups will continue to play an important role in overseeing the environmental practices of the coal industry, and a straightforward, understandable permitting process would facilitate public participation. Depending on the site, a realistic post-mining land use should be one of the determining factors for regulations imposed on approaches involved in reclaiming the mine operation.

5.9 Workforce Concerns

Federal and state regulatory agencies and industry face significant turnover in staff in the next few years (see Chapter 7). Estimates suggest that more than 50 percent of regulatory personnel may be eligible to retire in the next five years, with many federal and state agencies facing the loss of experienced staff, particularly mine inspectors. The pending loss of the generation that initiated the SMCRA programs in the late 1970s will leave a void of experience in many programs. Industry is also concerned with the loss of experienced staff members who are familiar with regulatory and environmental compliance issues. Replacing experienced staff with new hires may impact regulatory decisions, resulting in delays in permitting and environmental issue resolution, and can also affect enforcement and inspection. OSM and the states have developed programs to train new hires so that current knowledge can be passed to the next generation of employees. Many states and industry propose creating incentives to retain experienced staff. The projected increase in coal production could further exacerbate concerns associated with a lack of experienced staff by industry in preparing plans and applications to mine, as well by regulatory agencies in reviewing new permits and conducting mine inspections.

6. CONCLUSIONS

Significant progress has been made in the last 30 years in implementing changes in coal mining practices that protect the public, environment, and natural resources while substantially expanding coal production. Since the enactment of several key legislative acts, environmental practices have been implemented that produce improved site reclamation, including reforestation and the creation of rangelands, prime farmlands, and wildlife habitats. This level of environmental protection is expected to continue as federal and state regulatory programs develop, but more importantly, as the coal industry increasingly recognizes the need for voluntary measures to protect the viability of the industry.

Because of environmental regulations, coal operations engage in practices that eliminate or minimize impacts on land, air, water, and wildlife through performance standards goals. Practices such as "beyond compliance stewardship" are becoming accepted in coal companies, and have resulted in improvements in reclamation and revegetation practices that produce post-mining land uses that provide greater opportunities for wildlife, landowners, communities, and industry. Implementation of current practices has improved water (AMD prevention, sediment control, and hydrologic protection) and air (PM and greenhouse gases) quality, and has increased opportunities for post-mining land uses. In addition, federal, state, industry, and community efforts to reclaim abandoned coal mine lands is an ongoing process that will take many years and significant funds to complete; however, these efforts are necessary to reduce safety and environmental problems resulting from legacy issues associated with past coal mining practices.

Several unresolved national and regional issues remain to be addressed as coal production expands in the near future, according to the latest EIA projections. Environmental impacts will vary depending on resource quality, quantity, and distribution; geologic integrity; climatic and biological factors; and protection of cultural and historic landmarks. Increased attention will have to be focused on drainage waters, reclamation practices, air quality concerns with methane and fugitive dust, greater disturbances to hydrologic systems, increased ground subsidence, broader habitat displacement, and added waste management at mines and preparation plants. Continued research and innovative technologies will be required to address these problems. Further advances in the ability to reduce or eliminate environmental impacts will lead to better land, air, and water stewardship, and the continued production of coal for the nation's energy needs.

Some significant issues that need to be addressed include the following:

National Issues: Various challenges confronting environmental protection from both expanding and new mines transcend coal regions, although their magnitude and importance may vary by region. Overall, current and impending national environmental issues include threatened and endangered species; air and water resource protection; greenhouse gas emissions (such as methane); coal byproduct minimization and use; and protection of the public.

Regional Issues—Appalachia: To maintain current production levels in this region, underground mines will extract coal from greater depths and thinner seams. As a result, current concerns about MTM and VFs will continue to be of environmental, social, and economic importance to local communities. Water resource quality and quantity related to AMD and underground mine pools, stream buffer zones, and protection of aquatic organisms (such as mussels) are also of major significance, as are threatened and endangered species (including, most notably, the Indiana bat) and revegetation and post-mining land use issues.

Regional Issues—Interior: The anticipated consequences of the projected increase in coal mining activities in the Interior region will further amplify issues associated with subsidence from increased longwall mining; prime farmland reclamation; threatened and endangered species issues; protection of the public and property from the effects of blasting; and water resource modifications.

Regional Issues—Western: Although large surface mines in the PRB will continue to expand, additional underground and surface mines will also contribute to the region's projected increased coal production to the year 2030. These activities will result in added concerns related to: air quality associated with fine and coarse PM and gases from mining, vehicular activities, and blasting; surface water and groundwater issues; threatened and endangered species; reclamation and revegetation practices; and inefficiencies in the current leasing and permitting processes for mining coal on federal lands.

Based on the discussions above, the following recommendations are appropriate.

- ***Reduce impacts on water resources and quality.*** Subsurface and surface hydrologic properties and water quality are affected during coal mining. Industry and federal and state regulatory agencies, in conjunction with research organizations, must develop better science-based technologies for modeling hydrologic changes and address water quality concerns related to sedimentation, AMD, and the impact of trace elements that occur both during and after mining. The loss of water resources through elimination or degradation during mining and reclamation requires a greater emphasis on the part of industry and regulatory agencies to develop habitats essential for aquatic and wildlife ecosystems.

- ***Address prominent regional environmental problems.*** Prominent and high-profile issues in each of the three coal-producing regions have the potential to define the environmental performance and overall acceptance of the coal industry. Mountaintop mining and valley fills in Appalachia may be limited in the future because they are highly controversial with the public. It will be important for the coal industry to look for ways to reduce disturbance to important stream resources, perhaps by limiting the number and size of VFs. Regulatory agencies will need to work closely together to determine how best to monitor the impacts of these operations in order to reach permitting decisions and to provide permit oversight that ensure that impacts to the public and the environment are minimized. Air quality issues, especially related to fugitive dust and methane release, are of major concern throughout the United States, but increasingly important in the Western region. Regulatory agencies should consider enhanced air quality monitoring and protection measures to ensure that communities adjacent to mining operations are adequately protected. Greater coordination is needed to protect threatened and endangered species from the adverse effects of coal mining operations, particularly in the Interior and Appalachian regions. Regulatory agencies, in consultation with the public and industry, must ensure that permits issued in these areas contain mitigation and protection measures so that mining will not jeopardize the continued existence of these biological resources.

- ***Implement an effective and transparent community engagement process.*** The coal industry must adopt and implement an effective and transparent community engagement process emphasizing conservation of biodiversity and integrated approaches to post-mining land use planning involving all stakeholders. Increased involvement is required within the coal industrial complex to address environmental concerns by local communities and concerned citizens. Initiatives, awareness, and opportunities must be developed among industry, federal and state agencies, community organizations, and local citizens to enhance and ensure a better understanding of environmental issues and prospects associated with the life of a coal mining operation.

- ***Enhance reclamation planning and performance measures.*** Despite the tremendous progress made in surface mine reclamation, there is growing public concern that restoration and post-mining land use are not occurring in a timely manner. The status of reclamation, often gathered from bond release information, is an inadequate measure of the extent of actual field work or success of reclamation. Industry, federal agencies, and state regulatory agencies must develop reasonable deadlines for reclamation and post-mining land uses. Because coal mining is a temporary use of the land, planning for reclamation and measures of reclamation performance must be integrated into mine plans with the full participation of industry, government, mining community, and other interested parties, so that post-mining land use is enhanced and successes are accurately reported.

- ***Develop science-based and technologically feasible regulations and practices.*** Environmental concerns, public attention, and controversy will influence coal expansion in the coal-producing regions. This subject is particularly important in Appalachia because of population distribution, physical characteristics, cultural and social issues, and the legacy of coal mining. Although existing regulatory standards, coupled with improved "beyond compliance" environmental stewardship by many coal companies, have been successful in minimizing impacts from coal mining operations, addressing long-term environmental concerns requires greater effort and collective attention by all stakeholders. Federal and state regulatory agencies, working with industry and communities, must develop science-based regulations that include technically feasible guidelines and best practices to effectively address environmental concerns, and encourage adoption of new technologies and approaches that minimize impacts.

- ***Improve the permitting process on federal lands.*** About 40 percent of the nation's coal production is from mines located on federal lands and this share is projected to increase in the future. The federal government, in consultation with the community and industry, should consider restructuring federal coal leasing and permitting programs to eliminate duplicative and overlapping requirements in coal leasing and permitting processes, which often create inefficiencies and barriers to public participation, and hinder meaningful consideration of environmental impacts. The current complex system often results in significant time delays without obvious benefit to the public or the environment.

- ***Encourage additional funding to support research and workforce development.*** Increased research funding to federal and state agencies and research organizations is required to address environmental impacts of past, existing, and future mining operations. Increased funding will also be required to sustain federal and state regulatory agency personnel levels and to support development and use of enhanced technology. With impending retirements, the number of experienced regulatory specialists will decrease, potentially leaving a void that will prolong the permitting process and affect permitting and enforcement in ways that could impact future environmental protection and coal production.

Chapter 7 The Workforce Challenge

1. SUMMARY

The coal mining sector will face significant challenges in meeting its needs for workers between now and 2030. Although many of these challenges are similar to those that other industries and countries face with the retirement of the current Baby Boom Generation, the projected increases in U.S. coal production will also create additional demand for new workers. To meet the need for an expanding workforce, the safety and reputation of the coal industry, potential movement of the workforce to and from the coal sector, competitiveness of salary and benefit programs, human resource development cultures, and limitations on education and training resources must be considered. This chapter discusses the major workforce issues and challenges, presents workforce projections to the year 2030, and offers recommendations and action plans for the coal mining sector at large.

The current coal mining workforce of approximately 90,000 is a well-paid cadre of professionals that fulfills a number of different jobs and tasks. Using Energy Information Administration (EIA) productivity and production projections (EIA, 2006a), 21,000 additional coal mining workforce positions will be needed in the various coal producing regions of the United States by the year 2030. Accounting for retirement and turnover of the existing workforce, almost 45,000 new miners will be needed in the coal sector. Assuming and applying conservative retention rates, about 64,000 new entrants to the industry must be recruited and trained by the year 2030 to achieve projected production targets.

Although it is clear that the projected manpower increase is reasonable, it is unclear how it will be realized. New incentives may be necessary to recruit employees from other industry sectors and non-coal mining areas. Different recruitment and trainings needs and strategies will be necessary for different categories of employees. Educational and training resources will place some limits on the availability of some of these professionals. Furthermore, new vocational programs will be necessary and will play a significant role in meeting the needs of the coal sector.

2. INTRODUCTION

Over the next 20 to 30 years, workforce education and training issues may have the most significant impact on U.S. coal production. The coal industry, like most mining sectors, has greatly increased mechanization and automation, which has led to high levels of productivity and a marked decrease in the need for labor to produce coal. However, projected increases in production between now and 2030, coupled with the graying of the American labor force, will result in a shortage of workers in every category. With the enormous loss of mining and technical skills in the mining industry, the recruiting of workers and the staffing of mines to keep the system together and functioning will be a difficult challenge. In addition, the educational and training resources are not currently in place to bridge the gap.

To recruit and retain the necessary workforce and meet the new production levels requires changes in the training, education, and corporate culture infrastructure. In particular, the case of technical workforce availability and competitiveness of the U.S. economy is a matter of national concern. In the recent report, *Rising Above the Gathering Storm*, a National Research Council committee addressed the issue of the eroding technical workforce and the need for the nation to focus on science and technology in meeting the nation's needs, including "affordable energy" (NRC, 2007c). The committee recommended significant increases in funding for science and technology education and research to ensure that the U.S. economy remains competitive in the world market. The coal sector is a prime example of a basic industry that can benefit from such recommendations.

2.1 Coal Mining Workforce

Data obtained from the National Mining Association (NMA), based on the Bureau of Labor Statistics (BLS) census, estimated that the 2,113 coal mining operations in the United States employed 85,693 individuals in 2006. Contractors servicing the coal mining sector employed an additional 37,281 individuals. According to employment data on information from the Part 50 database, which is collected from the industry by the Mine Safety and Health Administration (MSHA) and compiled by the National Institute of Occupational Safety and Health (NIOSH), the coal sector workforce was 91,867 in 2005. This discrepancy is due to differences in data definitions and collection methods. Figures suggest that about 30 percent of the mining workforce are contractor employees who perform different functions from mine to mine. With the pressures on hiring replacements for retiring miners and ramping up operations, experienced contractor employees have been hired at a greater pace.

BLS indicated that the average wage for coal miners in 2006 was $66,601—over 150 percent of the U.S. national average of $42,405 (Table 7.1). This difference is even more pronounced in five coal-producing states (Montana, New Mexico, North Dakota, West Virginia, and Wyoming) where coal mining sector employees earned more than twice the statewide average for all industries.

2.2 Professional, Skilled, and General Labor

There are demographic, education, salary, and other differences among employees, depending on the type of position they occupy in the coal industry. Within the coal mining sector, as in many other industrial sectors, various categories can be used to classify the total workforce. The following categories were identified from information received from operating coal companies: managerial and sales, professional (such as engineers and geologists), technical (including administrative personnel), tradesperson (such as electricians, plumbers, and mechanics), skilled workers (such as continuous miner and dragline operators), and laborers. The last four categories are also referred to as coal production workers.

The proportions of personnel in each of these categories can vary widely based on the size of the company, the type of mining operation (surface or underground, large-scale or small-scale), and the overall corporate structure. Table 7.2 illustrates the proportion of the workforce in different job categories from data obtained by two coal producers. Not all companies use all categories, and may classify skilled labor and tradespersons differently, as reflected in Table 7.2.

These workforce distinctions are important because of differing trends in the retention rate, age distribution, and retirement age of employees

TABLE 7.1 Annual coal mining wages vs. all industries, 2006.

TOP STATES	MINING[1] (AVERAGE)	ALL INDUSTRIES (AVERAGE)
Alabama	$64,577	$35,520
Colorado	$70,558	$43,664
Indiana	$67,855	$36,610
Kansas	$80,499	$36,191
Kentucky	$59,815	$34,922
Maryland	$49,751	$44,527
Montana	$66,403	$29,386
New Mexico	$75,606	$33,409
North Dakota	$73,551	$31,023
Ohio	$55,700	$38,105
Pennsylvania	$65,384	$41,013
Texas	$75,886	$43,269
Utah	$62,666	$34,727
Virginia	$59,931	$43,666
West Virginia	$64,801	$31,999
Wyoming	$73,689	$36,272
Average wage for all U.S. coal miners: $66,601		
Average wage for all U.S. workers: $42,405		

[1] Excludes oil & gas extraction. SOURCE: U.S. Bureau of Labor Statistics. Updated: September 2007

TABLE 7.2 Distribution of the coal mining workforce.

COMPANY TYPE	POWDER RIVER BASIN PRODUCER	EASTERN PRODUCER
Production (million tons)	138.1 (100% Surface)	24.8 (42% Surface)
Production (percent U.S. total)	11.9%	2.1%
Total workforce	2,324	3,666
WORK FORCE DISTRIBUTION		
Managerial	1.8%	17.1%
Professional	2.2%	3.1%
Technicians	4.9%	7.0%
Tradespersons	26.9%	*
Skilled Labor	62.6%	69.5%
General Labor	1.5%	3.2%

* Included in other categories

within each category. Training and education needs, corporate work life strategies, and other factors may also be extremely different among people in other classifications.

2.3 Alarming Aging and Demographic Trends

Coal mining, like all other industrial sectors in the United States, is facing the aging of the workforce at every level. Based on BLS (2007) data for 2006, 54 percent of the coal mining workforce is over 45 years of age, the median age is 46.6 years, and the mean age is over 50. According to Toossi (2007), Baby Boom Generation retirements will limit the growth in the labor force over the next 40 years. The age of coal mining employees is generally higher than for other commodity sectors, but the overall distribution is similar. Figures 7.1 to 7.4 depict the age distribution within the coal workforce nationally and in the three coal-producing regions, as defined in Figure 1.3. These figures indicate that the mean age of U.S. coal miners is 51, supporting a recent projection by Quillen (2008) that the mean age of coal miners is 50 and the median work experience is 20 years.

Over the next five years in the United States, retirement of senior managers across industries is estimated as high as 50 percent. Overall, studies report that over 46 percent of all workers in the utility industry are expected to retire in the next

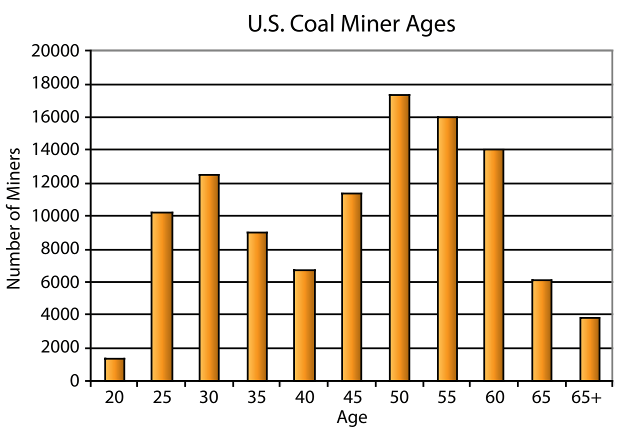


FIGURE 7.1 Distribution of ages of coal mining employees.

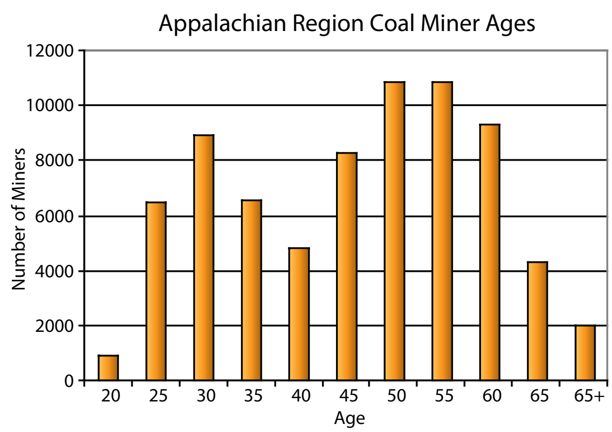


FIGURE 7.2 Distribution of ages of coal mining employees in the Appalachian region.

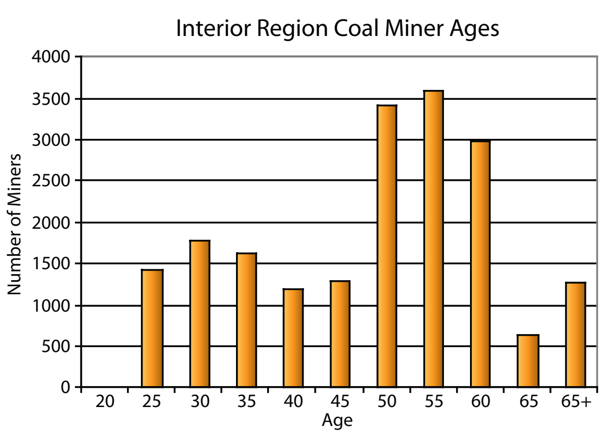


FIGURE 7.3 Distribution of ages of coal mining employees in the Interior region.

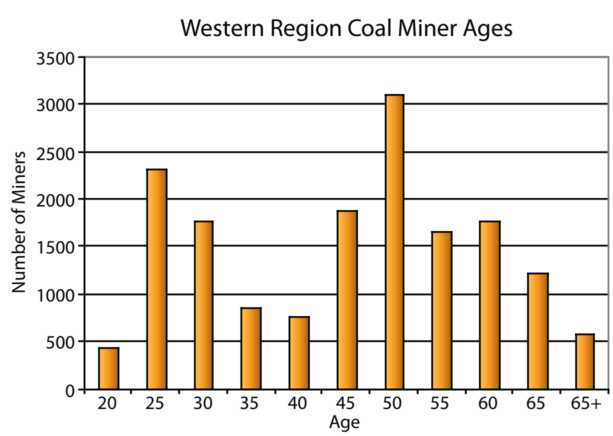


FIGURE 7.4 Distribution of ages of coal mining employees in the Western region.

10 years (ScottMadden Management Consultants, 2007). Other studies have shown that 55 percent of the salaried workforce will retire in the next five to seven years (American Petroleum Institute, 2005).

These demographics are similar to those in related industrial sectors and for mining industries in other countries. For example, a 2005 report on the Canadian mining industry noted that over 50 percent of the mining workforce was between 40 and 54, an age group that represents only 39 percent of the total Canadian workforce (MITAC, 2005). A more recent study in Australia also identified strong growth in older workers within the mining sector in that country (Lowry et al., 2006). As in the United States, projections indicate increased retirement rates starting in 2007, when the Baby Boom Generation begins to reach 65. Similar demographics are reported in other U.S. energy-serving sectors as well (ScottMadden Management Consultants, 2007).

2.4 Recruitment and Training Challenges

The coal mining industry faces several challenges with regard to recruiting and training new employees, many of which are related to the negative perception of the coal industry by the public, both in coal field areas as well as in the rest of the country. Historical cyclical employment trends within the coal sector rank among the major recruitment challenges. The coal industry downturn in the early 1980s, combined with a lack of major job growth in the sector that continued through the end of the twentieth century, led to 20-year gap and a lost generation of new employees joining the industry. As a consequence, there are few experienced, trained miners waiting to enter newly created industry jobs. Many of the miners that were displaced in those shutdowns have aged and are no longer viable recruits to re-enter coal mining sector employment.

Coal mining is perceived as a cyclic and dangerous occupation. In many mining communities, young people are discouraged by family, schools, and the community from entering coal mining. It is also suggested that high school students in coal communities, unlike the generation now retiring, are more inclined to choose careers that are less physically demanding (Joe Main, UMWA, retired, *pers. comm.*, 2008). Although some companies have reported a strong pool of job applicants following the recent tragic incidents (Laws, 2006), the rash of fatalities at coal mines in 2006 and 2007 has probably reinforced perceptions of the industry safety, making it increasingly difficult to recruit and retain a quality cadre of new employees in the industry. Recently enacted statutes on coal mine safety have created additional requirements for training, safety equipment, and procedures that present hurdles for new employees.

Another challenge is the reputation of the industry as rather low-tech and the occupation as physically labor-intensive. The opportunity for use of technology and upskilling is often assumed limited. As these are important factors for younger employees entering the workforce, the low-tech reputation of the coal mining industry is another barrier to recruitment. Many entry-level employees may be engaged in general labor categories, or in jobs that involve less-complex tasks, which may reinforce their perceptions that mining is low tech and may lead to lower retention rates.

The in-depth new miner training, mine maintenance, electrician, equipment operator, supervisory, and other training and educational programs that existed through company, academic, and government support virtually disappeared during the market decline of the late1970s and have not been replaced. The few programs that are in place today appear to be developed by the major coal companies to mainly benefit that particular company's mines. Companies on the other end of the spectrum (i.e., smaller companies, contract mining operations, and contractors performing mining activities at coal mines), with limited resources, may be resorting to staffing mines with employees that have rather limited experience and training.

2.5 The Potential "Transfer" Workforce

In a 2007 presentation to the utility industry, ScottMadden Management Consultants (2007) discussed cross-sector and cross-industry challenges to build and maintain a competent workforce. One company that participated in that study identified competing employment opportunities as one of the top four HR challenges facing coal operations in the western United States (Marshall, 2007).

In fact, there are significant opportunities for worker migration into the coal mining sector. The construction and automotive labor pools may be prime candidates for such workforce transfer, for three reasons. First, current economic cycles indicate that there may be a significant number of displaced workers in those industries. Second, they show very different age distributions than the coal mining sector, as depicted in Figures 7.5 and 7.6. Third, many of the skills in these sectors are applicable and transferable to the coal mining industry.

2.6 Other Considerations

Although much available information has been focused on skilled and general labor pools, similar recruitment, training, and retention considerations apply to managerial, professional, tradesperson, and technician positions in the coal industry sector. Some management positions may not require a specialized mining or coal industry background; however, the professional category is founded on technical and scientific training. A 2004 study by Downing Teal reported that 52 percent of mining professionals were over 50 years of age and 28 percent were over 55 (McCarter, 2007). Assuming retirement of the current cadre at age 62 and the projected growth of the mining industry, an additional 400 new mining engineering graduates are necessary each year, just to maintain current levels in all mining sectors. In 2007, there were 123 B.S. graduates in mining engineering in the nation (McCarter, 2007). Thus, to meet the needs across the entire mining sector requires more than tripling the current output. In addition, using MSHA data from 2002, 15 percent of the active mining engineers are employed in coal mining. Accepting this assumption, 60 new mining engineering graduates must enter the coal sector annually to replace retiring engineers and account for new growth.

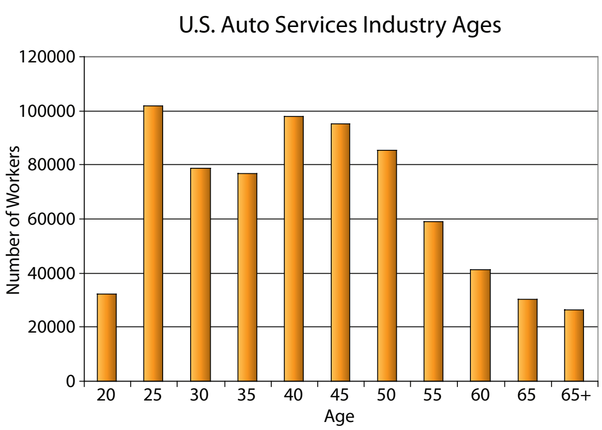


FIGURE 7.5 Distribution of ages of auto services employees in coal mining states.

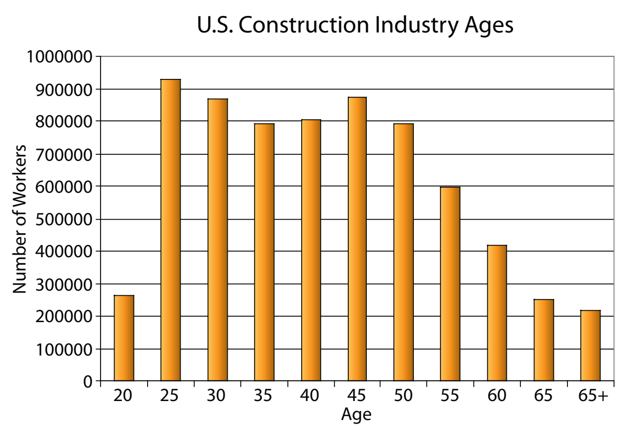


FIGURE 7.6 Distribution of ages of construction industry employees in coal mining states.

BOX 7.1 GENERATIONS

Though there is no commonly accepted definition across sources, the terms "Generation X," "Generation Y," and "Millennium Generation" are used here to denote the following:

- The "Baby Boom Generation," or "baby boomers," designates those born between the end of World War II, approximately 1946, to 1963.
- "Generation X" designates those born between 1964 and 1976.
- "Generation Y" designates those born between 1977 and 1995.
- The "Millennium Generation" designates those born between 1996 and 2005.

The above studies also emphasized that institutions providing educational opportunities in the broad mineral disciplines will not be able to expand without significant industry investment.

In the tradesperson, technician, and managerial categories, one critical consideration for recruiting and retaining employees is the ability of experienced staff to move easily to other mining sectors or to other industries in the geographical area around the mine. This migration to and from the coal mining sector can work in both directions; such "transfer" workforce may be a significant source for meeting future workforce demands.

The characteristics of the individuals who will be available to enter the workforce are also important to recruitment. As the Baby Boom Generation reaches retirement, most new hires will come from Generation X, Generation Y, and the Millennium Generation (see Box 7.1). These generations differ greatly in salient characteristics and expectations from the baby boomers. These three groups are generally very technology oriented or even technology dependent, do not have a view of "lifetime employment" or long-term loyalty to employers, and are looking for personal development and self-expression as much as career development (ScottMadden Management Consultants, 2007). On the positive side, this pool contains potential employees who are risk-taking, adaptable, and motivated self-starters and team players (Allen, 2003).

For many years, the upcoming onslaught of baby boomer retirement has loomed on the horizon and many corporate human resource (HR) professionals and departments have advocated within the corporate echelon the need to plan and prepare a long-range human resource action effort. However, fiscal realities and policies have often prevented companies, including many within the coal sector, from implementing succession planning that would include hiring replacements before the job is vacated, developing existing staff resources through training, and providing adequate continuous education, upskilling, and cross-training opportunities.

3. MAJOR FACTORS IN WORKFORCE DEVELOPMENT

3.1 Recruitment

Because individual coal mining companies do their own recruitment, there is not a coordinated, industry-wide effort to collectively recruit employees. Some companies have initiated outreach programs to improve the reputation of the industry, including exposure to students at primary schools. Such efforts, although long term in focus, may result in the development of educational programs and resources, funded by private and public partnerships, to meet the workforce needs of the coal sector.

In its report, "Staffing the Supercycle," the Mineral Council of Australia addresses similar recruitment challenges by recommending that "attraction and remuneration" systems be designed that give economic advantages to mining concerns (Lowry et al., 2006). In addition, the Council recommended a concerted effort to identify and target alternative labor reservoirs, such as people residing in areas outside traditional mining communities, and women. Similar strategies are also proposed in the Canadian mining workforce study, *Prospecting the Future* (MITAC, 2005). One additional recommendation for improving the workforce supply is recruiting in minority communities that have not been traditionally employed in the sector.

History may provide some insight to the problem of recruiting a coal mine workforce. In the 1970s, during the rapid expansion of the industry when more employees needed to be recruited, the nation experienced a tremendous growth in training and/or retraining programs, funded by government and industry, aimed at new and displaced workers. Because of very competitive salary/wage packages, a significant number of new entrants were attracted to the coal industry. The training and educational infrastructure that was in place during the last major expansion of the coal industry in the early and mid 1970s was dismantled during the industry decline of the 1980s and 1990s.

3.2 Education and Training Issues

A significant issue in developing a sufficient professional, technical, and managerial workforce is the availability of education programs at the degree level in minerals-related disciplines. Because managerial skills are more generic and those programs are available at a number of institutions around the country, no particular efforts were made to identify their availability. For professionals and technicians, however, a shortage of available programs is accepted and well reported.

There are a number professional disciplines related to the coal mining cycle for which specialized education is necessary. Because the Society for Mining, Metallurgy and Exploration, Inc. (SME) systematically collects data on mining schools, one can use mining engineering as a representative case for these disciplines. However, based on evidence and discussions with professionals in a number of related fields, similar trends are experienced for professional education in coal processing, geology and geologic engineering, environmental sciences, and reclamation-related disciplines.

The number of mining engineering programs in the United States has fallen from 25 in the 1980s to fewer than 15 today. Over that period, the number of graduates has fallen from a high of 700 in the early 1980s to 123 in 2007 (McCarter, 2007). SME data show some progress; for instance, there were only 87 mining engineering graduates in 2004.

Currently, there are approximately 821 students enrolled in mining engineering programs across the United States. It is projected that there will be approximately 200 graduates in mining engineering in the class of 2012.

Programs in geology, geologic engineering, and related fields have also seen decreases in numbers. Mining technology programs, once a mainstay of community colleges and vocational schools in coal mining areas, have in essence disappeared. A few programs in mining technology have been started, or at least contemplated, in recent years, but there is a shortage of data on the number of students enrolled or graduating from those programs.

Data on educational levels of the coal mining workforce (B. Watzman, NMA, *pers. comm.*, September 7, 2007), updated with recent statistics from the U.S. Census, demonstrate that most employees currently are limited to a high school diploma (Figure 7.7). However, with increased automation and mechanization, some specialized training is needed. Traditionally, this training has been provided by mining operators and equipment manufacturers, or through vocational programs; however, many of these programs have been discontinued. On-the-job training impacts

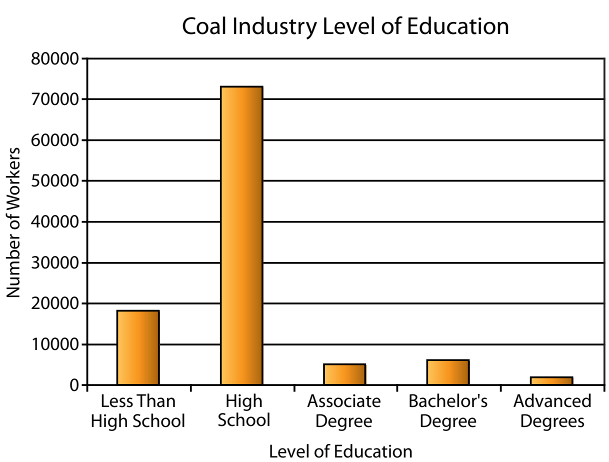


FIGURE 7.7 Current coal industry level of education, showing the significantly higher percentage of workers with high school diplomas.

productivity, can add costs to production, and may create safety hazards as unskilled personnel learn to use new equipment or conduct new operations. Increased focus on environmental and health and safety needs and productivity goals will require additional training across the spectrum of the coal mining workforce.

In addition to more specialized training, the workforce will require further formal education to work safely and productively with new technologies that are designed to meet increased concern for the environment and health and safety. For example, many industries and companies encourage technical personnel on a managerial track to obtain advanced business degrees (such as an MBA) and, to a limited extent, their technical/engineering professionals to obtain advanced specialized degrees in their area of discipline (such as an M.S.). Although some coal companies participate in such educational opportunities, as an industry, the sector needs to further support the professional development and continuing education of their managers and engineers. These educational opportunities should complement the educational needs and demands for improved and expanded skills for the remaining members of the workforce, who overwhelmingly are limited to high school diplomas.

Although some jobs in the coal mining sector may remain relatively unchanged over the next 25 years, most will become much more complex and will involve new skills for workers at that time. Incoming workers will bring enhanced technical capabilities that will make new training options more desirable than traditional methods. One key issue as coal mining techniques and processes change will be the integration of higher education with training and vocational education and even, in some cases, primary and secondary education.

Further, higher education institutions that lack a traditional coal mining focus may need to become more engaged in this specialty and supply additional professionals to the industry. Such institutions may also play a vital role in supplying additional workforce members from nontraditional sources. For example, mining-related schools may partner with institutions that serve minority communities in order to encourage and recruit students interested in entering the coal mining sector.

Additional training resources will also be needed within the mining industry to address the new skill sets that will be necessary to achieve increased coal production. Some companies that participated in the development of this report have created career development programs within their organizations and they envision an ongoing need for these programs (Rusnak, 2007; Boam, 2007). The increasing universality of Internet and distance learning approaches and resources can provide both coal mining companies located in remote areas and diverse groups of potential coal mining workers with opportunities for training and education that were not available in past decades.

3.3 Competitive Challenges

As indicated above, many of the workers required by the coal mining sector will have the opportunity to be employed in other industries in the same geographic area. Many of the skill sets of tradespersons and managerial, administrative, and technical staff are applicable in the construction, automotive services, electrical utility, and manufacturing sectors. These industries may enjoy the competitive advantage of a better reputation, in terms of safety and environmental performance, better working conditions, and perhaps more competitive salary and benefit packages, than the ones enjoyed by personnel in the coal mining industry. Many highly skilled or professional employees may find the rural communities where coal is often mined less desirable than the areas where they can obtain jobs in other industries. For example, mining engineers can often find employment with aggregate operations located near most major metropolitan areas in the country. An urban location may be more desirable for multiple-career families rather than remote areas that offer limited career opportunities.

Although national and local salary averages for jobs in the coal mining sector compare favorably with the average for all sectors (Table 7.1), in some states, the differences are much smaller, and the number of available positions and perceived working conditions may dictate which industry an individual chooses for employment.

3.4 Best Practices

A number of mining companies have responded to workforce challenges by changing corporate structure, HR functions, and their overall approach to employment. These programs address jobs across the spectrum, from general labor to professional and managerial positions. With the majority of the workforce being in skilled or tradesperson positions, these jobs have been a primary focus. Many companies have addressed these workforce issues, but the practices of some companies appear to be benchmarks and examples of best practice.

Some companies who participated in the kick-off meetings of this study reported special steps to improve recruitment. For example, BHP Billiton stresses the development of in-house resources and a detailed HR plan that includes new recruiting efforts. BHP Billiton, like many other large corporations, is considering sponsoring external HR and recruiting organizations, and is taking advantage of Internet-based recruiting, such as using sites like Monster.com as a means of reaching out to nontraditional communities (Boam, 2007).

Other companies are also looking into innovative ways to recruit, retain, and develop employees, with significant financial rewards and aiming at building loyalty, ownership, and pride. One recent example is shown in Box 7.2.

The approaches being used or contemplated by other industries, such as the strategies identified for use by energy and utilities industries (ScottMadden Management Consultants, 2007), are also potentially adoptable by the coal mining sector. Ideas that are potentially transferable include: outreach in high schools, cooperative agreements with technical schools, development of internship and cooperative education programs, affiliation with university career development offices, and dedicated marketing of the industry and jobs within the industry. The NMA has recommended coordinating these efforts by establishing a partnership among industry, educational institutions, training providers, and government (B. Watzman, NMA, *pers. comm.*, September 7, 2007). Some partnerships have already been established between industry and labor (J. Main, UMWA, retired, *pers. comm.*, 2008), focusing on recruitment, training, and retention. This partnership is in the process of examining different recruiting models and strategies to address competition for the same workers by other industries facing the same employment needs.

One company that contributed to this particular study, Rio Tinto Energy America, has focused energy and resources on the issue of both work life and personal life needs of the work force. In this case, and with the recent boom in coal bed methane exploitation in the Powder River Basin area of Wyoming, housing has become very scarce. This company has used their corporate leverage to obtain housing options for their workforce and is considering other ways to meet this basic need of their employees. Additionally, the same company reported their effort towards providing necessary health care resources to employees in such relatively remote locations. In the area of work life, the same group noted that they have provided new apprenticeship and other programs that enable improved career development (Marshall, 2007).

BHP Billiton also reported their implemented comprehensive and innovative corporate policies for workforce development in the coal mining sector. Such programs provide remedial training, apprenticeships, and scholarship programs for vocational-technical schools, among other educational benefits, to build a cadre of skilled tradespersons. The company also noted the employee involvement in career development planning. Finally, the same group reported companywide development of strategies for succession

BOX 7.2 ALPHA NATURAL RESOURCES INCENTIVES

Alpha Natural Resources recently instituted unprecedented compensation and benefits for its employees as a means of "expressing (its) appreciation…and…introducing incentives to attract and retain the next generation of miners." Employees were given shares of company stock, relieved of the need to contribute to benefits such as insurance, provided with new bonuses and cash payments, and provided with an "energy relief/fuel assistance" program to help offset the cost of commuting to remote mining sites. "We see this as a significant day—maybe the most significant—in our company's history," said Mike Quillen, Alpha's chairman and CEO. "Alpha's shareholders have benefited from their dedication and hard work, and it's time we publicly acknowledge their efforts (Coal Age, 2008)."

planning and other corporate initiatives to ensure that current and future workforce needs are met (Boam, 2007).

There are a number of innovative programs in other companies that can be considered as best practices. Examples are shown in Boxes 7.3 and 7.4. It is unclear, however, whether such programs are discussed among HR professionals in the coal sector, or if companies consider such innovative programs as matters of competitive advantage, thus keeping the details of these programs within the company.

BOX 7.3 PEABODY ENERGY TRAINING CENTERS

The efforts of Peabody Energy to prepare for the retirement of many of its experienced miners by developing training centers for new employees were discussed in a recent article (Laws, 2006). These centers are located near small mines, and four such centers already exist in West Virginia, Kentucky, Indiana, and Wyoming. New hires undergo a nine-week training class that includes work in simulators as well as hands-on experience in mines. According to a company spokesman, "We teach these young people the right way to do the work. When they hit the mine, they're ready to step into the workforce. It's working out very well" (Laws, 2006).

Peabody was concerned that recent mining incidents might limit the number of people interested in mining careers, but the company reports success in attracting recruits to their centers, even after these incidents. This success can be attributed in part to the company's commitment to health and safety.

BOX 7.4 CONSOL ENERGY TRAINING CENTERS

Consol Energy has developed a network of training centers, with more under development, to enhance their ability to operate efficiently and productively. One focus is on providing skills to both new and existing employees related to their jobs, but the major thrust of the program is Consol's "Absolute Zero" safety effort. "All training has been reviewed to ensure all employees understand our goals and how to achieve them," said Mark Hrutkay, Consol's employee development manager. "The new Absolute Zero approach has also had a significant and positive impact on recruiting new employees into Consol. It is easy to articulate and places Consol in a great position to attract top talent."

Consol recently started the "Consol Leadership School" to augment staff retention. The program, which consists of 12 modules to be completed over a four- to six-year period, prepares staff for taking on a management role at any of Consol's 17 mining complexes located in six states. Over 100 employees are currently enrolled.

The Consol training centers are located in Utah, West Virginia, Virginia, and southwestern Pennsylvania. The Utah center, near the Emery mine in Price, also involves the College of Eastern Utah. In an innovative development, Consol is considering an underground training facility at its Robinson Run mine in West Virginia (International Longwall News, 2008).

4. DATA COLLECTION AND WORKFORCE PROJECTIONS

4.1 Current Census of the Coal Mining Workforce

One significant challenge in determining how many employees are engaged in the coal mining sector is the different definitions used by the various agencies that collect such data. This issue was highlighted earlier in Section 2.1, where the discrepancy among BLS, MSHA/NIOSH, and EIA was discussed. Because many of the tools that allow for analysis of future workforce needs in the coal sector are based on EIA 2005 production and productivity estimations, the EIA manpower data have been used in the analysis to calculate and project future coal workforce needs.

Predicting changes in the coal mining workforce over the next decades requires a number of assumptions and considerations, as shown below:

- 2005 Address/Employment MSHA Part 50 data were used (instead of 2006 data) because the EIA Coal Productivity Forecasts are for 2005 base data.
- Differences in EIA and MSHA coal production data are due to differences in data collection processes. The production values reported by EIA were used for workforce calculations.
- Grouping age data into three different regions (Appalachian, Interior, and Western) makes it easier to predict which locations will be impacted by workforce shortages. States such as Kentucky and Montana are hard to differentiate between supply regions (see definitions in Table 7.2).
- Complete and accurate age data are not readily available and typically are only reported when employees are involved in accidents.
- Data obtained from the Census Bureau do not always correlate well to data obtained from other sources.
- Coal miners' anticipated retirement age was assumed to be 62 years old.
    - As a result of the assumed retirement age, the calculations for retirement replacements assumed that two out of five miners in the 60–65 age bracket would remain in that age bracket and the other three are assumed to retire.
- The retention rate for new hires is assumed to be 70 percent. Based on some reported company data, this rate may be a worst-case assumption.
- For the 10-year shifts in time, 2010 to 2020 and 2020 to 2030, seven of 12 new hires are assumed to be in the 18–25 age range and the other five of 12 are assumed to be in the 25–30 range.

Based on those assumptions, productivity estimates from the EIA were used to calculate the necessary number of miners in each region based on the projections of coal production in the EIA base case scenario. "Man-hours" represents the hours of production workers and do not include managerial and professional categories. Tables 7.3–7.6 illustrate the calculations.

4.2 Needs for Labor, and Skilled and Professional Employees

Based on the current workforce census, projected levels of productivity and coal production, as presented in the Tables 7.3–7.6, and the projected retirement and retention rates discussed earlier, Tables 7.7–7.10 show the projected workforce levels between now and 2030. In reviewing these tables it should be noted:

- "Number of miners" is taken from U.S. Census data from coal-producing states only. It is reasonable to assume that the Census data are primarily based on responses from production workers.

TABLE 7.3 Production per man-hour (tons/man-hour).

REGION	2005	2010	2020	2030
Appalachian	3.75	3.57	3.63	3.62
Interior	5.00	5.06	5.03	4.94
Western	12.23	12.44	14.77	12.67

SOURCE: EIA, 2007b.

TABLE 7.4 Regional coal production estimations (million of short tons).

REGION	2005	2010	2020	2030
Appalachian	397	357	339	346
Interior	149	156	206	251
Western	585	626	744	998
TOTAL	**1131**	**1139**	**1289**	**1595**

SOURCE: EIA, 2007b.

TABLE 7.5 Required man-hours to achieve production.

REGION	2005	2010	2020	2030
Appalachian	106,048,937	99,870,758	93,280,337	95,383,488
Interior	29,849,940	30,958,459	40,909,599	50,852,524
Western	47,835,957	50,305,248	50,412,187	78,738,527
TOTAL	**183,734,834**	**181,134,465**	**184,602,124**	**224,974,538**

SOURCE: http://www.msha.gov/STATS/PART50/p50y2k/p50y2k.HTM

TABLE 7.6 Number of coal employees required based on man-hours.

REGION	2005	2010	2020	2030
Appalachian	53,024	49,935	46,640	47,692
Interior	14,925	15,479	20,455	25,426
Western	23,918	25,153	25,206	39,369
TOTAL	**91,867**	**90,567**	**92,301**	**112,487**

SOURCE: Calculated from production per man-hour data, assuming a typical work week of 40 hours and 50 work weeks per year.

- “Percent change” in Tables 7.7–7.10 is from the previous time period.
- “Required new miners” is calculated based on assumed retirements and changes in productivity and total production.
- “Required trainees” assumes a 70 percent retention rate; that is, 70 percent of persons trained actually become new miners.

The totals in Tables 7.7–7.10 reflect a spectrum of job functions. As mentioned earlier, the proportions of personnel in each of these employment categories can vary widely, based on the size of the

TABLE 7.7 Workforce projections, Appalachian region.

YEAR	NUMBER OF MINERS	CHANGE	REQUIRED NEW MINERS	REQUIRED TRAINEES
2005	52,024	x	x	x
2010	49,935	-5.8%	8,561	12,230
2020	46,640	-6.6%	14,415	20,593
2030	47,692	2.3%	19,751	28,216

TABLE 7.8 Workforce projections, Interior region.

YEAR	NUMBER OF MINERS	CHANGE	REQUIRED NEW MINERS	REQUIRED TRAINEES
2005	14,925	x	x	x
2010	15,479	3.7%	4,221	6,031
2020	20,455	32.1%	12,394	17,706
2030	25,426	24.3%	11,146	15,923

TABLE 7.9 Workforce projections, Western region.

YEAR	NUMBER OF MINERS	CHANGE	REQUIRED NEW MINERS	REQUIRED TRAINEES
2005	23,918	x	x	x
2010	25,153	5.2%	4,764	6,805
2020	25,206	0.2%	3,684	5,262
2030	39,369	56.2%	14,075	20,107

TABLE 7.10 Workforce projections, U.S. total.

YEAR	NUMBER OF MINERS	CHANGE	REQUIRED NEW MINERS	REQUIRED TRAINEES
2005	91,867	x	x	x
2010	90,567	-1.4%	17,546	25,066
2020	92,301	1.9%	30,493	43,562
2030	112,487	17.9%	44,972	64,246

company, the type of mining operation (surface or underground, large-scale or small-scale), and the overall corporate structure. Workforce studies conducted in Canada and Australia also demonstrate the central role of skilled or semiskilled employees in the coal mining sectors in those countries. Of the anticipated increase of 15,785 jobs in the Australian coal mining industry, 4.5 percent of the growth is projected to be in general labor, 49.9 percent in skilled workers, 26 percent in tradespersons, 2.6 percent in technical employees, 7.8 percent in professional employees, and 9.2 percent in management and administration (Lowry et al., 2006).

There are also significant differences in the retirement age and retention rate among the different job categories. Unfortunately, no definitive data were available to this study that could allow quantification of these differences. However, anecdotal evidence indicates what is intuitively obvious: jobs that have greater physical demands have higher turnover rates and lower retirement ages. Data for all industries seem to support these observations (BLS, 2008).

In summary, the data and workforce projections indicate that, based on projected production increases alone, an additional 21,000 persons will be needed for the coal mining workforce by 2030. Because another 24,000 new jobs will be needed to fill open positions dues to retirement, a total of 45,000 new workers will be needed to fill projected workforce needs. These figures are supported by recent industry estimates (Quillen, 2008) that have projected a need for 50,000 new workers in the next 15–20 years. Assuming conservative retention rates, the data indicate that 64,000 new workers will need to be recruited and trained.

5. ISSUES AND CHALLENGES

5.1 Effects of Workforce Replacement on Safety, Productivity, and Profitability

The addition of large numbers of new employees within the coal mining sector over the next two decades will inevitably influence productivity and safety. Less-experienced employees often are associated with more accidents and higher incident rates than their more experienced colleagues (Groves et al., 2007). One company that participated in this study compared the workers at a coal mine to a sports team, and indicated that when members of the team change, the effectiveness, efficiency, and safety of the team is impacted (McAtee, 2007). This company, representing small operators, reported that among the most significant safety challenges for the coal industry are “the ergonomic challenges facing an aging work force in thin coal seams, the large influx of new employees into the coal industry and the associated training issues, employee turnover and the potential safety problems resulting from unstable work groups, and the lack of experienced supervisors and the potential risks associated with the quality of front line leadership skills.”

In recent years, the aging workforce in the coal sector has been experiencing more injuries as a result of the challenges inherent in performing physical tasks at more advanced ages. Chronic injuries and illnesses are also more common in older workforce populations, and require additional time for recovery (Moore et al., 2008). Studies have also noted that older workers are at a higher risk for serious or fatal incidents in part because of exposure to more difficult jobs with greater inherent risks (Groves et al., 2007).

Safety issues will require enhanced training both for new employees to prevent accidents, and for experienced employees to build increased awareness of chronic injury and illness, and increased risk of fatal accidents. Additionally, programs such as the ones reported by a company in this current study that include pre-employment safety testing, may also be key components of new training to address safety issues (Boam, 2007). Another major coal operator in this study noted the importance of safety, culture, and the well-publicized company motto, "Absolute Zero" in creating a corporate culture that influences the attitude and actions of the workforce (Holt, 2007).

Enhanced education and training may also be the answer for addressing productivity issues in the growing coal mining sector workforce. The use of innovative advanced simulation, virtual reality training, and other vendor-provided training may allow new employees to become familiar with equipment prior to being exposed to the production environment. Companies will need to adopt extensive on-the-job training, apprenticeship programs, mentoring, and other similar approaches in order to help mitigate losses in productivity that may be associated with new workers.

In summary, workforce replacement has inevitable impacts on safety and productivity, and, as a result, profitability. Addressing training and education challenges, developing a corporate culture that enhances retention, and drawing upon experienced workers to help mentor new employees in processes and procedures will have a great influence on how much workforce turnover will impact safety, productivity, and profitability.

5.2 New Workforce Pool

As discussed earlier in this chapter, the pool of available employees will come primarily from Generation X, Generation Y, and the Millennium Generation. Given the different characteristics of these generations, coal sector employers will have to revise HR policies to take advantage of the skills, abilities, and attitudes that these individuals bring to the workforce, and will have to adapt to their needs and attitudes. For example, there will be a need for more training, job shadowing, mentoring, and career and personal development opportunities to allow and encourage employees to change jobs within the company, rather than to move out to another company or industry. Some companies are already responding to these needs. For example, one company reported that they have initiated a number of strategies to address these needs, including apprenticeship programs, scholarships, hiring bonuses, relocation assistance, detailed succession planning, and career path coaching (Boam, 2007).

Among the pool of potential workers, issues such as the use and abuse of alcohol and other drugs may be prevalent. A recent report indicates the highest levels of alcohol and drug abuse occur in the coal mining and construction industries. The study also indicates that many reports of abuse of drugs such as OxyContin come from "economically depressed, rural areas housing labor-intensive industries such as logging and coal mining" (Laws, 2006).

There is also a pool of potential workers in the veterans returning from ongoing military actions around the world. Many of these individuals may be less adverse to the perceived risk and problems in working conditions associated with coal mining. Additionally, they have been trained in various skills that may be easily applicable in the coal sector.

5.3 Location of New Workforce

The change in the location of production forecast between now and 2030 will see a shift of coal mining employment opportunities from the Appalachian region to the west, particularly to the Powder River Basin and the Interior coal producing region. In the near term, between now and 2020, workforce needs in the Appalachian region will decrease by 5.8 percent by 2010 and by 6.6 percent by 2020 (Table 7.7). However, the projections in Table 7.7 indicate the need for coal-mining workers in the Appalachian region will increase by just over two percent by 2030.

The increase in need for miners follows a different trend in the Interior region. In 2010, it is projected that there will be a 3.7 percent increase over 2005 levels; a 32.1 percent increase by 2020; and a 24.3 percent increase by 2030 (Table 7.8). The data indicate another trend for the Western region: a 5.2 percent increase through 2010; an additional 0.2 percent increase by 2020; and an impressive 56.2 percent increase over the decade between 2020 and 2030, when production in the region is projected to skyrocket (Table 7.9).

Based on projections for the total coal-sector workforce and accounting for retirements and other losses, by 2030 there will be a need for 19,751 new coal miners in the Appalachian region; 11,146 in the Interior region; and 14,075 in the Western region (Tables 7.7–7.10). The total projected need for new coal-mining workforce is 44,972 (Table 7.10). Assuming an attrition rate of 70 percent, the projections indicate that by 2030, approximately 28,216 new industry recruits are needed for the Appalachian region, 15,923 for the Interior region, 20,107 for the Western region, and 64,246 total for the United States (Tables 7.7–7.10).

These numbers show that it will be necessary for some of the new coal workforce participants to transfer from other industrial sectors. Age distributions in the construction and automotive services industries in coal mining states (Figures 7.5 and 7.6) indicate that individuals with similar skill sets are available for recruitment into the coal sector. In addition, there are employees in other mining sectors, such as aggregates, metals, and other nonmetal production, that may be enticed into the coal industry.

It is unclear what incentives may be necessary to encourage these transfers to occur. In addition, apprenticeship programs and other training provided by the coal mining sector may provoke transfers out of the sector to other jobs that may be more appealing for various reasons. This negative job flow is particularly true among tradespersons and technicians. Because many of the coal producing areas in the West are not in close proximity to population centers, this shift presents a challenge. In addition, cultural norms within rural communities tend to limit the mobility of workers from one area of the country to others.

Wage and salary differences between coal mining and other industry sectors may entice entry into the industry from a variety of other fields. Those salary differences are not as pronounced between coal mining and other types of mining, and many skill sets in the different mining sectors are very specialized and may differ widely, providing a disincentive to transfers between those sectors.

Additionally, as the U.S. population increasingly concentrates in metropolitan areas, the availability of a workforce in proximity to coal mining will be limited. To encourage workers to relocate to mining areas, recruiting efforts may be required at locations a great distance from coal mining operations. Drawing the needed workers will require the addition of community services, such as housing, medical facilities, schools, retail, and other service resources in relatively rural coal mining areas.

5.4 Impact of the Global Labor Marketplace

Australia and Canada studies (MITAC, 2005; Lowry et al., 2006) show that international mining interests, including coal, will face similar labor shortages and demographic and recruiting issues as the United States. They indicate the need for an additional 70,000 mining employees in each country by 2015, with additional increases likely after that. "There is a chronic shortage of skilled people, and wages have skyrocketed," reported a commodity strategist in Canada (Delaney and Bailey, 2008). In response, some international mining houses are taking aggressive action to meet their manpower requirements, especially in the area of recruiting scientific and technical personnel, by focusing directly on the global marketplace and offering high salaries to mining engineers and geologists. According to Delaney and Bailey (2008), salaries are up 44 percent in three years at major mining houses such as BHP Billiton Ltd. (Australia) and Teck Cominco Ltd. (Canada), approaching or even topping the average salary for MBAs entering the United States workforce.

According to Wheatley (2008), the Brazilian Vale mining group is preparing for the shortfall by building new technical schools, domestically and overseas. According to the company, "Vale is growing in an extremely aggressive way and it needs competent professionals that just don't exist. Rather than fighting over them, we have decided to help train them." Vale plans to train 3,000 engineers to fill a need for 1,000 internal positions, while still providing an additional workforce pool for subcontractors (Wheatley, 2008). Vale and BHP Billiton are aggressively recruiting professionals and engineers in the global marketplace. BHP Billiton has run English-language ads in Brazil encouraging professionals to "think about calling Australia home." Vale has reported recruitment ads in four overseas markets (Australia, Canada, the United Kingdom, and the United States) and plans to recruit one-fifth of its new professional staff from outside Brazil (Wheatley 2008).

For now, international recruitment applies primarily to the engineering and scientific professionals of the mining workforce. These trends may have some impact on international movement and recruiting of tradespersons. There is no evidence as yet of such movement at the unskilled workers' level.

Global marketplace issues have an impact on U.S. coal interests in two ways. First, global recruitment of U.S. graduates interested in pursuing coal industry careers will further shrink the already limited pool available to the domestic coal industry. Second, given the aggressive global recruitment efforts of the major mining houses, it will be increasing difficult for U.S. coal companies to compete and recruit technical talent from overseas.

5.5 Training and Education Needs

Given the wide range of jobs within the coal mining sector, there is a great diversity of educational and training resources available to support those functions and skills. As previously stated, maintenance of the current number of mining engineers in the United States across all commodities will require as many as 400 graduates per year, which is about three times the number being produced by U.S. universities (McCarter, 2007). This projection does not include those engineers and scientists in other disciplines that will be needed to address increased production, changing technology, or differing regulatory requirements.

The number of skilled employees will increase more than any other classification of jobs within the coal sector. Although some of the training needed for those employees may be provided by the companies, other training may come from union programs, private training vendors, or government agencies. Changes in requirements, for example, those due to changes in health and safety laws, may require training of a large population of coal mining workers. On-the-job training and apprenticeship programs for tradespersons are also key parts of the training infrastructure that will need to be enhanced to meet the increased workforce's needs.

Although some programs in mining technology or vocational mining exist at a limited number of schools, the extent and availability of those programs does not address the need for additional workforce with those skills. Box 7.5 discusses one example of a program that has been created in Kentucky.

Labor organizations have also developed training programs to help ensure that new entries into the coal sector are thoroughly prepared for a career in coal. The United Mine Workers of America (UMWA) has established centers in West Virginia and Pennsylvania (see Box 7.6) that provide new

BOX 7.5 THE KENTUCKY COAL ACADEMY

One recently created mining vocational program is the Kentucky Coal Academy, which was created by the Kentucky General Assembly in 2005 as a part of the Kentucky Community and Technical College System (KCTCS) (see http://coalacademy.kctcs.edu/index.cfm). The academy is a statewide training program intended to meet the workforce needs of the coal industry. According to the Academy's website:

"The first program goal is to provide short-term training for new miners to satisfy the industry need for skilled workers. A second is the creation of a career path in mining to sustain the viability of the coal mining career and support the coal industry. The Kentucky Coal Academy is comprised of four of KCTCS' community and technical colleges located in the eastern and western Kentucky coalfields. The mission of the Kentucky Coal Academy is:

- To **educate and train** the coal workforce of the future.
- To **create and sustain** jobs in the coal industry.
- To **provide career pathways** for miners from high schools and area technology centers, which will include certificates, associates degrees and baccalaureate degrees.

A key element of the mission of the KCA will extend coal education at the secondary level through the Kentucky Junior Coal Academy. The extended early educational opportunity will provide three career paths for students interested in mining. These paths include:

- Employment in the industry immediately following high school graduation.
- Pursuit of a two-year degree as a pre-engineering technician or an Associate's degree in Mining through KCTCS.
- Pre-Engineering (toward a 4+year degree in Mining Engineering)"

miners with nine weeks of training related to various aspects of coal mining and health and safety (J. Main, UMWA, retired, *pers. comm.*, 2008).

Specialized education and training will be needed for the workforce that transfers from other industrial sectors, from other geographic areas, and possibly from other countries. In some cases, this training may be very basic, such as an overview of the coal mining industry or coal geology; job specific, such as how to operate a particular piece of equipment; or essential but not job related, such as teaching English to non-native speakers.

5.6 Corporate Culture and Commitment

The committee for this study discussed and exchanged ideas with representatives of small, medium, and large coal mining companies, government agencies, and others involved in the coal mining sector. Many of the presentations and materials obtained from the mining companies addressed corporate philosophies and culture, particularly relating to safety and workforce development. The issues discussed by company representatives clearly indicated that a number of companies are in the forefront of HR practices and can serve as examples of best practices in this area.

BOX 7.6 THE MINING TECHNOLOGY AND TRAINING CENTER, INC. (MTTC), UNITED MINE WORKERS OF AMERICA (UMWA)

According to the UMWA website (http://www.umwa.org/index.php?q=content/career-centers):

"As the nation's dependency on coal increases and the existing workforce ages, the labor demand for coal miners is increasing. It is the mission of the UMWA Career Centers to offer training programs for new miners, as well as individuals who have been dislocated from the mines."

The UMWA MTTC, Inc., offers a nine-week training program for new entrants into the mining industry, delivered at two locations: Beckley, West Virginia, and Ruff Creek, Pennsylvania. The training is designed to build a solid foundation under individuals that seek a mining career (Joe Main, UMWA, retired, *pers. comm.*, 2008) and exceeds the minimum 40-hour training requirement. The miners receive in-depth training on mine ventilation, mining systems, and a variety of other mining subjects. According to the website, http://www.umwacc.com/new_page_16.htm: "At the successful completion of the course, students will receive a certificate from either Penn State University (for students attending the Ruff Creek, PA Campus) or the Community and Technical College at West Virginia University Institute of Technology (for students attending the Beckley, WV Campus). Additionally, students will receive state certification (after successfully completing all work and passing all necessary tests) and a card from MSHA (Mine Safety and Health Administration). These certifications will give graduates the necessary criteria to enter the mining industry."

The MTTC also provides mine foreman training and is in the process of developing other training programs (J. Main, UMWA, retired, *pers. comm.*, 2008).

For example, some companies reported a retention rate for new employees of about 70 percent. Other companies, with more extensive programs focused on workforce and personal development, reported retention rates closer to 90 percent.

As mentioned earlier, many companies are responding to their current and future workforce needs. A variety of approaches are used, such as responding to housing and medical facility shortages, mentoring, career development programs, creating apprenticeships, and developing training centers, as in Boxes 7.3 and 7.4.

The career and personal development focus of some coal mining companies have resulted in lower turnover rates and greater job satisfaction. The commitment from the top echelons of a number of companies to a corporate culture that is dedicated to safety and to nurturing workforce development is also apparent. In addition, programs focused on work life and personal growth will be critical to developing long-term loyalty and to enhance the ability to recruit staff from locations distant from the coal mining operations.

5.7 Workforce Development Strategies

5.7.1 INDIVIDUAL COMPANIES

Companies should consider several strategies to address the additional workforce needed to sustain and increase coal production between now and 2030. Among these approaches are: emulating the industry leaders and benchmark practices; dealing with local issues, such as housing shortages; providing competitive salary and benefit packages; addressing perception issues by being open with local communities; developing mentoring and personal development opportunities; changing the corporate culture to build brand loyalty to the company; and developing resources for effective community recruiting, both from the community near the coal mine and from more remote communities with larger potential labor pools.

5.7.2 COAL INDUSTRY

Individual companies bear the largest burden for recruiting their own workforce. Because coal mining is extremely regionalized, the issues that impede acquisition of sufficient workers transcend company boundaries. There is a role for local, state, and national industry groups in building the future coal mining workforce. These organizations can contribute resources and encourage company efforts; build bridges between companies to allow for cooperative efforts and develop frameworks and venues for those efforts; support educational and training institutions; work with governments to build and facilitate public and private partnerships; support the funding of research, which provides additional support for higher education; support local vocational and technical schools, high schools, and other educational institutions by providing resources and expertise; and, perhaps most importantly, work to change the perception of the coal mining sector as an employer and good citizen.

5.7.3 GOVERNMENT

There is a role for government at all levels in supporting the growth of coal mining workforce as well. The types of actions that local and state governments can take may vary greatly from those which are appropriate for the federal government. At the local level, one key emphasis must be on providing the infrastructure necessary to support expanded communities and expanded coal mining workforces. For example, the need for housing, medical services, and education may be addressed in part through governmental action.

At the federal level, other actions are more appropriate. The types of actions in which federal agencies may need to engage include: supporting comprehensive job training and employment development programs and partnerships; funding and supporting coal-related research; collecting and providing good data related to coal mining and related workforce issues; renewing support for local education and vocational training; supporting professional educational; supporting safety programs and training; and brokering industry cooperation.

In addition to these support actions, government agencies that deal with coal mining issues are faced with meeting their own workforce needs. The retirement crisis for the coal mining sector affects government agencies at all levels as well. At best, the replacement of the current experienced personnel is resulting in a major loss of experience and knowledge. In some agencies, retirements result in permanent loss of positions with more serious impacts related to fulfilling mandated missions. In many cases, the ability of government to respond to the challenges of workforce recruitment and development in the same ways that the coal mining industry can respond is limited by public policy, funding limitations, and government employment rules.

5.7.4 EDUCATIONAL AND TRAINING INSTITUTIONS

Traditionally, there have been clear divisions between educational institutions (particularly higher education institutions) and training providers who serve the coal mining sector. Occasionally, these barriers have been overcome through implementation of vocational training programs or mining technology programs that have relied on or been based within the educational community. One strategy that may be important for meeting workforce needs involves breaking down existing barriers between educational and training institutions. The audiences for education and training are often very different groups, and fall within the spectrum of job classifications. The opportunities for coordination and cooperation are numerous.

Within the higher education community, the survival and possible expansion of coal-mining-related educational programs, such as mining engineering programs, will require university administrators and leaders to be convinced of the need for such programs and their ability to remain sustainable as independent disciplines of education and research. The efforts of the industry and government must also include outreach to education.

As with all other participants in the coal mining sector, education and training institutions must develop succession plans for professors and instructors. The average mining faculty age has been increasing dramatically, and the supply of qualified replacements continues to be very low. The limited support in R&D funding available to the discipline, as noted in the NRC (2007a) study, *Coal: Research and Development to Support National Energy Policy*, has addressed this issue in more detail, including the difficulties in maintaining viable graduate programs at the Ph.D. level, the pipeline to the professorate. A recent study by SME projects the need for 21 additional mining engineering faculty members in the next two years alone (McCarter, 2007). Even if these new faculty are available, there will be need for research funding and other support to allow them to succeed within the requirements of the U.S. academic community.

To help the coal mining sector acquire a sufficient workforce to meet the need for increased production, some innovation will be required in educational and training institutions. Among the most critical improvements will be developing cooperative programs with government, industry, and other educational institutions to leverage resources and create a common approach. Additionally, educational institutions and training providers will need to focus on distance learning and other similar approaches, such as the use of extension services, which have been common in agriculture for the past 150 years. With the variety of education and training resources that will be needed for the growing coal mining workforce, no one delivery mechanism, nor provider, will be appropriate in all cases. There will need to be a multitude of approaches and providers.

6. CONCLUSIONS

The coal mining sector will face significant challenges in meeting its needs for workers between now and 2030. Although many of these are similar to challenges that other industries and countries face with the retirement of the Baby Boom Generation, projected increases in U.S. coal production will also create additional demand for new workers. This significant workforce swing will impact all types of jobs in all areas of the coal mining sector, from coal producers to the coal community at large, including suppliers and service providers, educational and training institutions, and government agencies.

For many years, retirement of the baby boomers has loomed on the horizon and many corporate HR professionals and departments have long advocated planning and preparing long-range HR action efforts. However, fiscal realities and policies have often prevented companies, including many within the coal sector, from implementing succession planning that would include hiring replacements before the job is vacated, developing existing staff resources through training, and providing adequate continuous education, upskilling, and cross-training opportunities.

The workforce needs estimated and projected in this chapter, possibly more conservative than other industry estimates, have identified:

- A need for an additional 21,000 persons to the total coal mining workforce by 2030, based on increased production alone
- Additional 24,000 jobs due to retirements within the existing workforce, for a total of 45,000 new coal mining positions for the sector to the year 2030; this number conservatively supports coal industry estimates of 50,000 new positions
- Assuming conservative retention rates, to achieve 45,000 new coal mining employees, over 64,000 persons will need to be recruited and trained

These projections are limited to the general production workforce and do not include the serious deficit in managerial and professional positions that, according to most estimates, is expected to reach serious proportions in a few years.

This pool of new workers may come increasingly from areas distant to the coal mining activities, from women and minorities, from new generation workforce entrants, and from swing recruits from other sectors, all of which will pose new challenges to the coal sector. The addition of large numbers of new employees will inevitably influence productivity and safety. Training issues, employee turnover, and potential safety problems resulting from unstable work groups, along with the lack of experienced supervisors and potential risks associated with the quality of front line leadership skills, pose concerns. This new workforce will also create additional and often specific educational and training needs and demands.

International recruiting, as a means of alleviating domestic problems, will be challenging, because other countries with substantial mining industries, such as Australia, Brazil, and Canada, are also projecting significant mining workforce shortfalls and are aggressively recruiting worldwide. The U.S. coal sector and community must consider the global situation, including competitive position and recruitment options, in developing manpower strategies.

The following recommendations are offered to address the issues of workforce recruitment, retention, and career-long development in the coal sector at large:

- ***Create a new pool of workers for the coal mining industry.*** Developing a pool of potential workers at all levels will require actions by coal producers, coal suppliers, state and federal governments, and educational and training institutions. Companies must develop, or reinforce, corporate philosophies and cultures that promote the development of employees, offering competitive salary and benefit packages and providing a caring and rewarding environment in order to enhance recruitment, retention, and development.

- ***Integrate the impacts of a massive labor swing into human resources and operations strategies.*** A major labor transition could have significant impacts on worker productivity, health, and safety performance, and even on social and cultural environments in the workplace and on mining communities. Developing and supporting innovative, accelerated training programs, for all levels of employees, will be necessary if the sector at large is to achieve its targeted manpower goals.

- ***Strengthen mining-related disciplines at higher-education institutions.*** Globally and nationally, there is a severe educational crisis in the engineering and scientific disciplines related to the coal mining upstream cycle. Major problems include undergraduate recruitment and enrollment, support and sustainability of graduate students and programs, and faculty succession and development of the future professorate in these fields. Mining-related disciplines in higher-education institutions must be reinforced, supported, and embraced by the broad coal community. Resources are needed to enhance student and program support and provide research funding opportunities that are necessary for the sustainability and growth of any discipline and professional field within the higher-education environment. Coal-related disciplines already represent a subcritical mass of effort that, without strong community support and commitment, may lead within a few years to critical technical and professional manpower shortages in the sector.

- ***Expand training institutions and resources on a regional basis.*** Building a workforce that supplies a sufficient number of skilled employees will require enhancing and expanding training centers and facilities. Companies, unions, private training vendors, federal and state agencies, and institutions should work together on this effort. A network of community colleges and vocational schools is required to train workers regionally. Traditional training must be supplemented with new training options offered by advanced simulation and virtual reality. On-the-job training and apprenticeship programs for tradespersons need to be enhanced. Development of distance learning opportunities, including interactive, Internet-based training, and satellite television courses, will become necessary to meet training and vocational educational needs, particularly in remote areas.

- ***Overcome perception problems of the coal mining sector.*** The coal mining sector needs to overcome perception issues and public mistrust to become an employer of choice. The coal community must address its public image by promoting active community engagement, fostering pride in coal-related disciplines, and embracing the career-long development of and commitment to current and future employees. A community-wide program founded on building and facilitating public and private partnerships and focusing on improving the image of the coal mining sector as a good employer and responsible citizen is needed. Image improvement should be a major goal for the entire sector and coal community.

Chapter 8 Conclusions and Recommendations

This study focuses on six primary components related to the upstream coal production cycle that could influence the ability of the U.S. coal industry to meet projected production targets over the next few decades and achieve a coal production capacity consistent with the nation's long-term energy goals and environmental aspirations. Although much of the data and analysis included in the study focuses on the next two decades, to the year 2030, many of the issues have a longer time horizon.

The upstream addressed by this study are: coal resources and reserves; mining technology and resource optimization; coal preparation; health and safety issues; environmental protection, practices, and standards; and workforce challenges. The study reviews each topic in detail. It identifies problems, discusses progress and strengths, and recommends areas of improvement. Where appropriate, the discussion references the broad coal sector and community (i.e., coal industry, government, equipment suppliers, academia, environmental groups, and the public).

While preparing the study and formulating the conclusions, the Report Committee received valuable input from industry leaders, government agency employees, academics, other experts in the field, and interested citizens, all of whom contributed towards framing the discussion around the six major issues.

The central findings and themes of this study, extensively supported by background information, discussions, and conclusions in the main chapters of this report, are presented below.

1. INFORMATION CHALLENGES

There is a fundamental need for better and timelier data related to all aspects of the coal sector. Much of the information that would enable sound decision-making regarding the future of coal production, including scientific data and information on current performance, is not available. Government and industry must work with other stakeholders to ensure the information is collected, disseminated, and analyzed in a way that is useful.

All six chapters clearly demonstrate and document the need for publicly accessible and reliable information. In many cases, the data necessary to make sound judgments regarding coal reserves, the effectiveness of current or proposed environmental or health and safety regulatory programs, the demographics of current and future labor pools, and other such issues were either difficult to obtain or simply not available. By way of comparison, information and data from several federal regulatory agencies, the Energy Information Administration, the U.S. Geological Survey, the International Energy Agency, and Office of Surface Mining Reclamation and Enforcement on reserves, production, and environmental performance for the coal sector are far less available than that for the oil and gas sectors. In today's information-based society, information and access to data and other substantive knowledge are critical for decision-makers in industry, government, and the public sector. It is therefore essential that regulatory, scientific, and resource-management agencies, and private entities collect and make available useful and timely information related to coal production.

2. TECHNOLOGY NEEDS

To address changing conditions, there is a need to develop and adopt better technologies in all facets of the upstream cycle. Although new technologies are imperative for effective and efficient coal production and for improving health and safety conditions and environmental performance and stewardship, over the past few years, the reduction of government and private R&D investment has limited their development and adoption. Government, the coal industry, and academic and research institutions must work together to increase funding in this area.

The reduction of government funding, in particular, including the elimination of the U.S. Bureau of Mines in the 1990s, has significantly impacted the U.S. R&D infrastructure necessary to support the coal sector. The preservation of knowledge in crucial technical areas of coal mining is threatened by the lack of support for graduate-level research programs and Ph.D. programs in a number of areas (e.g., ventilation, mining systems, coal preparation, reclamation/restoration).

Large, global mining equipment manufacturers and vendors are engaged in equipment- and product-oriented R&D that benefits the coal industry as a whole. In addition, other new technologies also enter the U.S. coal mining sector from international R&D efforts, mainly from Australia. Because equipment manufacturers benefit from selling equipment to broader industrial markets, special equipment needs of the relatively small coal sector often go unmet. On top of this, equipment manufacturers are often committed to evolutionary development of already existing product lines, rather than researching revolutionary technologies and alternatives to existing approaches. Products and technologies developed internationally often do not meet specific challenges of U.S. mining conditions, such as mining thin coal seams, alternatives of mining under the severe topography encountered in the Appalachian region, novel methods of cleaning and processing U.S. quality coals, and meeting national environmental and health and safety concerns and regulatory measures.

Advanced technologies are needed for U.S. coal operations to integrate mining systems with the geologic environment and allow more predictable and truly continuous operations. Increased introduction of automatic mine monitoring systems for air, water, ground stability, and other important parameters will enhance health, safety, productivity, and production. To reduce the ergonomic stresses that accompany working in thin seams, it is necessary to develop automatic and autonomous controls on underground mining machinery.

Coal quality is expected to decline, necessitating new technologies to process this new coal. In the Appalachian and Interior regions, new technologies are required to process feed coals with increasingly difficult washing characteristics. Because western coals have traditionally required little preparation, Western coal operations could potentially face even greater challenges if additional coal preparation is needed.

Although significant progress has been made in the last 30 years in implementing changes in coal mining and reclamation practices to protect the public and the environment, increased attention must focus on technologies in other areas described in this report, such as water resources protection, revegetation practices, air quality concerns, and waste management, including excess spoil placement and stream buffer zones.

Because of economic and technical risks and the large investments required, few mining companies undertake cutting-edge research and development. Concerns over competitive advantage have limited collaboration, and equipment manufacturers are reluctant to invest in technology unless there is a proven market for adoption. Thus, there is a need for greater involvement in and support of mining technology research by the federal government and the private sector to meet these challenges.

3. IMPROVING PERFORMANCE

There is a fundamental need to change the culture of the entire coal sector to one that focuses on "beyond compliance" approaches to dealing with regulations and public trust. To become publicly accountable, the coal industry must voluntarily adopt practices that go beyond minimum standards and assume beyond compliance practices. Additionally, government agencies must also be accountable and focus on continuously improved science-based regulations and technology transfer. Beyond compliance for government agencies should include a greater amount of technical and compliance assistance and active involvement with local, state, and corporate entities in ensuring public education on environmental and health and safety issues.

The coal industry as a whole should widely adopt the approaches that several leading companies already practice to achieve results that go beyond what is required for compliance. While this philosophy has predominantly focused on environmental and health and safety standards and performance, many companies have also been effective in using this approach to address workforce issues, develop and adopt new technology, and share information. Additionally, government agencies must provide more technical assistance to support innovative methods and practices. The agencies must also go beyond their minimum required performance in regulating, developing technology, and providing information.

The recent adoption of more sophisticated risk management approaches by both industry and regulators to address environmental and health and safety issues is a good example of exceeding the minimum standards and requirements of current regulatory programs, allowing for better performance and potentially leading to a greater societal acceptance of coal production and utilization. A number of coal producers are involved in "beyond compliance" practices such as supporting local economic development, strengthening social and infrastructure capacity, and practicing environmental protection, restoration, and post-mining land use. These companies have corporate sustainable development policies and guidelines in place that provide guidance for operations and community involvement. Management leadership must establish higher environmental performance standards and actively pursue engagement with all stakeholders and interested parties within the community to ensure that coal mining is conducted in a responsible manner.

Companies noted for beyond compliance mine health and safety approaches have enjoyed better reputations with the workforce and the public. Mining companies must go beyond mine safety regulations, conduct thorough assessments of risks, and identify methods to eliminate risks inherent in systems and processes involved in mining operations. In addition, promoting a safety culture as the top priority of senior management and setting truly ambitious health and safety goals has positive impacts throughout the organization.

4. ECONOMIC AND BUSINESS CHALLENGES

The coal mining sector must address economic uncertainty, avoid supply interruptions, and promote production stability. If coal is to remain a significant part of the energy mix in the United States, past economic and business practices that resulted in boom and bust cycles must be avoided. Supply-demand dynamics and the lucrative export market are important considerations in market stability. Many of the large coal producers are publicly traded companies and must answer to their stockholders for their business performance. Investments in new production capacity for these companies must be made on the basis of accepted business practices. Because of the need for a secure domestic energy supply, the government and coal consumers also have a vested interest in ensuring that supplies are uninterrupted and stable.

Historically, periods of increased coal prices and production (boom cycles), similar to the one currently experienced in the United States, have been followed by downturns (bust cycles), due to a short-term business focus and failure of the coal mining industry to address longer-term challenges of sustaining production capacities. This up-and-down cycle promoted instability that impacted investment, markets, coal development, infrastructure improvements, labor uncertainty, and even public trust. It was difficult to justify large-scale investment in reserves that would not be in the supply chain for several years.

In contrast, during the extended period of high coal prices in 2007 and 2008, several factors have made short-term production increases difficult. Among the causes are the long lead time needed for reserve acquisition and environmental permitting, transportation issues, lack of a skilled workforce, and shortages of mining equipment and consumable materials such as off-road tires. In the longer term, however, these factors must be addressed if coal production capacity is to meet projected future needs.

Uncertainties about health and safety and environmental laws and regulations, public acceptance of coal production and utilization facilities, and the threat of carbon legislation also make capital decisions on production expansion and equipment replacement or upgrades difficult. Opposition to coal usage has mobilized community involvement in coal mining development and permitting. The contribution of coal mining to greenhouse gas generation (methane during mining and carbon dioxide from burning coal) and, therefore, to global warming, must be critically assessed. Unless the uncertainty with regard to carbon dioxide emission control is resolved, through policy or by technological developments such as carbon capture and storage, greenhouse gas emissions from coal-fired power plants will remain a major factor impacting private and public investment in coal mining.

Additionally, the federal government should address the role of coal in the domestic energy portfolio through explicit policy. Because of the widespread availability of domestic coal resources, clarifying its importance in a safe and secure domestic energy supply will help alleviate business and economic concerns about the production and use of coal.

5. WORKFORCE CRISIS

If the coal mining sector is to remain viable, it must address a potentially significant shortfall in the workforce at all levels. Retirement of the Baby Boom Generation and the entry of new generations into the workforce in the United States and around the world will contribute to a significant shortage of an available, qualified coal mining workforce at all levels and expertise. The coal mining sector will be in competition with many other sectors for new employees and must adopt new approaches for recruiting and retention. Even if these efforts are successful, a large labor shift will have significant impacts on coal mine productivity and health and safety and this transition must be carefully managed. Although industry will be most impacted by this shortage, both government and academia must also address this looming crisis.

The coal mining sector will face significant challenges in meeting its needs for workers between now and 2030 because of retirements, migration to and from the coal sector and coal mining areas, and the potential for increased coal production. This significant workforce swing will impact all types of jobs in all areas of the coal mining sector, from coal producers to the coal community at large, and from entry-level miners to management and professional positions, and will include suppliers and service providers, educational and training institutions, and government agencies. The impending turnover in the labor force will have inevitable consequences for productivity, safety, demand for training, and corporate structure and culture.

The development of a corporate culture that is positioned to adapt to the new and changing workforce is a critical aspect of meeting the workforce challenges. The career and personal development focus that some coal mining companies have implemented has resulted in lower turnover rates and greater job satisfaction. The commitment from the top echelons of a number of companies to a corporate culture that is dedicated to safety and to nurturing workforce development is also apparent. In addition, programs focused on work life and personal growth will be critical to developing long-term loyalty and to enhancing the ability to recruit staff from locations distant from coal mining operations. Companies must adopt approaches for workforce development that include: emulating the industry leaders and benchmark practices; dealing with local issues, such as housing shortages; providing competitive salary and benefit packages; addressing perception issues by being open with local communities; developing mentoring and personal development opportunities; changing the corporate culture to build brand loyalty to the company; and developing resources for effective community recruiting, both from the region near the coal mine as well as from more remote communities with larger potential labor pools.

6. EDUCATION AND TRAINING NEEDS

Education and training resources are not in place to ensure an adequate supply of professionals and workers and their continued development within the industry and the broad coal community. Education and training resources need to be reinforced to address employee development at all levels related to the upstream coal sector.

Government and industry will be called upon to finance and support training and education to produce sufficient expertise to maintain the performance level of the sector.

Globally and nationally, there is a severe educational crisis in the engineering and scientific disciplines related to the upstream coal mining cycle. Major problems include undergraduate recruitment and enrollment, support and sustainability of graduate students and programs, and faculty succession and development of the future professorate in mining-related fields. Resources are needed to enhance student and program support and to provide research funding opportunities that are necessary for the sustainability and growth of any coal-related discipline and professional field within the higher education environment, including engineering, geology, reclamation science, and others.

In addition, institutions providing educational opportunities in the broad mineral disciplines will not be able to expand without significant industry investment.

Building a workforce that supplies a sufficient number of skilled employees will require enhancing and expanding training centers and facilities. Companies, unions, private training vendors, federal and state agencies, and institutions should work together on this effort. Traditionally, this training has been provided by mining operators and equipment manufacturers, or through vocational programs. However, many of these programs have been discontinued. The few programs that are in place today appear to be developed by the largest mining companies for their own benefit; companies at the other end of the spectrum (smaller companies, contract mining operations, and contractors performing mining activities at coal mines) may have minimal internal training capabilities. Without additional training resources, these companies may have difficulty in staffing operations with an experienced and well-trained workforce.

A network of community colleges and vocational schools is required to train workers regionally. Traditional training must be supplemented with new training options offered by advanced simulation and virtual reality. On-the-job training and apprenticeship programs for tradespersons need to be enhanced. Development of distance learning opportunities, including interactive, Internet-based training and satellite television courses, may become necessary to meet training and vocational educational needs, particularly in remote areas.

7. SOCIETAL ACCEPTABILITY

It is imperative to address the societal acceptability of coal mining and utilization. Coal is a vital energy resource today and will likely remain so for the foreseeable future. Yet, there is little appreciation of the role that domestic coal production plays in meeting the nation's current and future energy demand in a safe and secure manner. As a result, coal production and utilization face both real and perceived challenges in societal acceptance. Therefore, for coal to remain a viable part of the domestic energy portfolio, the entire coal sector, including industry, government, academia, and nongovernmental organizations, needs to work collaboratively to disseminate factual information about the availability, importance, and impacts of coal production and use.

Much of the past information about coal production has been disseminated through the media, with varying degrees of accuracy and completeness. Often, the most readily available information has been about problems and challenges rather than advances and successes. To ensure that accurate, complete information is available for all parties, the coal industry and government agencies must directly engage local communities and citizens to share information, receive meaningful input, discuss the importance of coal with regard to domestic energy security, demonstrate environmental and health and safety performance, and share decision-making power. Unless the coal sector successfully engages the public and demonstrates its importance as an energy resource and meets the challenges identified above, the social acceptance of coal production becomes unlikely and coal mining and utilization may lose their social license. Given the global nature of the modern coal industry, sustainable development requirements and practices promoted in other parts of the world and even mandated by a number of major global financial institutions, will have a positive impact on the U.S. coal industry by reinforcing practices and cultures that address community and societal issues.

Some of the most serious issues facing the coal industry in the next few years are related to environmental concerns and social and community acceptance of the mining and use of coal. As a result, development and deployment of the best upstream technologies and practices and the wider acceptance and utilization of downstream advanced coal and carbon management technologies will have a significant impact on the environmental performance of coal, its acceptance, and its future sustainability and growth. Government regulators will have to increase efforts to adopt clear, science-based regulations and risk assessment protocols to assure a skeptical public that the production and utilization of coal is regulated and conducted in a manner that poses acceptable risks to human health and the environment.

It is important for the coal industry to create opportunities for engagement of all stakeholders and local communities. The coal industry, along with the rest of the mining sector, has traditionally addressed community engagement from a compliance and legal framework, and has focused on information and consultation via media releases, newsletters, websites, public meetings, and discussion groups. Most participants in the mining industry today clearly understand that local communities and local people impacted and affected by a mining operation must be openly engaged at a much higher level and in a process based on respect and ongoing dialogue. In essence, the entire industry should transition from an information-sharing, crisis, and defensive mentality to one that promotes pro-active dialogue, transparency, and public participation.

8. SUMMARY

Coal will continue to play an important role in the U.S energy portfolio, at least until 2030, which is the scope of this study. The discussion presented in this report on upstream issues is, therefore, appropriate and much needed to identify potential challenges and recommended areas of improvement. There are also issues of safety and security with regard to meeting the nation's energy demands from domestic sources such as coal. A cooperative effort should be established among coal producers, coal suppliers and equipment manufacturers, government agencies, academic institutions, and other nongovernmental organizations to examine system-wide economic contributions and to analyze costs and benefits to society and the environment that are created by all facets of coal operations. Elements to be addressed in such a lifecycle analysis may include factors associated with the extraction, processing, transportation, and utilization of coal. Worker health and safety issues, positive and negative environmental impacts, and contributions to the public wellbeing need to be fully assessed so that policymakers can make intelligent decisions regarding the role of coal in meeting the nation's future energy needs.

Appendix A
Biographies

Report Committee and Contributing Authors

HAROLD J. GLUSKOTER is a scientist emeritus with the U.S. Geological Survey. His research interests include national and international coal resource assessments. Dr. Gluskoter is one of the nation's leading coal geologists and he played a significant role in the national coal assessment. He was awarded the Geological Society of America's Gilbert H. Cady Award for contributions that advance the field of coal geology in North America. His research interests, in addition to coal resource assessments, have included coal geochemistry as it is related to coal utilization and the environment, and more recent studies of the potential for sequestering carbon dioxide in coal beds. Dr. Gluskoter also brings a state agency perspective through his former service with the Illinois State Geological Survey. Dr. Gluskoter received his Ph.D. in geology from the University of California, Berkeley.

MICHAEL E. KARMIS is the Stonie Barker Professor of Mining and Minerals Engineering and Director of the Virginia Center for Coal and Energy Research at Virginia Tech. His broad research interests are in mine planning and design, ground control, carbon sequestration, and the sustainable development of energy and mineral resources. An author of over 150 publications, Dr. Karmis has been active in consulting with the minerals industry, consulting companies, government organizations, and legal firms. He served as the 2002 President of the Society for Mining, Metallurgy and Exploration (SME). A Trustee of the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), Dr. Karmis has been elected to serve as the AIME President for 2008. He is a Distinguished Member of the SME, a Fellow of the Institute of Quarrying, and a Fellow of the Institute of Materials, Minerals and Mining. Dr. Karmis received his Ph.D. from the University of Strathclyde, U.K.

DR. GERALD H. LUTTRELL is the Massey Professor of the Department of Mining and Minerals Engineering at Virginia Tech. Since joining the faculty in 1986, he has completed R&D projects worth more than $14 million, obtained 15 process patents, prepared more than 200 technical reports, and authored more than 150 scholarly publications in journals and proceedings. His professional honors include the SVCC Outstanding Alumnus Award (1987), PCMIA Stephen McCann Educational Excellence Award (1995), Henry Krumb Lecturer (2001), Percy Nicholls Award (2005), and Frank F. Aplan Award (2007). He is a member of the Society of Mining Engineers (SME) and serves as the Treasurer for the Coal Preparation Society of America (CPSA). Dr. Luttrell's research interests include particulate separations, process equipment design, modeling and optimization, and plant circuit engineering. Dr. Luttrell participates in a variety of extension activities for mining and services companies, federal/state agencies, and nongovernmental organizations. He actively promotes technology transfer and has presented dozens of short courses and workshops for the mining industry.

RAJA V. RAMANI (NAE) is emeritus George H. Jr. and Anne B. Deike Chair in mining engineering and emeritus professor of mining and geo-environmental engineering at The Pennsylvania State University. Dr. Ramani holds M.S. and Ph.D. degrees in mining engineering from Penn State where he has been on the faculty since 1970. His research activities include mine health, safety, productivity, environment, and management, flow mechanisms of air, gas, and dust in mining environs, and innovative mining methods. Dr. Ramani has been a consultant to the United Nations, World Bank, and National Safety Council and has received numerous awards from academia and technical and professional societies. He was the 1995 president of the Society for Mining, Metallurgy, and Exploration, Inc. He served on the U.S. Department of Health and Human Service's Mine Health Research Advisory Committee (1991–1998). He has served on a number of NRC committees, including the Committee on Coal Waste Impoundments and the Committee on Technologies for the Mining Industries. In 2002, he chaired the Pennsylvania Governor's Commission on Abandoned Mine Voids and Mine Safety that was set up immediately following the Quecreek Mine inundation incident and rescue.

GEORGE F. VANCE is the J.E. Warren Distinguished Professor of Energy and the Environment of the Department of Renewable Resources at the University of Wyoming (UW). Dr. Vance has played an important role in the mining industry, specifically coal, coalbed methane, bentonite, uranium, phosphorus, and gravel mining, and reclamation/revegetation efforts involving disturbed ecosystems and environmental assessment and management. He has served as President of the American Society of Mining and Reclamation (ASMR) and Western Society of Soil Science, Interim Director of the Wyoming Reclamation/Restoration Ecology Center, and Associate Director for Research/Assistant Director of the UW Agricultural Experiment Station. In addition, he has been a member of Wyoming's Selenium Task Force on Soil/Spoil/Vegetation/Animal Selenium, Abandoned Coal Mine Land research program technical review committee, and is currently a member of the Wyoming Governor's Committee on Carbon Sequestration. Dr. Vance is a Fellow of both the Soil Science Society of America and Agronomy Society of America and received the ASMR Reclamation Researcher of the Year Award. He received his M.S. from Michigan State University and Ph.D. from University of Illinois in environmental sciences. Dr. Vance is author or coauthor of numerous books, book chapters, journal articles, and other refereed publications.

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JOHN CRAYNON is a Research Doctoral Graduate Student in the Department of Mining and Minerals Engineering at Virginia Tech pursuing a Ph.D. in Mining and Minerals Engineering with an emphasis on mining and the environment. He previously earned his B.S. and M.S. degrees in Mining and Minerals Engineering from Virginia Tech. Mr. Craynon is a licensed Professional Engineer in the Commonwealth of Virginia and has spent the past 24 years working in various positions in the U.S. Department of the Interior, focused on mining and environmental issues.

WILLIS L. GAINER is a recently retired manager with the U.S. Department of the Interior, who has an extensive background in regulatory program development, mining, reclamation, environmental protection, and NEPA-related projects. The majority of this experience has been in the permitting and regulation of coal mining operations. Most recently he served as Director of the Office of Surface Mining's Albuquerque Field Office and was Acting Director of the Casper Field Office. He has supervised multi-disciplinary technical teams and has coordinated the preparation of numerous Environmental Impact Statements (EISs). Mr. Gainer is a Certified Wildlife Biologist, a member of the American Society for Mining and Reclamation, and he earned his B.S. in Wildlife Management from West Virginia University.

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SASHA MACKLER is Research Director at the National Commission on Energy Policy, a project of the Bipartisan Policy Center. He joined the Commission in 2002 after spending several years as an analyst in the U.S. Environmental Protection Agency's Clean Air Markets Division. At the Commission, he conducts technical work on the economic, technological, and environmental aspects of energy production and consumption. While at EPA, Sasha was involved in the design and evaluation of national emissions trading programs. He also had a lead role in maintaining and enhancing the Agency's primary economic modeling tool for the electricity sector. Sasha's technical expertise includes economic and financial modeling; the engineering of energy production; and emissions trading policy design. Prior to his graduate studies and employment with EPA, Sasha lived in Europe and worked with an engineering firm specializing in sustainable and low-energy building design. He holds a B.S. in Geo-Mechanical Engineering from the University of Rochester and both an M.S. in Earth Resources Engineering and an M.P.A. from Columbia University.

NATE GORENCE is an Analyst at the National Commission on Energy Policy, a project of the Bipartisan Policy Center. Nate joined the Commission in late 2006 as a member of the technical research team. He spends the majority of his time examining the economic and environmental implications of a changing U.S. energy economy under varying policies and technologies. His interest in energy began while conducting research at his alma mater on the potential for bioenergy production in China. He holds a B.A. in Geography from Dartmouth College.

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