Environmental Issues Associated with Fossil Fuel Resources—An Evaluation of Research Opportunities for the U.S. Geological Survey's Energy Resources Program

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Environmental Issues Associated with Fossil Fuel Resources—An Evaluation of Research Opportunities for the U.S. Geological Survey's Energy Resources Program

By M.L. Tuttle and G.N. Breit

INTRODUCTION

Fossil fuel consumption in the United States has nearly tripled within the last 50 years (fig. 1), and is expected to continue increasing. As our knowledge and awareness of environmental consequences related to fossil fuel extraction and use grow, we as a nation, face the challenge of balancing our energy requirements with a desire for environmentally cleaner fuel. To help meet this challenge, the Energy Resources Program (ERP) of the Geologic Division (GD), U.S. Geological Survey (USGS) sponsored three internal workshops and a World Wide Web (WWW) workshop. The primary goal of these workshops was to identify those environmental issues that are related to fossil fuels, are national in scope, and are within the purview of the USGS as an earth-science government agency. Those issues so identified will be prioritized according to ERP's future research plan and according to the extent they provide an environmental framework for ERP's petroleum and coal assessments.

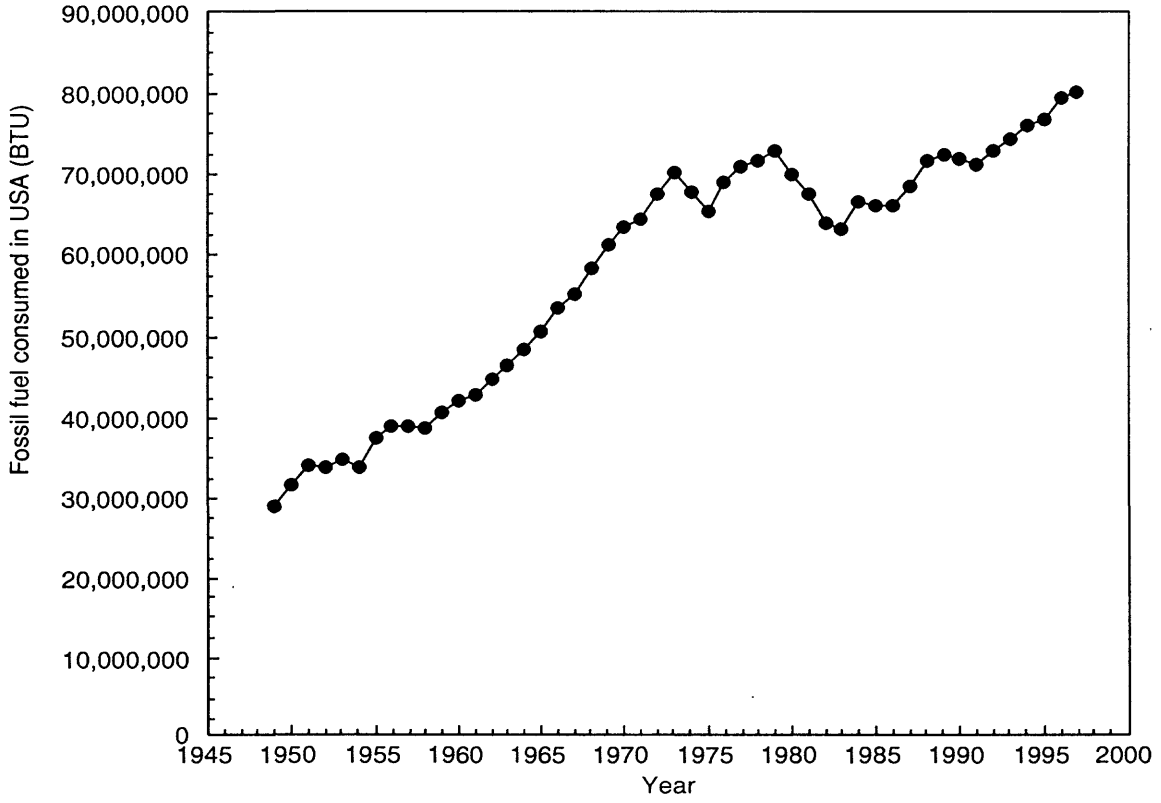

Figure 1. Graph of fossil fuel consumed in USA by year (data from EIA, 1999).

The purpose of this paper is to provide the results of the internal and WWW workshops as proposed topics of research for future ERP work, delineate studies to answer the questions related to each proposed research area, and link the studies to the seven science goals of the Geologic Division. The information provided herein will be used in preparing the USGS Geologic Division's FY2000 prospectus and ERP's next five-year strategic plan.

Acknowledgements. The authors wish to acknowledge information on ERP environmental projects provided by Les Magoon, Paul Lillis, Keith Kvenvolden, Tom Lorenson, and Bob Rosenbauer. Peter Schweitzer was instrumental in providing the software for the WWW workshop, Cheryl Adkisson for constructing the workshop web pages, and Laura Friedrich for constructing the web pages summarizing the internal workshops. Stan Mroczkowski, Jim Otton, Donna Read, and Dorothy Tanti provided notes of or logistical assistance for the internal workshops. This report reflects the collective input of numerous USGS managers and scientists—their participation in the workshops is greatly appreciated.

INTERNAL WORKSHOPS

Three one-day workshops were held for USGS scientists and managers, one workshop at each of the three USGS regional centers (Menlo Park CA, Denver CO, and Reston VA). The goal of the workshops was to provide answers to four questions:

1. What does "environmental" mean to the ERP?
2. What energy environmental issues face our nation within the next decade?
3. Which of these issues are relevant to scientific goals of the USGS and the ERP?
4. What criteria should ERP use to prioritize relevant issues?

A facilitator led the discussion in each of the internal workshops. Notes were taken and the discussions recorded. The notes and summaries of workshop results were posted on the ERP's web page for reference. Summaries are in the Appendix tables.

The outcome of these three workshops was the basis for drafting the six proposed topics of research that were the subject of a WWW workshop. Each research topic was evaluated with respect to the seven science goals of the GD of the USGS (Bohlen and others, 1998).

Goal 1—Conduct geologic hazard assessments for mitigation planning.
Goal 2—Provide short-term prediction of geologic disasters and rapidly characterize their effects.
Goal 3—Advance the understanding of the Nation's energy and mineral resources in a global geologic, economic, and environmental context.
Goal 4—Anticipate the environmental impacts of climate variability.
Goal 5—Establish the geologic framework for ecosystem structure and function.

Goal 6—Interpret the links between human health and geologic processes.
Goal 7—Determine the geologic controls on ground-water resources and hazardous waste isolation.

Each science goal has products that the GD has identified as important for the USGS to prepare and publish. These products are listed in the GD five-year plan, and those related to proposed ERP research topics are listed in the research topic descriptions.

The studies presented under each of the proposed topics are a combination of short-term and long-term research. The short-term scientific efforts will focus on pressing national issues that ERP expertise in earth science can address. The long-term research will provide a fundamental understanding of our energy resources in an environmental context. Although not specifically emphasized, the global nature of many important resource and environmental issues requires that international science activities be considered whenever appropriate.

WORLD WIDE WEB WORKSHOP

A WWW workshop was constructed using software developed by Peter Schweitzer of the USGS. This program enables browsers to register, provide comments on each research topic and the studies related to them, and communicate directly with the workshop administrator or other participants. Invitations were sent to State Geologists and key scientists at other government agencies and in academia. In addition, the invitation was widely distributed through the Department of Interior's (DOI's) Science Board and through an environmental distribution list from Vice President Al Gore's office. One week after the invitations were sent, the WWW workshop internet address was released internally within the USGS. The workshop remained open for 4 months after which time the web pages were accessible, but no longer interactive.

The six topics of environmental research and relevent studies presented in the WWW workshop reflect the outcome of the internal workshops. Our goal was to solicit feedback from colleagues and other interested parties outside the USGS to assess the impact of the six research topics being proposed. Below are the questions participants were asked to consider as they reviewed the proposed research topics and relevant studies.

- Are the issues addressed by proposed projects appropriate for the USGS and ERP?
- Are there additional broad issues that the ERP should consider?
- Do studies presented address scientific questions appropriate for the USGS and ERP?
- Are studies relevant to understanding energy resources in an environmental context?
- Are the studies of the appropriate scope?
- Are the scientific products useful to USGS customers? If not, what types of products should the ERP produce?
- Are there additional studies that the ERP should consider?

The workshop status report indicated that many people, especially from outside the USGS, were accessing the workshop. During one week, almost 300 visits were recorded. Figure 2 is a histogram showing the number of weekly hits on the WWW workshop site.

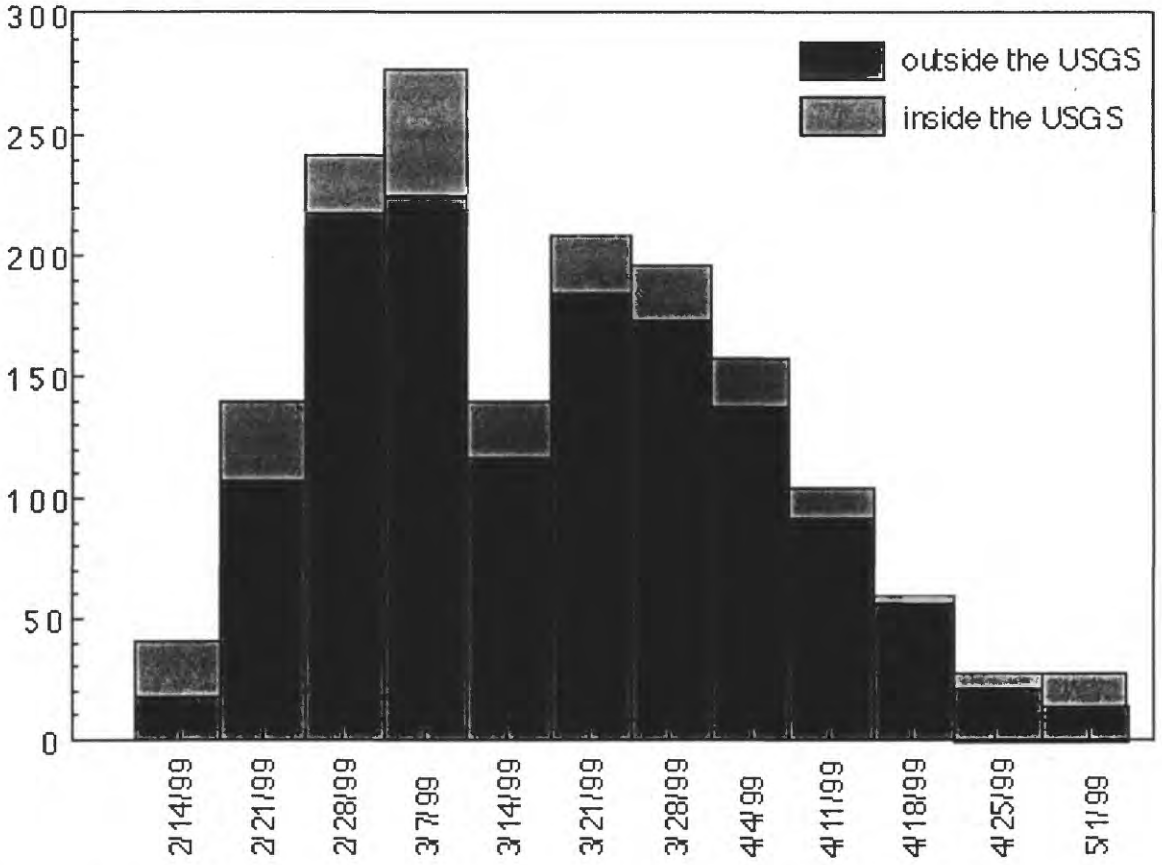

Figure 2. Histogram of the number of hits on the WWW workshop by week.

PROPOSED TOPICS OF RESEARCH

Geology Based Environmental Factors of Energy Production.

The production of oil, gas, coal, and geothermal energy and its effect on the environment are related to geologic conditions. Development of a resource and resource availability depend on such factors as reservoir character and complexity (oil and gas), overburden characteristics (coal), the potential for physical and chemical disruption of aquifers, susceptibility of the extraction site to subsidence, and the suitability of the extraction site for disposal of large-volume wastes. Knowledge within ERP of reservoir geometry, surface and subsurface geology, and hydrogeology provides a basis for evaluating the environmental consequences of energy extraction (e.g. subsidence, microseismicity, acid mine drainage, water production, CO_2 generation, waste disposal, and optimal drilling density). This information will help identify limitations on energy development. Such limitations are important input to ERP petroleum and coal assessments and to surveys of geothermal energy.

Current exploration and production of fuels is highly regulated with respect to environmental impact; however, many public and private lands have abandoned wells or mines and areas degraded by past activities (legacy issues). The intent of studies on this topic is to identify and understand the geologic factors related to environmental impacts of past, present, and future energy production, and to provide geologic data to the public, industry and governmental agencies, especially those with management responsibilities on Federal lands. In addition, the study results contribute to integrated, broader USGS efforts as proposed in the Geologic Division's Science Plan. Desired products for these integrated efforts are:

- Multihazard assessments for selected urban areas,
- Integrated life-cycle models of selected energy commodities,
- Total-cost assessments of the Nation's petroleum and coal.

SELECTED STUDY TOPICS

1. Subsidence due to petroleum production, coal mining, and geothermal development. Regional and local subsidence as expressed in surface sinks, ground deformation, microseismicity, and slumps have been linked to production from large oil and gas reservoirs, coal extraction from underground and surface mines, and the development of geothermal energy. Knowledge of the subsurface geology of sedimentary basins, and of rock mechanics (USGS hazards programs), is needed to assess hazards in selected regions of continuing production, and to produce vulnerability maps and databases for the ERP petroleum and coal assessments.

2. Overburden and associated waste rock from coal production. The thickness of overburden rock likely to be removed in the extraction of coal will be a factor in determining the development potential of a coal horizon. In addition, the chemical and mineralogical composition of these rocks is important to evaluate proper mine reclamation. Geological, mineralogical, and geochemical maps; geophysical surveys; and syntheses of the composition of these rocks in selected geographic areas will contribute to ERP resource assessments.

3. Aquifer disruption by drilling and mining. The development of any resource is constrained, in part, by the potential impact on aquifers. In some cases, the resource and aquifer are the same horizon (e.g., coal beds containing methane that are regional aquifers). The ERP, together with the Water Resources Division of the USGS, has expertise on geologic characteristics of aquifers and geochemistry of their waters, providing important data on aquifer susceptibility to disruption or contamination during resource development. These data could produce vulnerability maps and databases for aquifers in selected geographic areas as part of ERP resource assessments.

4. Acid mine drainage (coal). Acid mine drainage from coal mines is concentrated in areas of high-sulfur coal and relatively wet climates. It affects thousands of stream miles in the United States, particularly in the Appalachian region, and in some areas

accumulates as strongly acidic ground water in abandoned underground coal mines. The ERP has knowledge of the distribution of acid-generating coal and associated rocks. Combined with data on geochemical processes of acid mine drainage (Mineral Resources Program of the USGS) and on microbiology (Biological Resources Division of the USGS or non-USGS research partners), a comprehensive understanding of acid mine drainage in areas of coal production can be developed.

5. Geologic constraints on energy-related waste disposal. Sites of resource extraction are commonly sites of disposal of production/combustion wastes such as water produced with oil and gas, drilling wastes, overburden, and coal combustion solids. ERP can provide the subsurface geologic and hydrogeologic data to help assess the availability of appropriate strata for disposal.

Fossil Fuel Quality—Environmentally Sensitive Elements.

The abundance of environmentally sensitive elements in petroleum and coal affects its value and development potential. For example, significant elements include mercury, arsenic and sulfur in coal; sulfur, vanadium and nickel in oil; and sulfur in gas. This aspect of resource quality determines how oil and coal are processed and the composition of by-products likely to be produced during combustion (i.e., ash and gases). ERP resource assessments depend on reliable coal, oil, and gas quality data.

The ERP has an extensive database on the quality of domestic coal resources (COALQUAL; Bragg and others, 1997). In addition, cooperative studies have been proposed to collect and compile additional national and global coal composition data. Data sets on selected elements in petroleum (especially sulfur, vanadium, and nickel in oil) are available in established ERP databases. Existing and new data will be used in the ERP petroleum and coal assessments to evaluate limitations on resource development due to high concentrations of environmentally sensitive elements. The energy resource quality data contribute to integrated, broader USGS efforts as proposed in the Geologic Division's Science Plan. Desired products for these integrated efforts are:

- Integrated life-cycle models of selected energy commodities,
- Nationally consistent, regional-scale environmental geology and geochemistry data bases and maps,
- Total-cost assessments of the Nation's petroleum and coal.

SELECTED STUDY TOPICS

1. Fuel quality--composition of petroleum and coal. Sulfur and trace-metal content of coal and oil are important quality criteria along with API gravity of oil and the BTU and ash content of coal. Amounts of hydrogen sulfide, nitrogen, and carbon dioxide in natural gas are critical in determining its value. These chemical and physical properties affect development depending on technological advances and fuel demand. The ERP resource assessments rely on internally consistent compositional data (ERP maintains analytical capabilities to produce such data and develops new methods as

needed). This study continues to build upon existing ERP databases and applies the data by constructing maps of quality properties for geographic areas undergoing resource assessment.

2. Mode-of-occurrence of elements in coal and petroleum. In addition to element concentrations, the mode-of-occurrence of elements is also an important consideration. This is especially true for sulfur and trace metals in coal and for sulfur in oil and gas. The mineralogical and organic residences of elements in coal dramatically affects element mobility during production, processing, and combustion. Sulfur is partitioned into different hydrocarbon fractions during the refining of oil, and sulfur content of these fractions may limit downstream uses. The ERP uses mode-of-occurrence data to conduct surveys and refine evaluations of the quality of coal and petroleum in geographic areas during resource assessments. In addition, data on the mode-of-occurrence are valuable to industries actually processing the coal and oil.

Hydrocarbons in the Surface Environment.

Natural occurrences of petroleum and coal affect environmental conditions. Natural seeps of oil and gas occur in both terrestrial and marine settings, and organic compounds from coal beds affect water quality. In certain areas, these naturally occurring compounds are of greater concern than those released to the environment as a result of human activity.

The ERP has expertise and analytical equipment to chemically and isotopically characterize organic compounds in fossil fuels. The analytical data are used in ERP resource assessments and are critical to understanding and assessing the fluxes and fates of naturally occurring hydrocarbons. In addition, the results from studies on this topic contribute to integrated, broader USGS efforts as proposed in the Geologic Division's Science Plan. Desired products for these integrated efforts are:

- Integrated life-cycle models of selected energy commodities,
- Total-cost assessments of the Nation's petroleum and coal,
- Models of geochemical processes that affect ecosystem functions,
- Assessments of fundamental geologic fluxes that affect ecosystem dynamics,
- Summaries of the geology, geochemistry, and health effects of selected, potentially toxic organic compounds,
- Nationally consistent, regional-scale environmental geology and geochemistry databases and maps.

SELECTED STUDY TOPICS

1. Oil seeps. Natural seeps are used as indicators of petroleum buried at depth and provide information about the quality of potential fuels, migration pathways, and breaching of oil reservoir seals. The distribution, characterization, and flux of oil into the environment are important inputs for the petroleum system approach of the ERP

petroleum resource assessments. Describing and understanding natural seeps in coastal regions is of additional importance because tar residues from natural seeps are often confused with oil released in the marine environment by human activity. This study, in collaboration with the Coastal and Marine Geology Program of the USGS, focuses on processes related to oil seeps especially in sensitive coastal areas.

2. Natural hydrocarbons in groundwater. Some organic compounds associated with oil and coal in the ground are soluble in ground water. In addition, gas seepage into aquifers can substantially degrade water supplies as shown in some areas of coal-bed methane development. The extent and amount of natural concentrations of these hydrocarbons are poorly known and are difficult to describe in areas of production. Studies on this topic will provide information to understand natural processes affecting hydrocarbon contents of water supplies and will contribute to the evaluation of the impact of petroleum and coal production.

3. Baseline of hydrocarbons in coastal areas. Coastal areas are not only contaminated with oil from naturally occurring seeps, but also contain a host of other hydrocarbons associated with such activities as disposing of motor oil, flushing bunker fuel, and pumping from the bilge of ships. A survey of sensitive coastal areas will assist in determining and documenting the amount of hydrocarbons present (whether natural or related to human activities), and in developing a baseline in the event of a catastrophic hydrocarbon release.

4. Physical and chemical transformation of oil in the surface environment. Physical and chemical properties of oil are changed in the surface environment by a variety of processes. Knowledge of these changes is needed to assess the reliability of oil identification. In addition, an understanding of the transformation processes is needed to evaluate the long-term fate and impact of hydrocarbons in the surface environment. Some transformations are biologically mediated; therefore, the study also needs the collaboration of research partners with microbiological expertise.

CO_2 and Methane: Greenhouse Gases from Fossil Fuels.

The atmospheric concentration of carbon dioxide (CO_2) has been increasing since the beginning of the industrial revolution in the middle 1800's. Some researchers believe the increase in atmospheric CO_2 will cause a "greenhouse" effect resulting in a global rise of atmospheric temperatures. Combustion of fossil fuels is considered a major source of the increased CO_2. The amount of CO_2 produced per equivalent energy unit varies depending on the fuel--gas produces less than oil, and oil produces less than coal. In the future, national and global energy policies on energy mix may be mandated, especially considering international concerns and efforts to reduce CO_2 emissions. Sequestering of CO_2 in geologically isolated reservoirs may be a way to reduce CO_2 inputs to the atmosphere. However, knowledge of the geology of proposed reservoirs is necessary for successful implementation.

Although the contribution of methane to greenhouse-gas emissions is volumetrically smaller than from CO_2, it is a more "potent" greenhouse gas than CO_2. Natural fluxes

from oil, gas, hydrates, and coal contribute methane to the atmosphere. The magnitude of these fluxes is poorly known, thus more data are needed before, the contribution of methane from human activities can be more reliably assessed.

Studies of greenhouse gases in conjunction with resource assessments and other studies decribed below will contribute significantly to the integrated, broader series of USGS investigations on this topic as proposed in the Geologic Division's science plan. Desired products resulting from the integrated program are:

- An integrated life-cycle model of selected energy commodities,
- Total-cost assessments of the Nation's petroleum and coal,
- An assessment of fundamental geologic fluxes that affect ecosystem dynamics.

SELECTED STUDY TOPICS

1. Energy-mix scenarios: predicting future CO_2 emissions from fossil fuel. The global choices of energy sources will profoundly affect CO_2 emissions in the future. Intelligent choices require knowledge of the distribution of global fuel resources and their potential use to reliably estimate potential CO_2 production. ERP has extensive data from its national and global resource assessments that provide the basis for energy-mix scenario analysis. Through these analyses, ERP can contribute to the broader goal of understanding the national and global environmental impact on energy mix.

2. Methane sources. Methane emissions from oil, gas and hydrate production sites and coal mines contribute to the atmospheric flux. ERP, together with the Coastal and Marine Geology Program of the USGS, has the expertise to estimate the flux of methane from these sources on national and global scales.

3. CO_2 sequestration. Injecting CO_2 at fossil fuel extraction sites can enhance petroleum recovery but also provide an opportunity for CO_2 sequestration. ERP has extensive knowledge of the geology of natural gas reservoirs and coal beds that may be applied in studies to (a) evaluate the amount of CO_2 that can be sequestered in reservoirs, (b) survey the distribution of potential sequestration horizons, and (c) forecast the long-term fate of CO_2 injected into the disposal reservoirs.

4. Natural hydrocarbon (organic carbon) sinks through time. ERP has studied the burial of organic carbon over geologic time as part of numerous studies on the origin of petroleum and coal. This knowledge will contribute to understanding sources and sinks of organic carbon as part of the global carbon cycle.

Metals Released during Production and Use of Fossil Fuel.

Fossil fuels commonly contain trace amounts of metals that are considered potentially harmful to ecosystems and human health. During fuel processing and combustion, these metals concentrate in residual by-products or are released directly to the air and water.

Residual by-products are typically placed in disposal sites where they may interact with water and biota, eventually resulting in release of metals to the environment.

Studies on this topic will focus on the mobility, baseline concentrations, and bioavailability of metals in fossil fuel by-products that are of environmental concern. Such studies will provide a basis to assess the contribution of fossil fuels to the natural cycling of these metals at the earth's surface. In addition, the results contribute to integrated, broader USGS efforts as proposed in the Geologic Division's science plan. Desired products for these integrated efforts are:

- Integrated life-cycle models of selected energy commodities,
- Total-cost assessments of the Nation's petroleum and coal,
- Models of geologic and geochemical processes that affect ecosystem functions,
- Summaries of the geology, geochemistry, and health effects of selected potentially toxic elements, mineral phases, and organic compounds
- Nationally consistent, regional-scale environmental geology and geochemistry databases and maps,
- Integrated geological, geochemical, and biological assessments of regions where contaminated sediments may accumulate.

SELECTED STUDY TOPICS

1. Baseline of metals in the environment. Fuel production, processing, and use can increase concentrations of trace metals in surrounding sediment, soil, and water. Determination of the amount and extent of increased metal contents cannot be assessed without knowledge of conditions pre-dating changes attributable to fossil fuels. Baseline studies of the chemical composition of soils, sediments, and water will provide a basis for such determinations. This effort is especially appropriate on Federal lands.

2. Bioavailability of energy-related metals. Metals in fossil fuels and their by-products enter the environment as solids, gases, or dissolved in water. The ability of organisms to accumulate these metals is a complex function of metal availability; chemical transformations in soil, sediment and water; and pathways of uptake and ingestion. Determination of the form, amount, and distribution of bioavailable metals from fossil fuels is necessary to estimate risk to organisms and ecosystems. Studies on this topic should work collaboratively with the Mineral Resources Program of the USGS to provide data to biologists and ecologists.

3. Geochemical aspects of by-product disposal. Fossil fuel production and use result in a variety of by-products such as coal cleaning residues, fly ash, flue gas desulfurization solids, water produced with oil and gas, and scales and sludges drived from produced water. Although portions of these products are used beneficially, most require disposal. The by-products may contain significant concentrations of metals. The amounts and ease of release of these metals should be evaluated as part of a geochemical characterization of the by-products. The ERP has specialists that are knowledgeable about the mineralogy and the composition of solid phases that

accumulate these trace metals, as well as having the capability to predict the reactivity of minerals. Results of analyses can be used to forecast the consequences of long-term interaction of the by-products with the near-surface environment.

4. Contribution of metals in fossil fuel to the overall metal cycle. Metals in fossil fuel, whether entering the environment by natural processes or human activity, change residence and form as a result of chemical and biological processes. Studies on this topic should be designed to reduce uncertainties in determining the effects of metals associated with fossil fuel on the natural cycling process. Results will be integrated with the three projects discussed above to develop unified models explaining the fate, transformations, and impact of metals released from fossil fuels.

Environmental Influences on the Future of Fossil Fuels.

Future production of national and global energy resources will be affected by environmental concerns. Individuals, industry, public policy makers, and regulators perceive these concerns differently. Therefore, objective scientific information is essential for establishing appropriate policies regarding domestic and foreign energy resources, for making wise decisions regarding Federal land use, and for maintaining a viable and environmentally sound domestic energy industry.

Studies on environmental influence will integrate geologic and geochemical data from ERP energy environmental studies with other scientific disciplines to address socially relevant issues. The goal of these partnerships is to produce comprehensive products such as:

1. Scenarios of the environmental impacts of future energy production and use,
2. An assessment of fossil fuel impact on human health,
3. Evaluation of socioeconomic constraints on fossil fuel production and use.
4. A survey of fossil fuel impact on fragile lands.

SELECTED STUDY TOPICS

1. Environmental impacts of energy mix. The goal of studies on this topic is to maintain an understanding of the national and global environmental impacts related to all geology based energy resources (conventional and non-conventional petroleum, coal, hydrates, geothermal energy, and uranium). An integrated summary of environmental aspects of energy production is of special use to regulators, developers of policy, and land-use planners, and also will serve as a key input for energy scenario planning.

2. Human health effects from fossil fuels. Fossil fuels exploitation can affect human health. Studies on this topic, in collaboration with researchers in the human health community, will provide data for evaluating the link between fossil fuels and human health. Relevant data include surveys of elements and compounds of a national and global health concern, and help to identify the pathways across the geo-environment/human interface.

3. Socioeconomic impact of fossil fuel. In the past, energy resource production and use was driven by relatively simple economics--cheapest energy was best. Now and in the future, a complex set of social and economic factors is controlling energy production and use. These factors include rapid growth in energy demand (especially in third world countries), concern about global climate change, clean air and water concerns, and development of alternative energy sources. The ERP needs to be aware of these factors and work with economists to assess the socioeconomic effect on future fossil fuel supplies and the energy mix.

4. Ecological disturbance from fossil fuel development and use. The disruption of ecosystems is a growing concern, especially with respect to fragile lands in urban areas, coastal zones, and other regions of national importance. Fuel production and use variably contribute to these disruptions by changes in land use and alteration of the natural fluxes of sediments, compounds and elements. These fluxes can be placed in the context of natural geologic (e.g. sedimentation and erosion) and geochemical (e.g. metal fluxes and air composition) conditions. Studies on this topic will integrate information from other USGS projects and from ecologists to provide a perspective on how energy-related fluxes into the environment impact ecosystems.

ENERGY RESOURCES PROGRAM ENVIRONMENTAL STUDIES—FY99

The ERP currently funds several environmental research studies that will be ongoing in FY2000 or may be revisited in future funding cycles. Included at the end of this report are contributions by ERP researchers summarizing these studies in terms of criteria developed to assess ERP environmental research topics/studies (table 1).

Table 1. Criteria developed to assess Energy Resources Program environmental research topic/studies.

Scale of concern	Impact on societal decisions
Federal/DOI role	Who cares now?
Energy Resourses Program role	Role of solid earth science
Resources available ($, FTE, expertise)	Research vs. data compilation
Potential for collaboration	Knowledge to reduce uncertainty

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PETROLEUM SEEP STUDY

by R.G. Stanley

SCALE OF CONCERN.

Naturally occurring seeps of oil and gas are found in hydrocarbon provinces throughout the world in both terrestrial and marine settings. Natural seeps contribute an unknown but noticeable and possibly significant amount of petroleum pollution into surface environments, including streams, oceans, and the atmosphere. Oil derived from natural seeps can be confused with the residues of oil products accidentally or deliberately spilled by human activities; therefore, there is a need to accurately distinguish spill residues from natural residues so that any liability is assigned properly to those responsible for the spill. Seeps of natural gas add methane (a more potent greenhouse gas than carbon dioxide) to the atmosphere, and must be evaluated as part of any effort to limit the total greenhouse gas burden of the atmosphere. Because oceanic oil seeps and spills and greenhouse gas emissions ignore political boundaries and can have impacts that are both devastating and costly, they are of broad national and international concern.

FEDERAL/DOI ROLE.

Many oil and gas seeps occur on Federal lands, in the oceans, and in areas of mixed state and local jurisdictions. As a Federal agency, the DOI can reasonably and efficiently work on problems that cross local and state jurisdictional boundaries. Furthermore, the Department of the Interior can support Federal and state environmental policing agencies (e.g., the U.S. Coast Guard and the California Division of Fish and Game) by providing research support in identifying primary sources of spilled oils and in developing new and improved chemical parameters for correlation purposes.

ENERGY RESOURCES PROGRAM ROLE.

Among other things, the Energy Program is responsible for providing up-to-date and comprehensive analysis of oil and gas resource information that facilitates land use and environmental decisionmaking. Research on hydrocarbon seeps clearly falls within the scope of Energy Program duties.

RESOURCES AVAILABLE (FUNDING, STAFFING, EXPERTISE).

The USGS staff includes many specialists in the fields of petroleum geology, regional geology, marine geology and geophysics, organic geochemistry, and fluid flow modeling. Many of these individuals already have much experience in working with oil and gas seeps. In addition, the USGS currently supports organic geochemical laboratories in Denver and Menlo Park with experienced staff and state-of-the-art equipment and instruments for analyzing hydrocarbons from seeps, spills, and producing fields.

POTENTIAL FOR COLLABORATION.

The opportunities for collaboration are high among many state, local, and Federal agencies that are concerned about potential contaminants, including both anthropogenic and natural sources of oil and gas. These agencies need accurate information on the locations, geochemistry, volume, geologic settings, and potential impacts of seeps. In

California, for example, there is potential for collaboration with concerned agencies such as the U.S. Coast Guard, the Environmental Protection Agency, and the California Division of Fish and Game. Within the USGS, there are opportunities for collaboration between the Energy Resources Program, Coastal and Marine Geology Program, and the Water Resources Division. Other potential collaborators include Federal agencies that administer lands and offshore areas with hydrocarbon seeps (including the National Park Service, U.S. Air Force, U.S. Army, Bureau of Land Management, U.S. Forest Service, and Minerals Management Service); local governments and water agencies; and researchers at various academic institutions.

IMPACT ON SOCIETAL DECISIONS.
Comprehensive baseline studies of the locations, geochemical compositions, and geologic settings of hydrocarbon seeps will provide relevant databases upon which societal decisions can be confidently supported. In turn, these databases will soon be large enough to help determine whether a given oil slick on the ocean was derived from a natural seep, or, alternatively, was spilled from a ship or leaky pipeline. Certain seeps may have unique chemical signatures, so in some cases it may be possible to trace oil derived from such a seep to a unique point source. The question of natural vs. anthropogenic sources is of particular importance in the Los Angeles, Santa Barbara-Ventura, Santa Maria, Santa Cruz-Monterey, and San Francisco Bay areas, where natural hydrocarbon seeps are present, population density is high, and offshore Pacific Ocean tanker and petroleum production activities take place. Seep databases also might impact societal decisions regarding petroleum exploration in marine sanctuaries and provide guidelines for establishing new sanctuaries.

WHO CARES NOW?
Federal, state, and local governments and the public are concerned about oil and gas pollution in our environment; they want it cleaned up quickly and correctly, they want the sources of the hydrocarbon pollution to be identified, and they want the responsible person(s), if any, held accountable.

ROLE OF SOLID-EARTH SCIENCE.
The understanding of seep occurrence requires both geology and petroleum geochemistry, disciplines well established in the solid-earth sciences. The USGS staff currently includes many regional experts and some world-class experts in these fields.

RESEARCH TOPIC VS. DATA COMPILATION.
Studies of hydrocarbon seeps require new research in the fields of geology and organic geochemistry (see following section). Data compilation is also needed to (1) create and continually update digital maps and databases of seep locations and characteristics, and (2) create geochemical databases that include the large chemical data set generated from hundreds of analyses of produced crude oils, seep oils, and hydrocarbon source rocks.

KNOWLEDGE TO REDUCE UNCERTAINTY.
Important unanswered questions that can be addressed by current scientific capabilities include the following.

- For any given seep, why are hydrocarbons leaking out of the earth at that particular spot? From what source rocks were the hydrocarbons derived, and what pathways did the hydrocarbons follow from the source rocks to the surface? Can seeps at the surface be correlated with subsurface accumulations of oil and gas?
- What is the volume per unit time of hydrocarbons released by natural seeps? How has this flux changed over time?
- What is the ultimate destination of hydrocarbons from seeps and what is the impact of these hydrocarbons on biological, chemical, and physical systems in the natural environment?
- What changes take place during weathering of crude oil, and how do these changes affect the reliability of oil characterization and correlation with other oils and with source rocks?
- What geochemical criteria are most reliable for use in discriminating natural seep oils from accidental spills caused by human activities such as extraction and transportation of petroleum? Are these criteria reliable when both substances are found in the same region and both are from common sources?
- How do oil and gas seeps in terrestrial environments affect the quality of surface and ground water?
- Can gases derived from natural sources be distinguished from those released by human activities? Can we quantify the impacts of gas from natural seeps on atmospheric hydrocarbon pollution?

PRODUCED WATER STUDIES

By George N. Breit

INTRODUCTION.

Water is a component of all petroleum reservoirs. During oil and gas production some water is brought to the surface where it must be properly handled to minimize environmental impact. This water varies greatly in composition but commonly contains dissolved salts, hydrocarbons, trace metals, and radionuclides, which render it unacceptable for uses other than enhanced petroleum recovery. Annual produced water production in the United States is roughly estimated to be 25 billion barrels/year. This approximates an average water-to-oil ratio of 10:1. As producing fields age, the proportion of water brought to the surface increases; some domestic fields presently have a water:oil ratio of 100:1. The amount and composition of produced water is a complex function of geology, hydrology and production engineering. Most of this water is re-injected to maintain reservoir pressure and to enhance the recovery of petroleum. Currently about 35 percent of water produced with oil and gas within the continental U.S. requires disposal. Most is injected into the subsurface, a substantial portion is evaporated in disposal ponds, and a small percentage is discharged into surface streams.

Prior to properly recognizing the adverse impact of some produced water on the environment, disposal of this water was by the most economic method available. Historical methods included discharge into surface streams, storage in unlined impoundments, disposal in poorly maintained injection wells, and simply running the water over the ground. Impacts of these past practices are apparent in salt scars visible at the surface, contamination of soil and surface water, and plumes of saline water that affect groundwater supplies.

SCALE OF CONCERN.

Oil companies, land management agencies, landowners, developers, state and federal regulators, and environmental groups are all interested in aspects of the produced water issue. Oil companies are interested in understanding the amount and composition of water likely to be produced in developing areas so their production designs include the appropriate water handling capacity. Old production platforms along the Gulf Coast cannot support larger water separation units and must be shut in. High contents of potentially toxic compounds in offshore produced water have rendered some resources unattractive to developers. Identifying and using injection horizons for produced water disposal near coal-bed methane resources are an important consideration in permitting and development. In a survey of major concerns by marginal well operators in 1998, produced water was listed after only oil and gas pricing. Land managers require knowledge of whether a proposed oil and gas development includes reasonable capacity for handling the water in an environmentally acceptable manner.

Regulators and environmental groups express concern for the salts, BTEX (benzene, toluene ethylbenzene and xylene), trace metals, and NORM (naturally occurring radioactive material) contained in produced water and how they may impact sensitive

areas and aquifers. The total number of wells drilled in the United States for the purpose of petroleum production is estimated to be 2.4 million in 36 states. Only about 880,000 are still in production. Depending on the plugging practices, these wells may remain as conduits to the surface and shallow aquifers. In 1986, the U.S. Environmental Protection Agency (EPA) summarized a survey of states to determine the sources of groundwater pollution; 22 states identified oil and gas brine pits as a significant source of pollution. Two of the states identified brine pits as the primary source of groundwater pollution.

FEDERAL/DOI ROLE.

Federal land managers are seeking knowledge and expertise by which to evaluate produced water for permitting develoments, environmental impact statements and potential risks to other resources they manage. The legacy of past and some continuing practices of produced water disposal continue to degrade land and water managed by U.S. agencies--Forest Service (FS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA) and National Park Service (NPS). Contamination of drinking water and agricultural lands is evident in several states. These federal agencies have a need to access information and expertise to aid in decision making, remediation, and restoration.

ENERGY RESOURCES PROGRAM ROLE.

Understanding the amount and composition of water produced from a reservoir can advance knowledge of the flow dynamics, origin, and geologic controls on petroleum production. Water can render a resource uneconomic, thus it is a factor to be considered in resource assessments. Databases develped within ERP can be used to address these issues in certain areas, but expertise on the quantity and quality of produced oil-field water is needed on a national level.

RESOURCES AVIALABLE (FUNDING, STAFFING, EXPERTISE).

The USGS maintains capabilities appropriate for the study of produced water. The Energy Program maintains expertise and information on petroleum geology, reservoir characteristics, fluid flow, petroleum production databases, petroleum engineering, analytical chemistry and geochemistry that is essential for the evaluation of ecosystem impacts by Water Resources Division (WRD) and Biological Resource Division (BRD) scientists.

POTENTIAL FOR COLLABORATION.

Potential collaborators range from federal and state agencies to academic consortia and petroleum producers. Within the USGS, several divisions support investigations related to produced water. WRD, for example, has had, and is continuing investigations examining the impact of produced water on the quality of surface and ground water in several states. Federal land and resource managers in BLM, BIA, NPS, FS, and Fish and Wildlife Service deal with issues associated with current and past petroleum production and the permitting of new developments. State agencies that oversee oil and gas production have solicited advice and collaboration in dealing with produced water issues. Petroleum producers and their trade organizations and contractors have sought information on produced water and knowledge on the geologic conditions and processes that affect water composition.

IMPACT ON SOCIETAL DECISIONS.

The permitting of petroleum resource development and the remediation of sites impacted by produced water are two areas in which additional information on produced water will aid decision-making processes. The amount and composition of water likely to be produced, how it will be handled, and the options for disposal are a necessary part of a petroleum resource development plan. Nonetheless, the information available is commonly incomplete. Federal land managers need information and expert advice by which to judge the completeness of development plans and the potential affects on other resources. Presently the Nation expends large resources in the clean-up of contaminated sites. Some of these clean-up actions are related to contamination from salts, NORM, and hydrocarbons transported in produced water. Comprehensive information on the fate of contaminants from produced water is generally lacking, which challenges the reliable assessment of environmental risk. Incomplete knowledge may result in overly stringent clean-up requirements or no action at sites of importance.

WHO CARES NOW?

Federal and state agencies, land owners, and petroleum producers have varying degrees of concern regarding produced water. EPA continues to express concern regarding the need to collect more quantitative and comprehensive information on produced water and its fate during disposal. Property owners express concern over the impact of produced water discharged into surface drainages and stored in impoundments. Petroleum producers seek information and understanding of the impact of water on production operations and resource development.

ROLE OF SOLID-EARTH SCIENCE.

Water produced with oil and gas is a product of fluid movement through and interaction with rocks. Developing a comprehensive understanding of the characteristics of water associated with a petroleum resource requires application of geology, sedimentary petrology, hydrology, and geochemistry.

DATA COMPILATION vs RESEARCH EFFORT.

Both data compilation and research are appropriate for investigations of water produced with oil and gas, but only limited systematic compilations of data on produced water are currently available. Numerous academic and industry investigations have tabulated information on some compositional characteristics of produced water, but these are not readily accessible except through time-consuming literature search. The U.S. Bureau of Mines (now Department of Energy) at Bartlesville, OK, compiled 77,000 records describing the composition of produced water, which is currently being edited by the USGS to increase of the reliability of the contained information. Data on the amounts of water produced are routinely collected by some states. Portions of this information are tabulated by Petroleum Information, Inc. in its production files, which are not readily compiled to produce systematic overviews of the information.

Fundamental understanding of the controls on produced water composition, its implications for resource development and environmental impact require focused research efforts. Continued geologic, geochemical and geophysical studies are needed to

determine the amount, transport and fate of contaminants contained in produced water in the near surface environment. This approach is also needed to verify the suitability of existing knowledge of biodegradation and other natural processes to accurately forecast the fate of contaminants contained in produced water.

KNOWLEDGE TO REDUCE UNCERTAINTY.

Important areas of study regarding produced water that can be approached through application of multidisciplinary scientific expertise include:

- systematic analysis of trends in the amount of water produced as a function of geologic characteristics of the reservoir;
- method development to apply water data toward understanding the geologic heterogeneity that affects development of petroleum reservoirs;
- investigation of controls on the composition of produced water among and within basins, including NORM and trace metals;
- determination of the extent and fate of contaminants that entered the surface environment by improper disposal of produced water and solids precipitated from that water.

COAL QUALITY AND COAL UTILIZATION STUDIES

by R. B. Finkelman

SCALE OF CONCERN.

Concern about the environmental impact of coal and coal use covers the spectrum from local problems to regional, national, international, and global issues. Emissions from coal-burning electrical generating utilities drift across national boundaries in North America and Europe, deteriorating visibility and denuding forests. Residential use of coal has caused widespread severe health problems in developing countries. The World Resources Institute estimates that as many as 3.5 billion people rely on traditional fuels for cooking and heating. The World Bank estimates that between 400 million and 700 million woman and children are exposed to severe air pollution, generally from cooking fires; a substantial proportion of these people rely on coal. The particulates, metals, gases (such as SO_x), and organic compounds (such as polycyclic aromatic compounds: PAC) can cause serious respiratory problems and toxic reactions. Leaching of PACs from lignite aquifers may cause or contribute to Balkan Endemic Nephropathy, a degenerative kidney disease that may be responsible for more than 100,000 deaths in the Balkans in a 30-year period.

FEDERAL/DOI ROLE.

The national, international, and global nature of the environmental impacts of coal clearly requires a federal oversight role. Among the national environmental problems attributed to coal combustion is the deterioration of air quality and visibility in national parks such as the Grand Canyon and Big Bend. DOI's responsibility as the steward of Federal lands and national parks requires that it protect these national treasures to ensure that future generations enjoy their grandeur. In the east, oxidized pyrite from active and abandoned coal mines produces acidic waters that affect the fauna, flora and aesthetics of streams flowing through Federal lands. Moreover, much of the Nation's coal resources are on Federal lands in western states. Ultimately, DOI has the responsibility for ensuring that these energy resources are used in an environmentally compatible manner. The reliable, objective coal quality information generated by the USGS can be used to determine the true environmental impacts of coal use. These data provide an important knowledge base that can help policymakers reach informed decisions.

ENERGY RESOURCES PROGRAM ROLE.

The Energy Resources Program has played a productive and highly regarded role in developing and disseminating information on the composition (quality) of coal. This information can be, and has been, used to assess the potential environmental and human health impacts of coal use. The Energy Resources Coal Quality databases (domestic and international) are unique and highly valuable products. The domestic coal quality database was used by the U.S. Environmental Protection Agency and by industry and others to address several key issues raised by the 1990 Amendments to the Clean Air Act. Legislation recently submitted in both the Senate and the House would require utilities to use the USGS coal quality database to establish their baseline emissions of mercury. The

analytical protocols (chemistry, modes of occurrence) developed by the Energy Resourses Program have achieved worldwide recognition.

RESOUCES AVAILABLE (FUNDING, STAFFING, EXPERTISE).
The USGS staff includes many experts in coal geology, chemistry, geochemistry, and petrography, and the agency's coal analytical facility in Denver Colorado is highly regarded. The coal quality databases that have been created and maintained by the Program are considered by many to be the standard.

POTENTIAL FOR COLLABORATION.
With regard to studies bearing on the impacts of coal and coal use on air and water quality, land use decisions, and industrial and domestic health issues, the USGS is currently interacting with 21 state agencies and about 30 countries in acquiring coal samples for analysis and inclusion in coal quality databases. Collaboration, and in some cases financial support, is being received from a number of other Federal agencies (including the Department of Energy, Environmental Protection Agency, Department of Defense, Armed Forces Institute of Pathology, and the National Cancer Institute), as well as private organizations (including the Electric Power Research Institute, CQ Inc., CONSOL, numerous coal companies and electric generating utilities) and universities (for example, Pennsylvania State University and the University of North Dakota).

IMPACT ON CURRENT SOCIETAL DECISIONS.
When the U.S. Congress passed the 1990 Clean Air Act amendments, worldwide attention was focused on the potential environmental and human health problems that could be caused by the emission of hazardous air pollutants from coal-burning power plants. The U.S. Environmental Protection Agency, therefore, sought reliable, comprehensive coal quality information to help assess the potential environmental and human heath impacts of these substances that might arise from coal use. The USGS COALQUAL database was selected to help address this issue. Since that time, policy makers in federal and state governments have faced many decisions concerning emissions of toxic components from coal combustion or combustion byproducts, decisions that could benefit from coal quality data generated by the USGS. Many recent coal quality related issues have been identified. Should emissions of mercury from coal-burning power plants be reduced? How can CO_2, SO_x, and NO_x emissions be further reduced? What is the role of minerals in causing or exacerbating coal miners respiratory problems? What proportion of the pollution in the Big Bend National Park is due to coal combustion from Mexico, Texas, or other sources? How much arsenic in surface waters and sediments in Alabama is due to weathering of coal containing arsenic-bearing pyrite?

Concerns about the environmental and health impacts of coal use are not limited to the United States. Environmental and human health problems attributed to coal use occur in Czechoslovakia, China, India, Ukraine, Russia, and elsewhere. The social cost of these problems is enormous and will continue to grow, especially in developing countries where low quality coal is used in boilers that lack or have limited pollution control systems. Use of coal for domestic cooking and heating in these countries poses a particular hazard to women and children who are exposed to the emissions on a daily

basis. Developing reliable information on this situation can aid in formulating appropriate foreign policy decisions.

KNOWLEDGE NEEDED TO REDUCE UNCERTAINTY.

Clearly, environmental and health problems create complex economic and social ills that will require carefully considered, multidisciplinary solutions. Reliable, comprehensive, and readily available coal quality data can help decision-makers to better assess the risks and limit the possible environmental degradation and impact on health. Additional information is needed to achieve this goal, including:

- Quantification of the modes of occurrence of elements in coal.
- Insights into the behavior of elements during coal cleaning, combustion, and leaching.
- Forms of elements in coal combustion byproducts (fly ash, bottom ash, etc.).
- Assessing the contribution of major coal-burning countries to global pollution.

COAL MINE DRAINAGE STUDIES

by Eleanora I. Robbins and C. Blaine Cecil

SCALE OF CONCERN.

Coal has been mined in the eastern United States for almost 300 years. Current surface mining is regulated by state or federal agencies, but prior to the Surface Mining Control and Reclamation Act of 1977, mining was not regulated. As a consequence, many states were left with major, costly environmental problems caused by historic coal mining. The U.S. Geological Survey (USGS) and other federal agencies have been working to understand the causes of and solutions to some of these environmental problems--coal mine drainage is one such problem.

When pyrite in coal and its surrounding rocks (coal-bearing strata)[1] is oxidized in the presence of oxygen, water, and bacteria, it releases iron, sulfate, and hydrogen ions, along with any trace elements that are present within the pyrite. Acid mine drainage (AMD) is the result of this oxidation process. Some residual components from present or past mining operations that are not acidic also contribute to environmental problems; therefore, the more general term of coal mine drainage (CMD) is more descriptive than AMD.

Coal Mine Drainage may issue from both surface and deep mines. Deep-mine discharge occurs from diverse sources: along fractures, from abandoned mine shafts, from seeps that are fed by pools of water filling old mines, and from boreholes drilled to relieve water pressure in mine pools. In some cases, pressures are so great that there are spectacular blowouts and landslides. Regulatory agencies need data to determine where water quality is impacted adversely from past and present mining, and to predict where water might be polluted by future mining operations.

FEDERAL/DOI ROLE.

Federal agencies that regulate or otherwise oversee CMD issues are in different departments. In DOI, agencies having regulatory functions are: Bureau of Land Management (BLM), Bureau of Reclamation (BR), Fish and Wildlife Service (FWS), and Office of Surface Mining and Reclamation (OSMRE). Other federal regulatory agencies are: Army Core of Engineers (COE), Environmental Protection Agency (EPA), Forest Service, and National Resources Conservation Service. Many of these agencies support at least a small amount of research into mining practices, CMD, mitigation, and remediation. The USGS is divided into four divisions, each of which provides objective scientific data for these regulatory agencies. The Geologic Division (GD) characterizes coal and coal-bearing strata; the Water Resources Division (WRD) studies water quality and discharge rates; the Biological Resources Division (BRD) studies the flora and fauna

[1] Coal is not the only lithology impacted during mining. Strata overlying and underlying the coal beds, as well as the partings within beds, are usually disturbed during mining and their chemistry plays a role in drainage issues.

upstream and downstream from mining; and the National Mapping Division (NMD) focuses on providing the physiographic framework for the scientific data.

ENERGY RESOURCES PROGRAM ROLE.
The Energy Resourses Program (ERP) funds most of the Geologic Division's work related to coal characteristics and coal mine drainage. Research is being conducted on litho-stratigraphic variations, microbial and spectral reflectance techniques, rock chemistry and mineralogy, and geologic framework studies. Data from these studies will be used to predict the relationship between mine drainage and variables controlling the composition of the coal-bearing strata such as paleovegetation, paleoclimate, paleo-sea level variations, paleotectonics, and sediment geochemistry.

Present day climate is an important factor affecting the location of CMD problems, especially AMD. Coal beds in the western US may contain pyrite, but because of aridity and the lack of perennial streams in the region, AMD is not usually a concern. This is particularly true in the Powder River Basin, where coals contain only minor amounts of pyrite. The lignitic strata of the Gulf Coast basin also contain small amounts of pyrite. Coal beds in the Illinois Basin may have unusually high pyrite and trace-metal contents, but these beds are not presently being mined. In contrast, in the Appalachian basin where coal has been extensively mined, ground water, surface water, and rainfall are sufficiently abundant to create continuous and visible problems with AMD. For these reasons, ERP is currently concentrating its CMD studies in the Appalachian basin.

RESOURCES AVAILABLE (FUNDING, STAFFING, EXPERTISE).
As indicated in earlier sections, laboratory facilities and experienced personnel are available within the USGS to conduct comprehensive CMD studies.

POTENTIAL FOR COLLABORATION.
The problems created by mine drainage are so large and so widespread that collaborative efforts among the USGS, federal regulatory and oversight agencies, as well as state agencies are required to understand and control the mine drainage system. Studies are needed especially to identify the linkages in the many interacting geochemical processes and to determine countermeasures. A case in point involves a study the manganese cycle to (1) identify the source of Mn in the coal and overburden, (2) quantify the mobility of Mn in ground and surface water, (3) design methods to sequester Mn at the mining site, and (4) determine the effects of Mn on the insects, molluscs, and fish communities in nearby streams.

IMPACT ON SOCIETAL DECISIONS.
At the present time, CMD affects thousands of miles of streams, property values, drinking water, habitat, the mining industry (plus the entire economic structure it supports), and the federal and state regulatory agencies. Energy markets determine where and how coal will be mined and used, and a variety of concerns affect those markets. Communities are forming watershed associations and initiating river improvement projects in response to potential decrease of property values due to AMD. Awareness is growing with regards to the AMD effects on sources and supplies of clean drinking

water. Concerns are growing that a major discharge into the Ohio River could occur if currently isolated AMD pools begin to connect as abandoned mines are filled and barriers collapse. The present and future research by the USGS and others on CMD will be of use to those struggling to address these societal issues, particularly in the Appalachian basin.

WHO CARES NOW?

Federal, state, and local governments and the public are all concerned about mine drainage and the environment. Many of the drainage problems stem from long abandoned mines that have no accountable party for mitigation funding. Actions are being undertaken at each governmental level and by industry, because the problems are immediate and some of them can be mitigated or remediated with essential research studies and the timely application of their results.

ROLE OF SOLID-EARTH SCIENCE.

Coal and coal-bearing strata are the ultimate source of any CMD problem, thus greater understanding of the depositional and paleo-environmental history of the coal-bearing strata is needed for prediction, mitigation, and remediation. The USGS staff includes many specialists in the fields needed to pursue studies bearing on the interactions between processes that create the CMD problems, and offer possible means for mitigation.

RESEARCH TOPIC VERSUS DATA COMPILATION.

State and federal agencies are leading the efforts to compile data from which generalizations can be drawn. These include locating sites of coal mine discharge, supplying geochemical data, and providing state and quadrangle maps. The USGS has the capability of placing these large local data collections into a regional understanding so that the data can be more readily accessible for further research.

KNOWLEDGE TO REDUCE UNCERTAINTY.

Important unanswered questions that are being addressed in part by current USGS investigations include the following:

- Why are there high sulfur coal beds that do not produce acid?
- Are there particular sequences of strata that naturally mitigate against AMD?
- Is the pyrite in the roof rocks rather than in the coal the major cause of AMD?
- Are there minerals other than pyrite that are releasing metals?
- Does the original matrix of the coal and overlying organic-rich shale change the oxidation potential of the enclosed pyrite?
- Can lithological sequences be classified as to whether or not they will create acidic runoff if disturbed?
- Can generalizations about the coal depositional environment be used to predict which coal beds will produce acid?
- Do time-equivalent coal beds behave the same and produce the same quantities of acid?
- Will all mines that produce AMD eventually stop generating acid? If so, can the end-point be predicted?

- Are statistical methods available to help determine the number of analyses that needed to to answer these and other questions?
- Are there data compilations of historical mine-pool blowouts that can be used to predict the sites of future blowouts?

Appendix

Table 1. Scoring, by region, of research topics discussed. [Each workshop participant was given 5 votes to distribute among the different research topics identified according to which they felt were most important. Topics identified vary among regions.]

Menlo Park CA	Score	Reston VA	Score	Denver CO	Score
Baselines	21	Natural Occurrence of Fossil Fuel	18	Waste Disposal and Use	14
Water Quality	16	Geological Input to Environmental Policy/Regulations	17	Biologic Impact	12
Assessment of by-products	10	Extraction/Production of Fossil Fuel	16	Water Cycle	9
Physical Hazards	6	Use of Fossil Fuel	14	Air Quality	7
Future Energy Needs	6	Element/compound in Fossil Fuel	11	Land Quality/Use	7
Human health	4	Carbon Cycle	8	Carbon Cycle	5
Socio-economic Impacts	4	Byproducts of Fossil Fuel	3	Greenhouse Gases	2
Climate Change	3	Human Health/Safety	3	Element/Compound Cycling	1
Land use-quality	2	Socio/economic Impacts of Fossil Fuel	3	Socio/Economic impacts of Fossil Fuel	1
Air Quality	1	Exploration of Fossil Fuel	1		
Greenhouse Gases	0	Storage of Fossil Fuel	1		58
CO_2	0	Processing of Fossil Fuel	0		
		Transportation of Fossil Fuel	0		
		Ecosystems	0		
	73		95		

Table 2. Environmental research topics in which ERP has a significant role. Shaded topics are those in which the USGS also has a significant role. [USGS significant role, indicates that the USGS is the lead U.S. government agency to address the research topic; ERP significant role, indicates that ERP is the lead program within the USGS to address the research topic. S, significant role; C, contributing role.]

Menlo Park CA	Reston VA	Denver CO
CO2 emissions under fuel-mix scenario (global)	Element cycling	Global fuel quality as it relates to air quality
Greenhouse (GH) gas emissions baseline (natural fluxes)	Baseline of geochemistry of fossil fuel (qual.,quant.,distri)	Produced water impact (C/S)
Hydrates as a source of GH gas (stability)	In situ processes affecting water quality	Resource-land exchange
Oil spills as they relate to water quality	Water as it relates to extraction/production	Removal of land during production
H_2O contamination as related to produced waters	Acid mine drainage	Quality & use of Fragile Lands (S for regional study)
Baseline/Background of oil & assoc. brine seeps	Mountain top removal	Energy component of element/compound cycling
Acid mine drainage	Characterizing coal clean products	CO_2 sequestration in carbon cycle
Assessment of by-products-temporally	Air quality as it relates to fossil fuel use	Geologic aspects of waste disposal
Assessment of by-products spatially	Water as it relates to by-products	Geochemical aspects of waste disposal
Quality of resources	Policy/Regs--fossil fuel characterization	CO_2 sequestration as waste disposal
Climate change as it relates to future energy mix	Policy/Regs--Fossil fuel availabilitly +cost	Bioavailability of toxins & compounds (S for regional study)
	Policy/Regs-scenario analysis	Ecological disturbance (S for regional study)
	Policy/Regs-Human Health	Endangered+threatened species (S for regional study)
	Impact of changing fossil fuel supply	Future supply of fossil fuel
	Impact of changing fossil fuel cost	
	Major modern carbon sinks	

Table 3. Grouping of topics identified in all workshops in which Energy Resourses Program (ERP) and the U.S. Geological Survey (USGS) have significant roles. [Cntr, USGS regional centers; M, Menlo Park, CA; D, Denver, CO; R, Reston VA; S, significant role; C, contributing role.]

Research Topic	Cntr	Studies	Remarks
Acid Mine Drainage	M,R		Denver, S for USGS and C for ERP
Global Fuel Mix Scenarios	M	CO_2 emissions under fuel-mix scenario-Global	
	M	Climate change as it relates to future energy mix	
	R	Policy/Regs--scenario analysis	
	R	Policy/Regs--fossil fuel availability + cost	
	R	Impact of changing fossil fuel supply	
	R	Impact of changing fossil fuel cost	
	D	Future supply of fossil fuel	
Baselines/Backgrounds	M	Oil and associated brine seeps	
	M	Greenhouse (GH) gas natural flux	
	R	In situ processes affecting water quality	
	R	In situ fossil fuel quality, quantity and distribution	Distribution relates to physical and chemical
	D	Bioavailability of toxins & componds	ERP role significant for regional study only
Cycle of element/compound within Energy Life cycle	M	Hydrates as a source of GH gas (stability)	
	R	Element cycling	
	R	Major modern carbon sinks	CO_2 sequestration?
	D	Energy component of element/compound cycling	
Produced waters	M	Contamination related to produced waters	
	R	Water as it relates to production/extraction	
	D	Produced water impact	ERP role S/C; C for USGS

Table 3. Continued.

Research Topic	Cntr	Studies	Remarks
Fossil Fuel By-products	M	Assessment of by-products- temporally	
	M	Assessment of by-products-spacially	
	R	Water as it relates to by-products	
	R	Air quality as it relates to fossil fuel use	
	D	Geologic aspects of waste disposal	
	D	Geochemical aspects of waste disposal	
	D	CO2 sequestration as waste disposal	
Fuel Quality	M	Quality of resources	
	R	Policy/Reg--fossil fuel characterization	This is part of implementation, not topic
	D	Global Fuel Quality as it relates to air quality	
Effect on Ecosystems & human Health	R	Policy/Regs--Human Health	This is part of implementation, not topic
	D	Ecological distribution	EPR role significant for regional study only
	D	Endangered+threatened species	EPR role significant for regional study only
	D	Resource land exchange	Land use issue
Oil spills	M	Oil spills as they relate to water quality	