

# NEW MEXICO'S ENERGY, PRESENT AND FUTURE

**Policy, Production, Economics,  
and the Environment**

**Brian S. Brister and L. Greer Price, Editors**

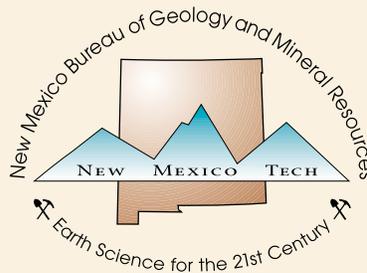
DECISION-MAKERS  
FIELD CONFERENCE 2002  
San Juan Basin



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New Mexico Bureau of Geology and Mineral Resources  
A Division of New Mexico Institute of Mining and Technology  
2002

**New Mexico's Energy, Present and Future: Policy, Production, Economics, and the Environment**

Brian S. Brister and L. Greer Price, Editors

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## Preface

This book was designed to accompany the second annual Decision-Maker's Field Conference in May 2002. The purpose of this year's conference is to provide the decision makers of New Mexico with an overview of the issues affecting the present and future of energy in New Mexico. Never has the topic of energy been more timely, uppermost in the minds of the American people and of those who shape policies that affect us all. New Mexico, with some of the most significant energy reserves in the lower forty-eight states, has been and will continue to be a major player in the energy future of this country. The focus of this guidebook is on the northwest portion of the state known as the San Juan Basin. This area for years has played a vital role in the energy business and overall economy of New Mexico. There is no question that the San Juan Basin will continue to play an important role in the foreseeable future, in spite of the ever-changing social, political, and technological structure of our society.

The broad topics represented by each of the five chapters were selected to provide a fundamental look at how energy is produced and made available in New Mexico. Each of the articles within those chapters was chosen to provide important background material, to provide a look at how things operate today, or to offer some insight into the promises and challenges that lie ahead. Fossil fuels remain the cornerstone of energy supply in the short and near term, and they must be managed effectively. Renewable/alternative energy resources (solar, wind, geothermal, biomass) have the potential to make significant contributions, as well, in meeting the long term needs of our state, the nation, and the world.

In the process of putting together the conference and the guidebook, we spoke with citizens, scientists, government regulators, and industry workers—all of whom recognized the advantages of improving our ability to be more efficient, practice conservation, and reduce our footprint on the environment at every step of the process, from production, processing, and generation, through distribution and consumption. There is no question that one of the challenges that lies before us is the need to balance our growing needs with the growing importance placed on the quality of our environment.

The articles were written by authors who are both knowledgeable in their field and capable of communi-

cating these complex issues to the public. The overall balance of the volume was determined in part by authors who were willing to write for us on a tight schedule. Within this limitation, we've tried to achieve a balance. We gratefully acknowledge the hard work of the authors and agencies who worked closely with us to bring this information to the public. We are grateful also to the many others—photographers, cartographers, designers, and so forth—who helped us make this book an effective tool.

We hope that the book will have a life and a value far beyond the three days of the conference. We intended it to serve as something of a reference, but it is in no way the final word. We see it, rather, as a good start. It was our overall intention to pose important questions rather than to provide definitive answers. We cannot frankly imagine a time when energy will not be a significant issue for all of us, in New Mexico and throughout the country. If this book is a small step in moving from discussion to some resolution of the many challenges that face us, then we will have achieved our goal.

-The Editors

# An Introduction from the State Geologist

Peter Scholle, *New Mexico Bureau of Geology and Mineral Resources*

**W**elcome to the second annual Decision-Makers Field Conference. This year we are focusing on New Mexico's energy resources and how they're used, today and in the future. The conference is organized by the New Mexico Bureau of Geology & Mineral Resources in conjunction with many partners, including several state and federal agencies, tribal governments, and private companies (listed in the front of this publication). We are grateful to those partners for their year-long support in planning, organizing, financing, and conducting this conference. We are equally grateful to the presenters who have prepared long and hard and, in many cases, traveled far in order to give you their insights into the complex energy issues that face this state.

The major rationale for these conferences is to offer information to legislators, government agency officials, and others in positions of influence within the state; to provide a hands-on look at how things work now; to investigate the scientific and technical constraints on resource discovery and exploitation; and to discuss possible scenarios for the future and what it would take to make them happen. Other purposes include fostering collaboration within the scientific community of the state, developing interactions between state agencies, introducing political leaders to scientists who can help to advise on future legislation, and producing a document (this volume) that can stand as a broadly understandable background piece for future discussions. The purpose of the conference is not to lobby for specific legislation. Participants have been asked to be as fair and impartial as possible, and we have taken great pains to produce a conference that provides a balance between competing points of view while retaining strong individual perspectives.

Over the next few days, we will deal with a range of topics associated with exploration and production of conventional fossil fuels, as well as issues associated with refining, transporting, and generating energy from these materials. We will explore ways to stimulate energy production (and thus increase state revenues) and examine some of the environmental consequences such strategies may pose. We will also take a look at realistic alternatives to conventional energy development. These are not black and white alternatives. Our energy future will almost certainly consist

of a mix of solutions, and the nature of the mix will be influenced by your decisions, and probably by decisions and actions that take place far from New Mexico. Let's briefly examine some of the larger issues of the coming energy debate.

The global community currently is wrestling with major energy-related problems: potential climate change and other environmental issues, political instability in the Middle East and its impact on oil supplies, and the frightening lack of security of international and domestic oil and gas supply and transport. The United States, as the world's largest single energy consumer, is in the process of formulating its own broad energy policy, the first serious effort at such a plan since the late 1970s. New Mexico will certainly be affected by such global and national policies (and it has substantial influence in the formulation of such policy, thanks to New Mexico's federal delegation). Within the context of broader energy legislation, however, New Mexico can forge its own policies and directions to a degree probably unmatched by any other state. We have a wide range of local options because we are blessed with a remarkable diversity of energy resources, both conventional and unconventional. New Mexico is fifth among all states in oil production (and fourth in proven oil reserves), second in natural gas production (second also in proven gas reserves), tenth in proven coal reserves (third in recoverable coal reserves from currently producing mines), second in total uranium reserves (and first in high-grade reserves), among the top three states in solar power potential (probably second only to Arizona; Fig. 1), has excellent wind power potential (especially in the High Plains areas of eastern New Mexico; Fig. 2), has substantial geothermal resources (especially in the area of relatively low-temperature resources), and excellent biomass generation potential (particularly given the state's extensive forests and feedlot/dairy operations). In addition, New Mexico is home to two national laboratories and several universities that conduct cutting-edge fossil-fuel and renewable-energy research.

Despite this broad spectrum of opportunities, New Mexico's energy options are not without difficulties. Intelligent use of our energy resources requires a detailed understanding of complex issues and careful

planning. Currently, both the state and the nation are largely dependent on fossil fuels. In New Mexico, petroleum and coal are not only the predominant “fuels of choice,” they are mainstays of our economy. Petroleum production alone accounts directly for 23,000 jobs along with 20% of the revenues in the state’s general fund and 95% of permanent fund income. Coal mining also supplies substantial revenues and more than 1,500 jobs at six mines and is now the state’s largest non-energy extractive industry in terms of product value (at \$591 million in 1998). Conventional fossil-fuel energy production thus will and must remain a substantial part of New Mexico’s energy mix far into the foreseeable future.

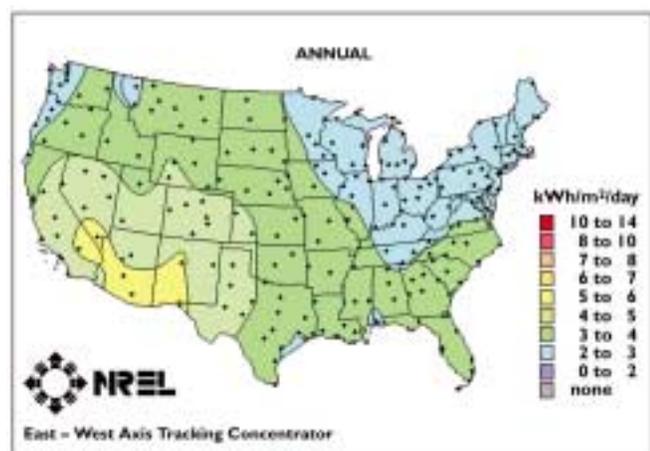


FIGURE 1 Average daily solar radiation per month.

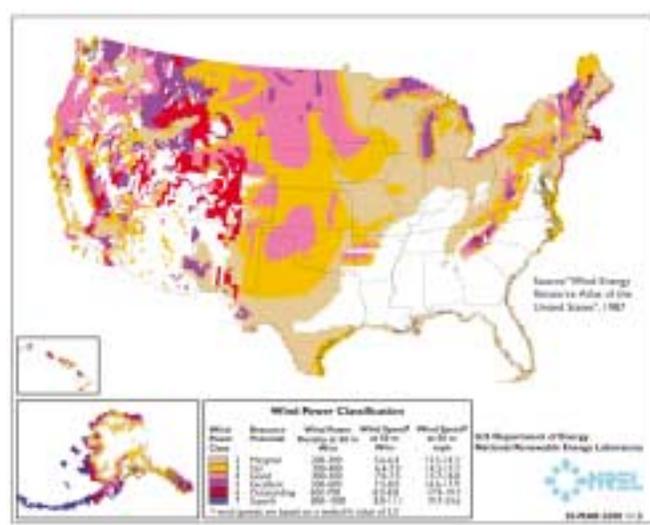


FIGURE 2 United States wind resource map.

At the same time, we must understand that fossil fuels are finite, nonrenewable resources. In the case of petroleum, most experts agree that we are irreversibly on the downhill side of the production curve, both as a nation and as a state. Figure 3 illustrates the national picture (using average daily production and consumption data). Petroleum production in the U. S. peaked in 1970 and has gradually declined since then to the point that current production is now barely above 1950 levels. That decline took place despite major advances in drilling technology (especially horizontal drilling), exploration methods (especially 3-D seismic imaging), and secondary/tertiary recovery techniques. Figure 3 also shows that U. S. petroleum consumption, unlike domestic production, has nearly quadrupled in the past 50 years (with the only substantial decline resulting from conservation measures instituted in the 5-year period following the Middle East oil crisis of 1976). As a result of the growing gap between domestic production and consumption, the United States now imports about 60% of the petroleum it consumes.

New Mexico’s petroleum production record is similar to that of the nation. Figures 4 and 5 show annual oil and natural gas production in New Mexico from 1924 onward. Oil production peaked in 1969 and has subsequently declined roughly to 1950 output levels. Natural gas supplies, on the other hand, continue to grow, and were boosted dramatically in the 1990s with the addition of coalbed methane output, which now accounts for nearly 25% of the state’s total natural gas production. The rest of the natural gas productivity increase comes less from the discovery of new fields than from the extraction of additional resources from prior discoveries. Although New Mexico’s gas production is at an all time high, natural gas is also a finite resource that must eventually peak and decline. Predictions of when the peak and decline will come vary substantially, but most envision at best a few decades at maximal production levels.

There are three observations that I would like to draw from these trends of petroleum production. First, the United States will not regain “energy independence” or much national security if it relies on oil and natural gas for its predominant energy supply. The decline in oil production, in particular, is unlikely to be reversed, regardless of the national policies we pursue, and it is difficult (or in some cases impossible) to provide adequate security for our extensive oil fields, refineries, and pipelines in this era of potential terrorism. However, if we wish to extend the life of

our oil- and gas-based economy, and we almost certainly do, we will need to provide opportunities for new and unconventional discoveries. That will entail allowing exploration in areas previously unexplored or under-explored, and those access decisions will undoubtedly be complicated by environmental concerns in many areas. In addition, we will probably need to provide incentives for the development of new technologies and the application of those technologies by the generally smaller companies that now dominate domestic petroleum exploration. If we value the energy independence and jobs provided by this industry, then we may need to share in the high costs of finding the “last drops of oil.”

Second, we should view the oil and gas deposits

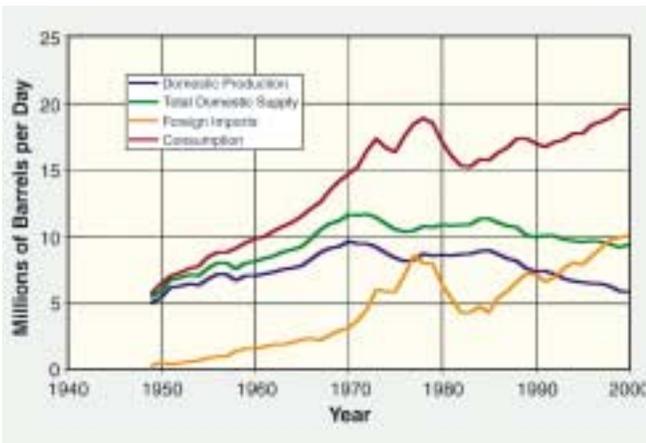


FIGURE 3 U.S. petroleum supply versus consumption.

that are still to be produced in New Mexico not simply as a resource to be exploited, but as a lifeline to help us through a transition to a different energy future. Oil, natural gas, and even the more extensive coal supplies will eventually be depleted, and we must be prepared for that day, with a mix of other energy sources: wind, solar, geothermal, and perhaps nuclear, all of which are available to New Mexicans. Energy conservation measures, including more fuel-efficient vehicles, better mass transit, and more energy-efficient homes, can extend the length of the transition period and decrease the amount of alternative energy capacity that must be created. Nonetheless, fossil fuels will remain very important even after a transition to renewables, especially to provide backup power at peak demand times or other times when renewables fail to generate sufficient power. Conservation can also allow us to save fossil “fuels” for non-fuel uses such as fertilizers and plastics (future generations no doubt will look

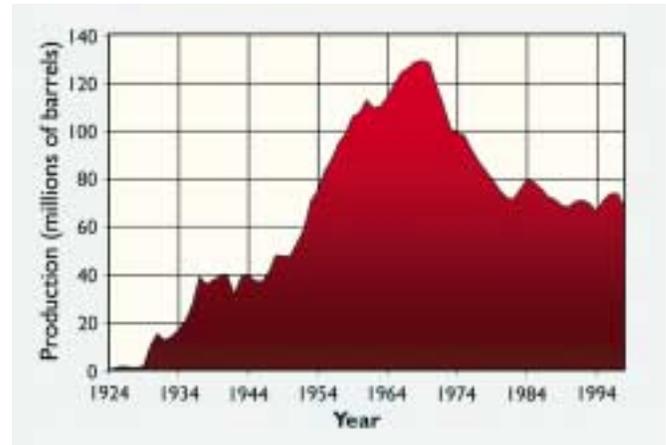


FIGURE 4 New Mexico's annual oil production, 1924-98.

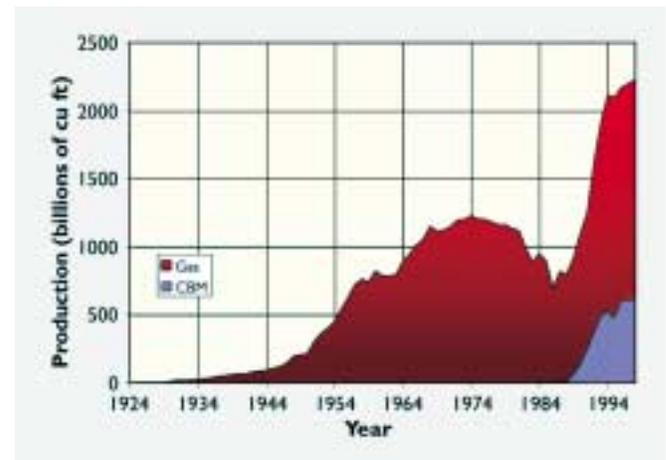


FIGURE 5 New Mexico's annual gas production 1924-98.

back with disbelief that we burned these precious materials simply to generate energy).

Third, it is important for us to recognize that the transition to a different energy future has already started. Look around! Small-scale solar applications abound, wind farms are being developed, and geothermally heated facilities are now a significant component of the economy in New Mexico's bootheel region. All three major American carmakers have announced that they will release hybrid energy or fuel cell cars within the next few years. And perhaps most significantly, the cost of generating power from solar and wind facilities is now quite close to being competitive with fossil-fuel-generated energy. This, combined with the environmental benefits of renewability, the lack of emissions, and the relative security of supply, means that

alternative energy is here to stay. Given its level of alternative energy potential and the quality of its energy researchers, New Mexico certainly could become a national leader in converting to more modern forms of energy generation. Indeed, it could also be a leader in manufacturing and marketing the technologies needed for the transition to the future. Whether it should and whether it will is up to you. The decisions you make, the priorities you establish, and the incentives or disincentives you put into place will determine if we move passively or aggressively into the future.

As you ponder these choices, I urge you to take a look at Denmark as a role model. This small nation, with a population of about five million and a land area only one seventh that of New Mexico's, has Europe's most robust economy while generating its energy through a mix of wind power, cogeneration at domestic waste incinerators, and conventional oil and natural gas. It has encouraged private investment for construction of wind facilities through tax incentives and by allowing investors to sell excess power back to the national grid. More importantly, this tiny nation now is a leader in wind energy research and produces more than 75% of the world's large power-generating wind turbines. It has turned a national need into a national resource through an interesting mix of vision, education, devotion to environmental principles, and aggressive manufacturing and marketing. By the way, it did this while maintaining a thriving petroleum industry—indeed, Denmark is now a net oil-exporting nation. There is nothing in this story, however, that New Mexico could not match!

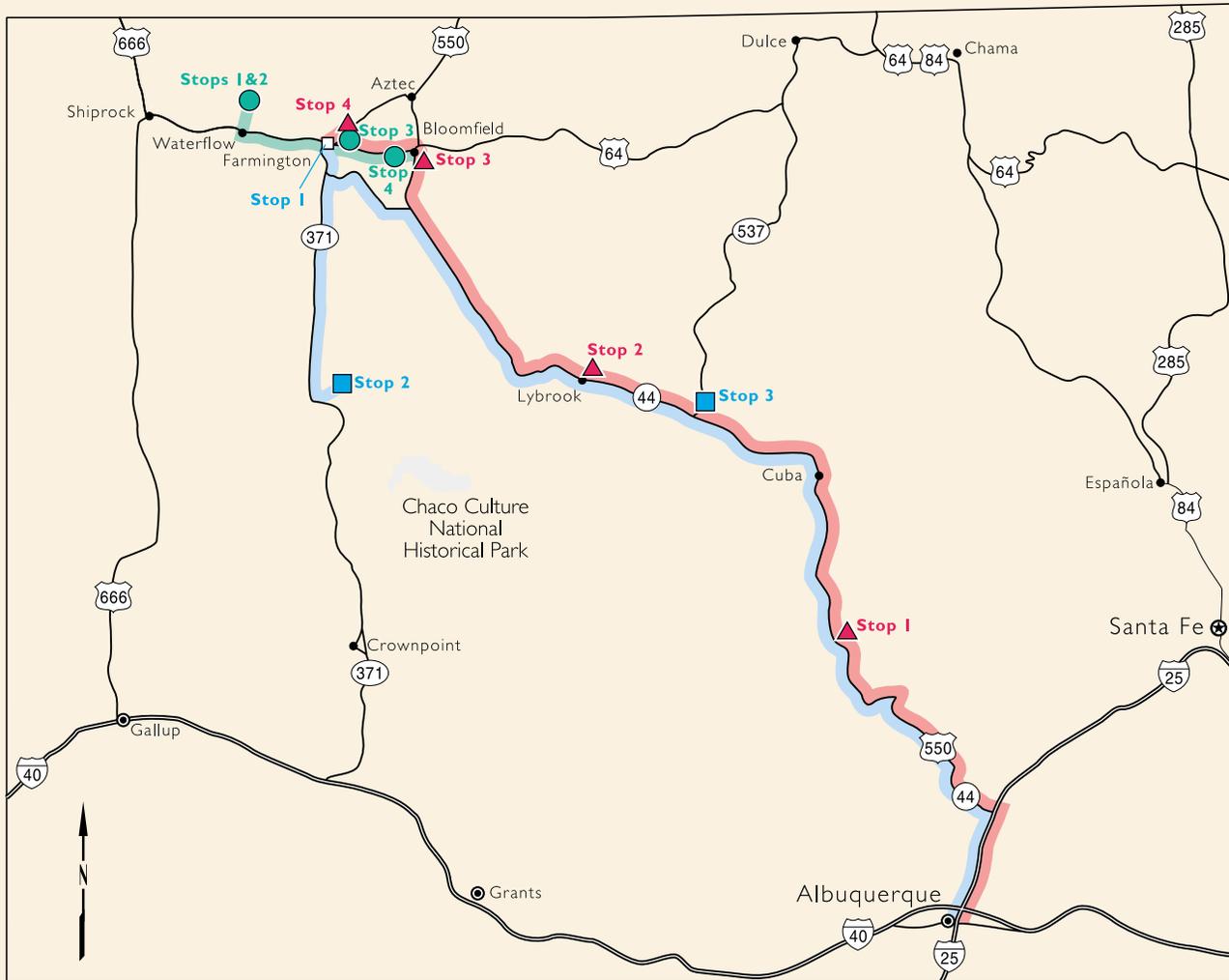
Clearly our work is cut out for us. I hope that this conference will supply you with the information, the concepts, and the contacts needed to make wise and informed decisions in coming years. Together we can achieve the needed vision, and hopefully an understanding of how to deal with the stresses that inevitably accompany such profound societal changes.

# THE FIELD CONFERENCE

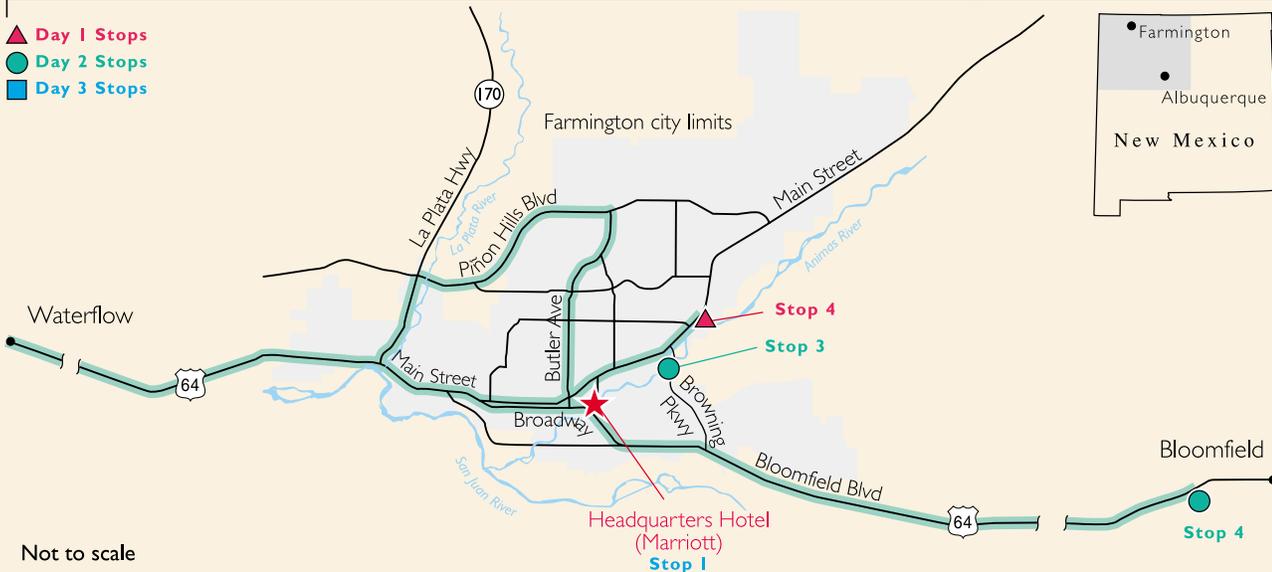
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San Juan Basin



# Field Conference Routes



- ▲ Day 1 Stops
- Day 2 Stops
- Day 3 Stops



Not to scale

New Mexicans enjoy abundant and relatively inexpensive fossil fuel energy resources in the form of coal, oil, and natural gas. Yet such resources are finite and have cost trade-offs in terms of environmental degradation and global security issues. New technologies are being developed to use these resources more efficiently, particularly in the form of fuel cells that harness electricity-producing chemical reactions and involve a variety of fuels derived from both fossil and biomass (derived from plants, animals, and bacteria) sources.

There is a growing niche for renewable energy resources that don't require fuel to generate power. Hydroelectric power generation is a long-established method of harnessing natural energy; this is currently our most important form of renewable electrical power. Although our arid climate limits the potential for hydroelectric power, New Mexico is well situated to take advantage of other renewable forms of energy, particularly wind power for commercial-scale applications. On a small scale, solar energy in particular can bring power and heat to otherwise underserved remote locations. Geothermal heating has gained a foothold in New Mexico for agricultural purposes. Several factors will make these energy sources commercially viable in New Mexico in the near future. These include a strong desire on the part of the public to reduce pollution, ongoing improvements in cost and functionality through continued research and development, and interest on the part of decision makers to find ways to stimulate the practical application of these energy resources.

This session focuses on recent progress in the development of renewable energy resources. It will conclude with a discussion of what decision makers might do to encourage implementation of these new technologies.

#### PRESENTATIONS

- Renewable Energy in New Mexico: Current Status and Future Outlook  
Chris Wentz,\* *Energy Conservation and Management, EMNRD*
- Indian Pueblo Cultural Center Photovoltaic Project  
Dave Melton,\* *Diversified Systems Manufacturing LLC*
- The Promise of Solar Energy  
Carl Bickford, *San Juan College*
- Practical Uses of New Mexico's Geothermal Resources  
James Witcher,\* *Southwest Technology Development Institute, New Mexico State University*
- Recent Advances in Fuel Cell Research  
Charryl Berger, *Los Alamos National Laboratory*
- Net Metering in New Mexico  
Patrick Scharff,\* *Public Service Company of New Mexico*
- Incentives for Stimulating Development of Renewable Resources  
Ben Luce,\* *New Mexico Solar Energy Association*

\* Indicates that the speaker is an author of a paper in this volume

## Wednesday Evening May 8, 2002

OPENING SESSION

### ADVANCES IN RENEWABLE ENERGY RESOURCES

*Marriott Courtyard Hotel, Albuquerque*



This 600-kilowatt wind turbine near Clovis is the only commercial wind turbine in New Mexico.

## Day 1 Thursday Morning May 9, 2002

### STOP 1 AN INTRODUCTION TO SAN JUAN BASIN ENERGY RESOURCES

*Holy Ghost Spring Overlook, Jemez Pueblo*

This stop overlooks Holy Ghost Spring on lands of the Jemez Pueblo, some 50 miles from Albuquerque on NM-550. From this vantage point, a 360° view provides the perfect setting for discussing the fundamental geology that influences the types and amounts of earth-based energy resources enriching this corner of New Mexico. Sparse dry-land vegetation dots the landscape, yet the tiny treed oasis of Holy Ghost Spring reminds us of the importance of the nearby Nacimiento Range and other highlands surrounding the San Juan Basin as the sources of recharge to the aquifers and waterways of the region. Water resources here and elsewhere in New Mexico are limited. This limits the industrial, agricultural, and other activities that depend upon a reliable and abundant water supply. Yet the very fact that water takes up residence in the warm earth provides geothermal resources that are being tapped on the Jemez Pueblo for heating purposes.

At the overlook, as at other sites around the margins of the San Juan Basin, rock formations tilt toward the basin center. These are the same rocks that contain oil, natural gas, and coal in the basin subsurface. Years of geologic study and insights gained through mapping, prospecting, and drilling have provided a thorough understanding of the reserve characteristics of the San Juan Basin. With careful planning, improved technology, and favorable economic conditions, the basin will continue to be developed as one of the nation's most important natural gas-producing basins, and New Mexico's export "cash cow," for decades to come. The potential for the San Juan Basin to provide long-term, coal-based electrical power to the Southwest is perhaps even greater.

#### PRESENTATIONS

- Orientation and Overview of San Juan Basin Geology  
Brian Brister,\* *New Mexico Bureau of Geology and Mineral Resources.*
- Oil & Gas Natural Resources  
Ron Broadhead,\* *New Mexico Bureau of Geology and Mineral Resources*
- Foreseeable Development of San Juan Basin Oil and Gas Reserves  
Tom Engler,\* *New Mexico Tech*
- Jemez Pueblo Geothermal Project  
James Witcher,\* *Southwest Technology Development Institute, New Mexico State University*
- Jemez Pueblo Energy Perspective  
*Jemez Pueblo Representative*

Lybrook, New Mexico, is on the southern edge of the main oil- and natural gas- producing part of the San Juan Basin, about 112 miles from Albuquerque on NM-550. As in many Rocky Mountain basins, the basin margin fields tend to be oil prone, whereas the deep basin fields tend to produce natural gas. Classic oil field pumpjacks slowly bob up and down around Lybrook, extracting the last remains of the oil from reservoirs long past peak production. Yet not far to the north, northwest, and northeast, the San Juan Basin is just reaching its prime in terms of natural gas production.

Oil and gas fields require substantial infrastructure before the product can reach a market. As a field is developed, there is an increasing demand for well sites, processing facilities, and road and pipeline right-of-ways. Unlike oil, natural gas cannot be trucked; it depends upon a system of pipelines for transport. The history of development of the extensive gas reserves in the San Juan Basin is closely tied to the “take-away” capacity of pipelines to move the gas out of the basin. “Booms” in development take place as take-away capacity expands with new pipeline construction, generally in response to a greater demand in major markets like California.

The plumbing system of natural gas infrastructure is technologically complex. Pressurization is required to move the gas. Safety and market standards require that the gas be a certain quality. Facilities like the Williams Companies gas plant at Lybrook exist to collect the gas and strip it of undesirable (but often economically valuable) components for interstate pipeline transport. Liquefied petroleum gas is stripped, bottled, transported, and sold as fuel. Natural gasoline becomes a refinery feedstock. At some plants, undesirable components like nitrogen and carbon dioxide may be removed. The resulting nearly pure methane, the blood of the arterial system, is the environmentally friendlier fossil fuel of choice for the next decade. The health of the aging artery system is of great concern to the public welfare.

## PRESENTATIONS

- Tour of Lybrook Gas Plant  
Grant Hammer, *Williams Energy Services*
- Orientation and Introduction to Natural Gas Infrastructure  
Brian Brister,\* *New Mexico Bureau of Geology and Mineral Resources*
- Pipeline Safety in New Mexico  
Rory McMinn, *Public Regulation Commission*
- Pipeline Security  
Dipen Sinha, *Los Alamos National Laboratories*

## Day 1 Thursday Afternoon May 9, 2002

### STOP 2 SAN JUAN BASIN NATURAL GAS INFRASTRUCTURE

*Williams Gas Plant & Environs, Lybrook*



Williams gas plant at Lybrook

## Day 1 Thursday Afternoon May 9, 2002

### STOP 3 ENERGY PRODUCTION IN THE CONTEXT OF MULTIPLE LAND USE

*Giant Refinery in Bloomfield*

Bloomfield may be the model for how industrial activity can build a thriving community. Standing atop the bluff on the southern bank of the San Juan River, one can see fishermen harvesting dinner from the cool and clear stream. The river is a vitally important water supply to users in New Mexico and many points downstream. To the right on the same bluff, an oil refinery produces gasoline and diesel fuel for distribution in New Mexico and Arizona. The refinery also uses its share of the river's water. Its proximity to the river naturally causes concern because of potential environmental impacts. Across the river, one sees a tree-shaded park complete with baseball diamonds and natural gas wells. Somehow, these disparate elements seem to fit together in this community; there are more than 40 wells scattered throughout the city limits, and many people work in the petroleum industry. Bloomfield is a central gathering point for several pipelines. Four plants visible on the far northern outskirts of town process natural gas or compress it for the long trip to California.

We are standing in a gravel pit. Gravel is one of the resources required in nearly every operation visible from this point: in construction, as aggregate in cement, as road base, and many more. The successful development of energy resources invariably requires the development of other natural resources, as well.

In nearly every direction from town, much of the land is held in the public trust by the Bureau of Land Management. That agency's job is a continual struggle with the two-headed monster of maximizing energy production for the public good of the present generation, while protecting the land for future generations. Competing uses for these lands today range from drilling and mining to ranching and farming. The scenic "vista scape" has incredible value for locals and tourists, and the raw, sparsely populated landscape is home to wildlife. This is an ideal site to ponder the benefits and tradeoffs of energy resource development.

#### PRESENTATIONS

- Bus Tour of Giant Industries Refinery in Bloomfield
- Orientation and Introduction  
Brian Brister, *New Mexico Bureau of Geology and Mineral Resources*
- Groundwater Protection vs. Remediation  
William Olson,\* *Oil Conservation Division Environment Bureau, EMNRD*
- Energy Production in Context of Multiple Land Uses  
Steve Henke,\* *U. S. Bureau of Land Management*
- Energy Issues and Conflicts of Rural New Mexico  
Tweeti Blancett, *farming and ranching advocate*
- Environmental Considerations  
Jim Hannan, *Sierra Club*
- Consequences of Regulatory Decisions on Land Access for Oil and Gas Development  
Robert Gallagher, *New Mexico Oil and Gas Association*

The Farmington Museum, on the banks of the Animas River and a short distance upstream of the day's final destination, is the newly constructed pride of the city. It displays memorabilia of the city's past and emphasizes the role of the development of the energy industry in the city's past, present, and future. Although rich in natural gas production and nearby coal-generated electric power generation, Farmington is partially supplied by two hydroelectric generation facilities. One is only a few hundred yards from our headquarters hotel on the banks of the Animas River, and the other is at Navajo Dam on the San Juan River.

### PRESENTATIONS

- Introduction  
Teri Conrad, *Education Consultant representing BHP Billiton*
- Welcome; The Importance of Extractive Industries to Farmington  
Bill Standley, *Mayor of the City of Farmington*
- San Juan Community College Renewable Resources Demonstration  
Carl Bickford, *San Juan College*

## Day 1 Thursday Afternoon May 9, 2002

### STOP 4 FARMINGTON MUSEUM



The Farmington Museum.

New techniques for advanced energy efficiency, chiefly through integrative design, can make very large savings cost less than small or no savings, whether in buildings, industry, or vehicles. These energy productivity techniques can form a balanced portfolio and an inherently secure energy system when combined with innovative supply technologies that provide the right quality and scale of energy for the task. Technological discontinuities can dramatically shift the energy system toward decentralized production, diverse and sustainable sources, a climate-safe hydrogen economy, and new means of implementation.

Tonight's speaker is sponsored by  
Public Service Company of New Mexico

## Day 1 Thursday Evening May 9, 2002

### KEYNOTE SPEAKER



*Amory Lovins  
Rocky Mountain Institute*

### THE COMING ENERGY SURPRISES: INTEGRATING ADVANCED EFFICIENCY WITH SECURE SUPPLY

*Marriott Courtyard Hotel*

## Day 2 Friday Morning May 10, 2002

### STOP 1 COAL MINING IN NEW MEXICO

*The San Juan Coal Mine, Waterflow*

The focus of this morning's stops is coal mining and coal-fired electric power generation. These two industries are intimately linked in the region. The thick Fruitland Formation coal on the San Juan Basin's western flank cannot be exported to distant power plants because of the lack of railway infrastructure. So-called "mine-mouth" power plants have evolved to use the resource where it is found. This relationship demands the existence of extensive coal reserves that can be mined at foreseeable production rates and relies upon long-term price and regulatory stability of the electric power industry. For these reasons, "legacy" power generation methods could remain with us for decades to come. However, this nation's coal reserves are enormous; coal-powered generation could continue for centuries. The continued development of mining and power generation technology is critical to our prosperity, based on current projections of future use of electric power. No less critical is our responsibility for the environment inherited by future generations.

The San Juan mine is undergoing a transition from surface to underground mining. Surface mining requires stripping huge volumes of overburden from above the coal and redistributing the spoil into areas to be reclaimed. Reclamation and mining occur simultaneously at such an operation. The mine is situated along the western Hogback monocline where the Fruitland coal dips eastward into the basin. The mining operation migrated eastward, deeper into the basin until the overburden became too thick for removal. Now the mine is gearing up for continuous underground mining. This avoids the problems of contamination of surface-mined coal with the non-coal overburden and inferior coal seams. It also minimizes surface disturbance, the need for reclamation, and some of the environmental consequences. The underground operation will significantly extend the production life of this mine, and it will improve the quality of coal consumed.

#### PRESENTATIONS

- Bus Tour of the San Juan Mine  
James Luther, *BHP Billiton*
- Orientation and Introduction to Coal Mining in New Mexico  
Gretchen Hoffman, \* *New Mexico Bureau of Geology and Mineral Resources*
- Production and Economic Issues  
Frank Dayish, *BHP Billiton*
- Regulatory Agencies Involved and Regulation  
James O'Hara, \* *Mining and Minerals Division, EMNRD*
- Innovative Practices in Mine Reclamation and Air Quality  
James Luther, *BHP Billiton*
- Navajo Nation Role in Coal Mining in the San Juan Basin  
Arvin Trujillo, *Navajo Nation*

Fifty-six percent of the electricity produced nationwide is generated from the combustion of coal. In New Mexico the percentage is much greater (88%). Nuclear, natural gas, hydroelectric, and fuel oils play a larger role in other regions of the country, but coal remains the dominant source for electricity because of its low cost and abundance. Half of the electricity produced in New Mexico is consumed in other states, including Arizona and California. Of the total energy consumed within the state, including electricity, gasoline for cars, propane for heating, and petroleum products for industrial uses, 46% is from coal in the form of electricity.

Generating power by coal combustion results in byproducts and emissions that are regulated by standards set by the U.S. Environmental Protection Agency (EPA). Although as much as 99% of fly ash can be removed from the flue gas by electrostatic precipitators, other emissions, such as sulfur dioxide, nitrogen dioxide, and carbon dioxide have adverse effects on the environment. Many people feel that existing standards are not sufficient to do what they were designed to do: keep air clean. New “clean coal technology” hopes to address these issues by raising the bar on source emissions and ambient air quality standards.

Power generating utilities typically own the transmission lines and distribution systems in a regional monopoly. The Electric Utility Restructuring Act passed by the legislature would have changed the face of the industry, but as a reaction to a recent power crisis in California, 2001 legislation delayed this action. The status of restructuring in New Mexico and transmission issues are currently pressing topics worthy of the continued attention of decision makers.

## PRESENTATIONS

- Bus Tour of San Juan Generating Station  
James Ray, *Public Service Company of New Mexico*
- Welcome  
Russell Huffman, *Public Service Company of New Mexico*
- Orientation and Introduction  
Gretchen Hoffman, *New Mexico Bureau of Geology and Mineral Resources*
- Raising the Bar: Continuous Improvement at San Juan Generating Station  
Pat Goodman,\* *Public Service Company of New Mexico*
- Air Quality and the Clean Air Act Amendment  
Sandra Ely,\* *New Mexico Environment Department—Air Quality Bureau*
- Transportation and Powerline Issues  
Lynda Lovejoy, *Public Regulatory Commission*
- Deregulation: Status Report  
Ernie C’de Baca,\* *Public Service Company of New Mexico*
- Closing the Gap Between Policy and Science  
Mark Sardella, *Southwestern Energy Institute*

## Day 2 Friday Morning May 10, 2002

### STOP 2 COAL-GENERATED ELECTRIC POWER

*The San Juan Generating Station, Waterflow*



Public Service Company of New Mexico's San Juan Generating Station, north of Waterflow.

## Day 2 Friday Afternoon May 10, 2002

### STOP 3 URBAN NATURAL GAS PRODUCTION

*Animas Park, Farmington*

Farmington, New Mexico, spans an area of some 25 square miles and has a population of nearly 45,000 people. The city is underlain by natural gas reservoirs including the Dakota Sandstone, Pictured Cliffs Sandstone, and Fruitland Formation coal and sandstone. Gas production from 80 wells within the city currently totals more than 5 billion cubic feet per year with a current value of approximately \$13.5 million (\$2.70 per thousand cubic feet). When so many people are in proximity to such industrial activity, there are naturally concerns about safety. Yet the city and gas operators have managed to find ways to coexist.

A variety of methods are being employed by both parties to minimize disturbances. Operators have installed noise-reducing equipment and structures. Many wells are landscaped to blend into their surroundings, some in park-like settings. Tanks with added leak protection may be hidden; others are decoratively painted where visible. The city has acted to reduce excessive truck hauling, particularly for those wells that naturally produce thousands of gallons of water per day, by accepting and managing produced water in the city sewage system. There is an ongoing education program designed to prevent accidents caused by curious youth.

This stop is at a well located within Animas Park on the city's Riverwalk, less than one mile from the headquarters hotel. This well is one that neither the city nor operators want to hide. Accompanied by historic oil field equipment, the well is labeled so that visitors can gain an understanding of the need and function of the equipment typically found at such sites, of the geology responsible for the gas reservoirs, and of the value to the community of such industrial activity.

#### PRESENTATIONS

- Orientation and Introduction  
Brian Brister, *New Mexico Bureau of Geology and Mineral Resources*
- Gas Production in Farmington from Producer's Perspective  
Tucker Bayless, *Independent Petroleum Association of New Mexico*
- Urban Production, Conflicts and Solutions  
Frank Chavez,\* *Oil Conservation Division, EMNRD*
- Produced-Water Filtration Research  
Robert Lee, *New Mexico Petroleum Recovery Research Center*

Salmon Ruin is one of a number of structures that are part of a prehistoric cultural complex centered at Chaco Canyon. At this stop we will tour the ruin to gain a deeper understanding of the cultural and religious significance of this and similar archaeological sites in the San Juan Basin. Salmon Ruin is a county-funded archeological museum and contract research center where archaeologists on staff conduct contract archaeological surveys for drilling and exploration projects. The museum receives royalties from a gas well on site. A discussion session will examine how cultural sites and concepts interact with energy production, particularly from the viewpoints of the different state and federal agencies that oversee the regulation of historic preservation.

### PRESENTATIONS

- Director's Tour of Salmon Ruin  
Larry L. Baker, *Salmon Ruin Museum*
- Orientation and Introduction  
James O'Hara, *Mining and Minerals Division, EMNRD*
- Partnerships to Conserve Cultural Resources  
David Coss, *New Mexico State Land Office*
- Archaeology on Public Lands  
James M. Copeland, *U. S. Bureau of Land Management*
- Historic Preservation Law  
Jan Biella, *State Historic Preservation Office*
- The Zuni Pueblo Perspective on the Development of Energy Resources  
Malcolm B. Bowekaty, *Zuni Pueblo*

## Day 2 Friday Evening May 10, 2002

### STOP 4 CULTURAL RESOURCES

*Salmon Ruin, west of Bloomfield*

## Day 3 Saturday Morning May 11, 2002

### STOP 1 SAN JUAN BASIN WATER RESOURCES

*Farmington Riverwalk on the Animas River*

Gasoline, natural gas, and electricity in New Mexico are readily accessible because they are inexpensive and abundant. Therefore, most New Mexicans take their energy resources for granted. Not so for water. The issues of adequate water availability and quality to a growing population are constantly being brought to our collective attention. Our continued prosperity, particularly in the short run, is more dependent upon water than energy. Water is critical to agriculture and industrial development, and limits the size and effectiveness of cities to serve their residents. As in the rest of the state, every drop is precious and not to be wasted, and essentially every drop is owned by someone.

Farmington, New Mexico is a city blessed with bank-full waterways but surrounded in all directions by the high and dry Colorado Plateau. Three rivers—the Animas, La Plata, and San Juan, born in the high San Juan Mountains of Colorado—come together within the city limits of Farmington, once called Junction City for the rivers' connection, later called Farmingtown (shortened to Farmington) due to the agricultural boon that resulted from abundant water in a fertile valley. Unlike most of New Mexico, all of Farmington's water supply comes directly from surface water, mostly from the Animas River. As in the rest of New Mexico, where the doctrine of prior appropriation is law, Farmington has limited rights to use river water. Many other users downstream have rights as well, determined by interstate compacts. This stop on the cottonwood-shaded banks of the Animas River provides an opportunity to review critical water issues brought to the attention of decision makers in last year's field conference in the Santa Fe region.

#### PRESENTATIONS

- Orientation and Introduction  
Frank Titus, *New Mexico Bureau of Geology and Mineral Resources*
- Interstate Compacts  
Norman Gaume, *New Mexico Interstate Stream Commission*
- San Juan Basin Groundwater Resources/Hydrogeology  
William Stone,\* *Los Alamos National Laboratories*
- Coal Water Rights  
Paul Saavedra, *Water Rights Division, Office of the State Engineer*
- Water and Energy Development on the Navajo Reservation  
Michael Benson, *Navajo Nation Department of Water Resources*

This stop is located at the Bisti badlands, about 35 miles south of Farmington, and is a good setting in which to discuss San Juan Basin “checkerboard” land ownership issues and to further discuss competing land use options. The stop literally straddles the fence separating an older reclaimed coal mine (Gateway mine) from the Bisti-De Na Zin Wilderness. Badlands topography is the scenically dramatic result of natural erosion of dry, poorly vegetated land and is a common landform of the San Juan Basin. Badlands are commonly formed where the Fruitland Formation, among others, are naturally exposed and eroded.

Fruitland coal beds are mined extensively at the San Juan, La Plata, and Navajo coal mines. The Gateway mine was a small-scale Fruitland coal strip mine on state land that trucked coal to the San Juan generating station in the 1980's. Although reclaimed to required standards, the Gateway mine's planed surface stands in stark contrast to the adjacent federally-administered wilderness area to the north, east, and south, and Navajo Reservation to the west.

The badlands of the Bisti/De-Na-Zin Wilderness were formally designated as such by Congress, first in 1984 in the San Juan Basin Wilderness Protection Act and later enlarged in 1996. The Wilderness is administered by the Bureau of Land Management and encompasses more than 27,000 acres. The coal reserves here extend far beyond the fence of the Gateway Mine, another instance in which energy resources are not always where we would prefer. The juxtaposition of the two at this spot offers a variety of technical and philosophical issues for decision makers to ponder.

#### **PRESENTATIONS**

- Orientation and Introduction  
John Pfeil, *Mining and Minerals Division, EMNRD*
- Badlands Geomorphology  
Dave Love,\* *New Mexico Bureau of Geology and Mineral Resources*
- When Production Meets Wilderness  
Doug Bland,\* *Mining and Minerals Division, EMNRD*
- Economics of Multiple Land Ownership  
Mark Hiles,\* *New Mexico Mining Association*

## **Day 3 Saturday Morning May 11, 2002**

### **STOP 2 WHEN PRODUCTION MEETS WILDERNESS**

*Bisti Badlands*

## Day 3 Saturday Afternoon May 11, 2002

### STOP 3 ENERGY ISSUES OF JICARILLA APACHE TRIBE

*Jicarilla Apache Reservation*

The Jicarilla Apache Reservation extends over much of the eastern third of the San Juan Basin. Rich oil and natural gas reserves on the reservation were historically administered by federal agencies on behalf of the tribe. Over time, the tribe has become increasingly proactive in managing the energy production and related environmental impacts on the reservation. At this brief stop, we will hear from Thurman Velarde of the Jicarilla Apache Oil and Gas Administration, who will describe the tribe's efforts to become an important and active participant in the process of energy production in the region.

#### PRESENTATION

- Managing Oil and Gas Development on the Jicarilla Apache Reservation  
Thurman Velarde, *Jicarilla Apache Oil and Gas Administration*

# BACKGROUND GEOLOGY OF THE SAN JUAN BASIN

DECISION-MAKERS  
FIELD CONFERENCE 2002  
San Juan Basin



# Fundamental Geology of San Juan Basin

## Energy Resources

Brian S. Brister and Gretchen K. Hoffman,  
*New Mexico Bureau of Geology and Mineral Resources*

**G**eology is a science that is inextricably linked to energy resources. Sub-disciplines of geology range from studies of the depths of the earth's interior to the interactions of the crust with the hydrosphere (water), biosphere (plants and animals), and atmosphere (air). Studying the geology of a region always reveals that there are many pieces to the complex geological puzzle of our planet.

Practically every energy resource imaginable is closely linked to geology. Obvious examples are those resources that we currently rely upon, such as oil and gas, coal, coalbed methane, and uranium. But geology plays a role in the development of renewable energy resources, as well. It influences the locations of dams that supply hydroelectric power. It has obvious connections to geothermal resources. It influences natural vegetation as well as crops, both of which can be used to produce biomass energy resources (firewood, ethanol, or bacteria-generated methane gas—all sources of energy derived from plants). Geology even plays a role in optimal placing of wind- and solar-driven power generators and heat collectors. Geology aids in providing the raw materials that make up the infrastructure of the energy industry, whether it's limestone and aggregate used to make concrete, silicon used to make semiconductors, or water used in cooling towers.

Natural resources are rarely exactly where we would like them to be. Therefore geologists spend many lifetimes ferreting out the clues, assembling the pieces of the puzzle, and building a logical and predictable geologic framework to give us an understanding of the location and extent of our energy resources.

### FUNDAMENTAL GEOLOGIC CONCEPTS

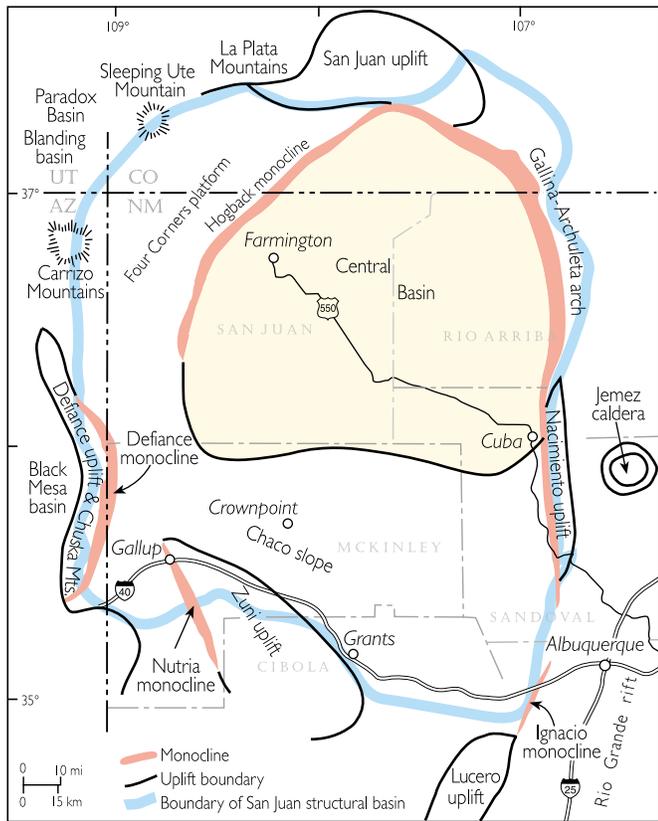
Although there are many varied aspects of the geology of northwestern New Mexico, the key concepts related to energy resources are geologic structure and stratigraphy, and how these have changed over time. Their importance to the geology of natural resources in New Mexico was first demonstrated at Hogback dome, west of Farmington, where the first commercial oil well in New Mexico was drilled in 1922. There, sedimentary rocks (strata) that were deposited at the earth's surface

as horizontal layers of sediment were folded into a dome-shaped geologic structure, which served as a trap for the accumulation of oil and gas. The Dakota Sandstone is the stratigraphic unit that hosts the oil, which migrated into the structure from source rocks nearby. Since the first successful oil well, activities associated with exploration and development in this part of the state have provided an extensive body of information on the subsurface. This information, combined with what we know of rocks on the surface (see map inside back cover), has given us a clear understanding of the geology of the region.

### STRUCTURE OF THE SAN JUAN BASIN

The San Juan Basin is the dominant structural and physical feature in the northwestern part of the state, covering more than 26,000 square miles in northwestern New Mexico and southwestern Colorado (Fig. 1). The central part of the San Juan Basin (Fig. 1) is a nearly circular, bowl-shaped depression. This structural depression contains sedimentary rocks over two and a half miles thick (up to 14,400 feet), ranging in age from about 570 to 2 million years in age. Features that define the margins of the basin are the uplifted, folded, and faulted rocks in adjacent mountain ranges. Rocks that are deep in the subsurface in the center of the basin are exposed at various localities around the basin margin, where they are more easily studied. In addition, wells and mines provide further clues to what lies in the subsurface and allow us to correlate those strata with rocks at the surface.

The San Juan uplift, La Plata Mountains, and Sleeping Ute Mountain of southern Colorado form the northern boundary of the San Juan Basin (Fig. 1). The Carrizo and Chuska Mountains and the Defiance monocline (uplift) define the western edge of the basin. The southern edge of the San Juan Basin is bounded by the Zuni Mountains (uplift), the southeastern edge by the Lucero uplift and Ignacio monocline. The Nacimiento Mountains (uplift) and the Gallina-Archuleta arch form the eastern boundary of the basin. These highlands surrounding the basin receive most of the rainfall in the area and are more heavily vegetated than the semiarid San Juan Basin.



**FIGURE 1** Structural features of the San Juan Basin and adjacent areas. From Craig, 2001.

The central basin is defined on the west, north, and east sides by the Hogback monocline, whose rocks dip steeply into the basin. Hogback dome, where the first commercial oil well in New Mexico was drilled, is a small structure that's part of the western Hogback monocline. The southern edge is defined by the Chaco slope, a gently dipping platform with about 2,500 feet of structural relief above the central basin.

The terrain within the basin consists of mesas, canyons, and valleys eroded from nearly flat-lying sedimentary rock units deposited during the Upper Cretaceous and Tertiary (about 95 to 2 million years ago). The San Juan Basin, and many of the smaller structural details such as the mountains and hogbacks that define the basin boundary, began to form about 65 million years ago.

The close relationship between energy resources and geologic structure in northwestern New Mexico is evident throughout the region. Coal and uranium have been mined on the western and southern flanks of the San Juan Basin, where these deposits exist at or near the surface. Major reservoirs of natural gas and oil are

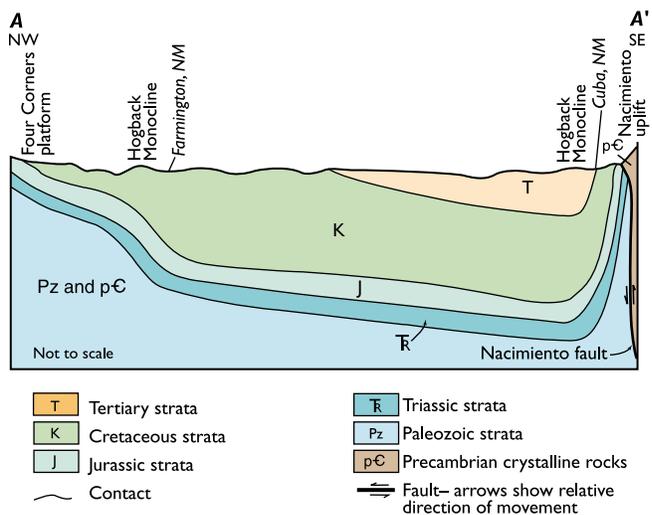
found within the central part of the San Juan Basin. Oil and gas have also been produced in lesser quantities from the Chaco slope and Four Corners platform regions.

**SAN JUAN BASIN STRATIGRAPHY**

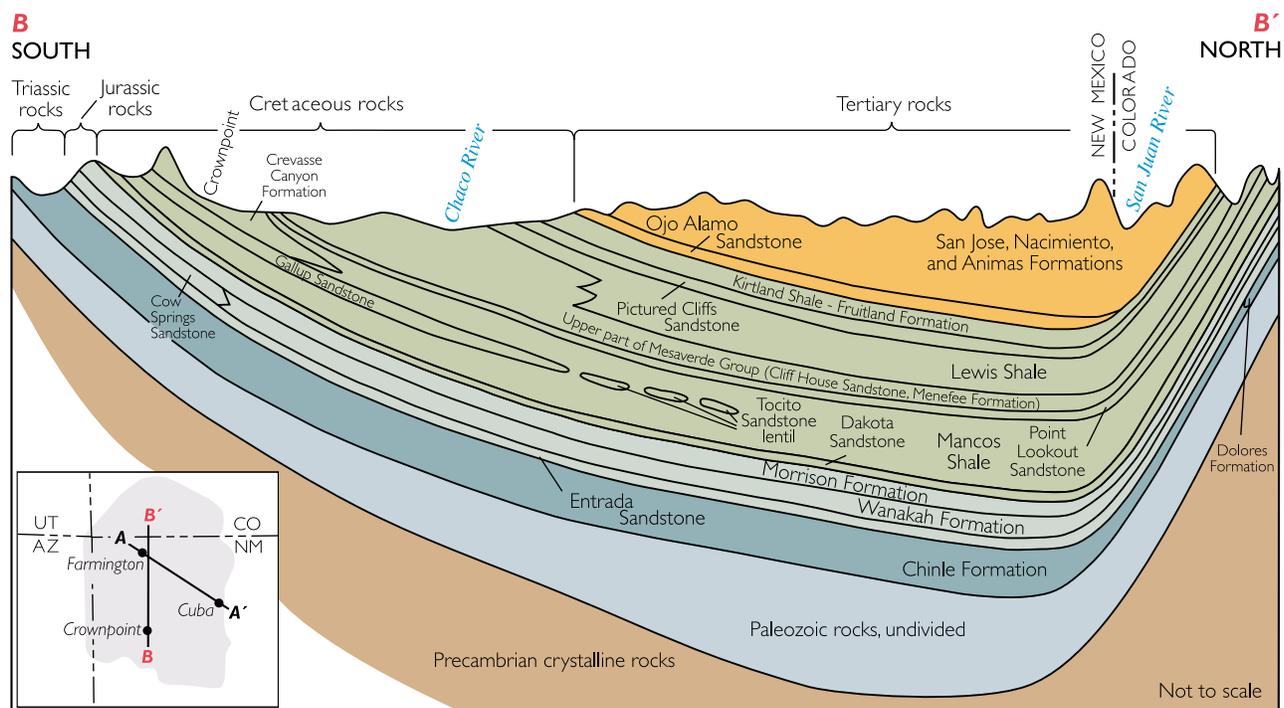
Stratigraphy is the study of the layers of rock in the earth's crust, from the types of rocks and their thicknesses, to depositional environments and time of deposition (see inside back cover). The sedimentary strata of the San Juan Basin dip inward from the highlands toward the trough-like center of the basin. Older sedimentary rocks are exposed around the edge of the basin and are successively overlain by younger strata toward the center of the basin, similar to a set of nested bowls (Figs. 2, 3).

The Precambrian rocks are the oldest rocks (about 1,500 to 1,750 million years old). They are considered to be the basement rocks of the region because they underlie all of the sedimentary rocks within the basin. They are exposed at the surface in a few localities in uplifts along the basin margin, including the Nacimiento Mountains, the Zuni uplift, and the San Juan uplift in Colorado. Granite and quartzite are common Precambrian rock types in those regions.

Most of the sedimentary rocks in the San Juan Basin were deposited from the Pennsylvanian through Tertiary periods (from about 330 to 2 million years ago; Figs. 2,3). During this time the basin went through many cycles of marine (sea), coastal, and non-marine (land or freshwater) types of deposition. These



**FIGURE 2** Diagrammatic east-west cross section of San Juan Basin, from Craig, 2001 (p. 8, comb. of section A and B).



**FIGURE 3** Diagrammatic southwest-northeast cross section of San Juan Basin, from Craigg, 2001 (p.12).

cycles are reflected in the characteristics of the rocks in the basin. Like the Precambrian basement, Pennsylvanian and Permian formations (about 330 to 240 million years in age) are exposed in those uplifts around the edge of the basin, most notably the Zuni uplift east of Gallup. These Paleozoic rocks are marine in origin, composed predominantly of limestone, shale, sandstone, and gypsum. Paleozoic rocks host several significant oil and gas fields west of the San Juan Basin and are fractured ground-water aquifers in the Zuni uplift region. Rarely are these rocks reached by drilling in the deeper part of the San Juan Basin, because they are found only at great depth.

Overlying these Paleozoic rocks are Triassic rocks (about 240 million years old). The Triassic was a time of nonmarine deposition, mainly by rivers and streams flowing into the region from the southeast. Triassic rocks include sandstone, siltstone, and mudstone of the Chinle Group and the Rock Point Formation. About 170 million years ago the area was covered by windblown sand dunes, preserved today in the Jurassic Entrada Sandstone. The Entrada is an excellent oil reservoir in several fields that line up in a northwestern trend along the Chaco slope. Stream-laid

sandstones of the Jurassic Morrison Formation were deposited throughout the basin during the Jurassic (about 145 million years ago). The Morrison is one of several well-known uranium-bearing rock units in the mining districts along the southern flank of the basin. A period of non-deposition and erosion followed the Late Jurassic, and no sediments are preserved from the earliest Cretaceous in the San Juan Basin.

By the Late Cretaceous (about 95 to 65 million years ago) the western U.S. was dissected by a large interior seaway (Fig. 4). The northwest-to-southeast-trending shoreline of the sea in northwest New Mexico migrated back and forth (northeastward and southwestward) across the basin for some 30 million years, depositing about 6,500 ft of marine, coastal plain, and nonmarine sediments. The marine deposits consist of sandstone, shale, and a few thin limestone beds; the coastal plain deposits include sandstone, mudstone, and coal; and nonmarine deposits include mudstone, sandstone, and conglomerate.

The Late Cretaceous formations in the San Juan Basin, from the oldest unit (the Dakota Sandstone) to the youngest (the Kirtland Shale), are summarized in Figure 5. There is a recurring pattern in the type of



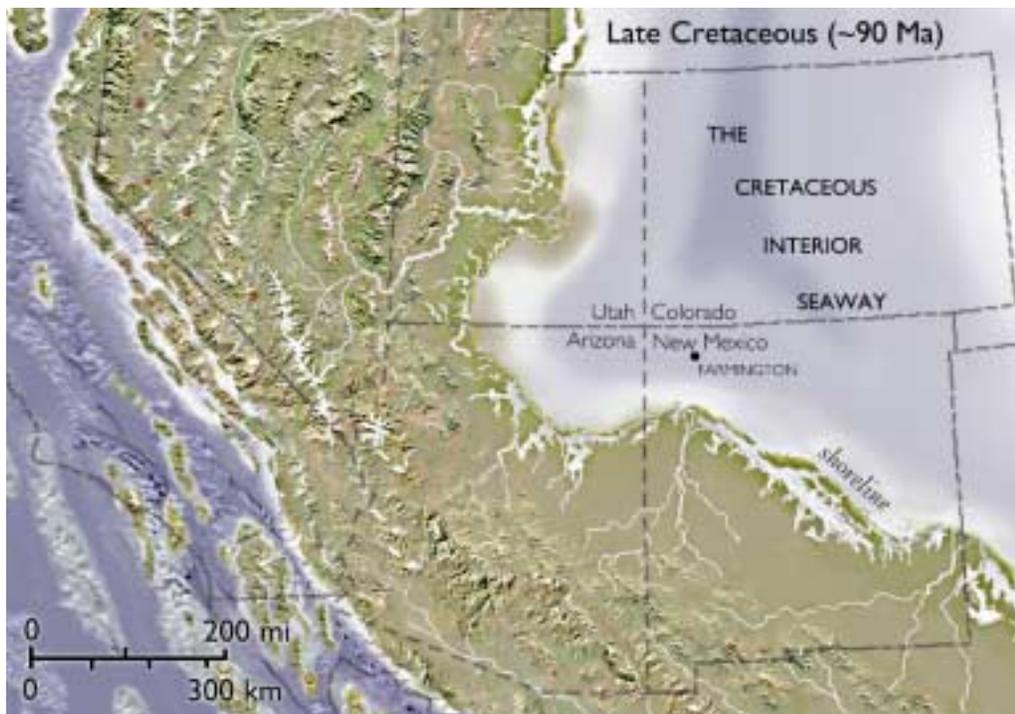
**FIGURE 4** Paleogeographic map of North America during Cretaceous time. Map courtesy of Ron Blakey.

sediments that were deposited during the Late Cretaceous. The movement of the shoreline back and forth across the basin shifted the depositional environment from nonmarine to marine, and back to nonmarine, until the end of the Cretaceous, when the seaway retreated from the basin and nonmarine deposits dominated the area. Figure 6 is a snapshot in time of the Four Corners region when the swamps and coastal plain environments prevailed. These deposits today are preserved in the Crevasse Canyon Formation, an important coal-bearing unit.

The Cretaceous stratigraphy of the San Juan Basin makes it one of New Mexico's crown jewels, as far as energy resources are concerned. Many of the Late Cretaceous sandstones are oil and gas reservoirs (Figure 5, and page 152). Marine shales are source rocks for gas and oil. Coal beds are both source and reservoir for coalbed methane. The combination of thick Cretaceous source rocks and a large area of reservoir rocks makes the San Juan one of the most important gas-producing basins in the U.S. today. The coal deposits from the Cretaceous near-shore peat swamps are the source of coal and coalbed methane. The most notable is the Fruitland Formation, which is currently the world's most prolific coalbed-methane field. It is also the source of mined coal supplied to the Four Corners and San Juan power plants west of Farmington.

Youngest	Formation	Rock type (major rock listed first)	Depositional environment	Resources
	Kirtland Shale	Interbedded shale, sandstone	Coastal to alluvial plain	
	Fruitland Formation	Interbedded shale, sandstone and coal	Coastal plain	Coal, coalbed methane
	Pictured Cliffs Sandstone	Sandstone	Marine, beach	Oil, gas, water
	Lewis Shale	Shale, thin limestones	Offshore marine	Gas
	Cliff House Sandstone	Sandstone	Marine, beach	Oil, gas, water
	Menefee Formation	Interbedded shale, sandstone and coal	Coastal plain	Coal, coalbed methane, gas
	Point Lookout Sandstone	Sandstone	Marine, beach	Oil, gas, water
	Crevasse Canyon Formation	Interbedded shale, sandstone and coal	Coastal plain	Coal
	Gallup Sandstone	Sandstone, a few shales and coals	Marine to coastal deposit	Oil, gas, water
	Mancos Shale	Shale, thin sandstones	Offshore marine	Oil
Oldest	Dakota Sandstone	Sandstone, a few shales and coals	Coastal plain to a marine shoreline	Oil, gas, water

**FIGURE 5** Late Cretaceous formations of the San Juan Basin.



**FIGURE 6** Snap shot of paleogeography of the Four Corners region during Late Cretaceous. Map courtesy of Ron Blakey.

From the end of the Cretaceous through the Tertiary (about 65 to 2 million years ago) the San Juan Basin was dominated by nonmarine deposition in stream channels, floodplains, lakes, and windblown sands. Volcanic activity to the north and southwest of the basin had some influence on the type of sediments being deposited within the basin. Tertiary rocks include sandstone, shale, and conglomerate. Tertiary rocks support the foundation of the dam at Navajo Lake on the San Juan River east of Bloomfield, where hydroelectric power is generated. Although Tertiary rocks have long been known to be aquifers in the northeast part of the San Juan Basin, only in the past decade has significant natural gas development in Tertiary rocks begun west of Dulce on the Jicarilla Apache Reservation.

### **GEOLOGY AND ENERGY RESOURCES**

Science is built upon a foundation of cumulative knowledge. Each successive geologic investigation contributes another piece of the puzzle of the how, where, and why of understanding natural resources. The fundamental concepts of geologic structure and stratigraphy are continually being refined. After 80 years of energy-related exploration, development, and geologic research in the San Juan Basin, there is still

much to be gained from further research. Mined energy reserves such as fossil fuels and uranium are often short-lived and must be continually replaced as they are consumed. Replacement is not an easy task; the easy-to-find reserves are generally the ones we've already found and produced. Thus, we now search for the subtle, and often smaller, deposits and reservoirs. Our ability to find them, and to develop them, is closely tied to our willingness and ability to better understand the geology of this important part of New Mexico.



## Badlands in the San Juan Basin

David W. Love, *New Mexico Bureau of Geology and Mineral Resources*

**B**adlands are intricately dissected, water-carved topographic features characterized by a very fine drainage network with high numbers of small rills and channels, and rounded narrow ridges with short steep slopes between the drainages. Badlands develop on sloping surfaces with little or no vegetative cover, eroding poorly consolidated clays, silts, and minor amounts of sandstone, fossil soils (including coal), and less common soluble minerals such as gypsum or salts. The term was first applied to an area in South Dakota, which was called *mauvaises terres* by the early French fur traders. The French and English terms not only imply that badlands are bad ground, they also imply sparse vegetation—not good for agriculture. The Spanish term *malpais* may be translated as badland, but the term is applied to fresh, jagged lava, which not only are impossible for agriculture, they are difficult to cross on horseback. Badlands in the western United States are common and locally charming features of the natural landscape. Over time, badlands are cyclically exposed, eroded, and buried in response to environmental conditions including shifts in climate, changes in local vegetation, and changes in stream levels and sediment supply. Ironically, mankind has created some badlands that “live down” to their connotative names, in areas that did not have badlands before (Perth-Amboy, New Jersey, and Providence Canyon State Conservation Park, Georgia, to name two). Understanding how natural badlands are created, function, and heal has important applications to land management practices (including mine reclamation).

Badlands are abundant in northwestern New Mexico, forming 30–40% of the area. They are interspersed with more vegetated stream valleys, rolling uplands, mesas, sandstone canyons, covered sandy slopes, and wind-blown sand dunes. Their formation requires:

- extensive exposures of easily erodible mudstone
- abrupt elevational changes between stream valleys and valley margins
- sparse vegetation
- a semiarid climate with a large annual range in precipitation intensities, durations, and amounts.

The San Juan Basin has extensive exposures of gently sloping, poorly consolidated mudstones that protrude above the valleys of many streams. Most of the mudstones have clays that swell up and are very sticky and slippery when wet, shrink and curl when they dry, and

are easily transported by water and wind. These mudstones yield very few nutrients when weathered to form soil and are rapidly eroded before most vegetation can eke out an existence. Some of the most extensive badlands are developed in coal-bearing rocks (the Menefee and Fruitland-Kirtland Formations), but mudstones dominate the geologic column at many levels throughout the San Juan Basin. These mudstones range in age from 285 million years to less than half a million years. Because average annual precipitation ranges from only 6 inches near Newcomb to 16 inches near the Continental Divide at Regina, vegetation tends to be sparse, ranging from grassland and sagebrush steppe to piñon-juniper woodland, depending upon elevation and soil type. The vegetation does not cover 100% of the ground in most places. Traditional land use, particularly intensive grazing, has reduced grass cover and increased pathways for concentrated runoff in local areas, initiating exhumation or extending badlands into previously covered areas.

Badlands form when runoff picks up and carries away overlying deposits and uncovers mudstone beneath. Mudstone is less permeable than overlying sandy deposits, and runoff increases as more mudstone is exposed. Strong winds may also remove overlying material. If the gradient for runoff is steep downslope, the sediments are carried to much lower elevations away from the incipient badland. The initial badland may be small, and may be buried again by local sheetwash processes or by windblown sand. Otherwise, the badland may expand upslope and along the sides of the drainage. The increased runoff may also connect to larger gullies downslope and help expand badland areas downhill. Over time, steep-sided badland exposures migrate up tributary valleys developed in mudrocks. Erosion progresses into upland areas that were formerly stabilized by a cap of alluvial deposits and windblown sand with good grass cover. As sediment is moved from the tops and slopes of individual features to the base of the slope and beyond, the features get progressively smaller while similar features evolve at ever-lower elevations. Regardless of size, common badland shapes are created and maintained by a series of natural processes:

- the dry crumbling, raveling, and blowing of weathered mud
- the flow of rain as sheetwash across the rounded hilltop

- the swell and downslope creep of saturated clays
- the accelerated flow and erosive force of rain and mudflows on steeper slopes
- the alluvial apron of particles shed from the hill as the flow of water loses velocity

Water that soaks into the weathered mudstone may dissolve chemical constituents, which then help disperse the clay and move it along a downward gradient and away from the hill. Removal of clay particles and dissolved constituents opens passageways or even small caves. These collapse into funnel-shaped areas known as “soil pipes.” Water and sediment passing through the pipes come out of the pipes at the base of the slopes and form small alluvial fans. When dry, the alluvial fans may be reworked into windblown sand dunes or sand sheets. Such deposits are highly permeable and may reduce surface runoff.

Some human-disturbed lands resemble natural badlands. Human-disturbed lands range from obvious mine-spoil piles and road dugways to more subtle areal changes in vegetation and changes in the rates of natural processes. Those disturbances that resemble natural badlands may need human reclamation, a task that is overseen by environmental-protection legislation, regulation, and legal adjudication. The goals of reclamation commonly are:

- to return the land to be near its “original” condition both in terms of contours of the landscape and its previous vegetation
- to restore natural function of the landscape so that wildlife may benefit
- to increase production of vegetation, preferably for animal forage
- to reduce sediment production and transport of sediments offsite
- to improve the chemical quality of both surface water and ground water.

The Coal Surface Mining Law sets performance standards concerning topsoil, topdressing, hydrologic balance, stabilization of rills and gullies, alluvial valley floors, prime farm land, use of explosives, coal recovery, disposal of spoil, coal processing, dams and embankments, steep slopes, backfilling and grading, air resource protection, protection of fish, wildlife, and related environmental values, revegetation, subsidence control, roads and other transportation, how to cease operations, and post-mining land use. These performance standards are set nationally but applied locally, a worrisome task considering the low rainfall and nutrient-poor soils in northwestern New Mexico compared to other parts of the United States. Historically, low vegetation cover and high sediment yields across the local pre-mining landscape already fail

to meet reclamation standards required nationwide.

An understanding of the ways in which badlands evolve helps us understand the complex processes shaping all of the landscape. Land managers can improve local long- and short-term reclamation by studying the “performance” of the natural (or least-disturbed) landscape—uplands, badlands, alluvial bottomlands, and windblown sand dunes—with an eye on both existing standards and the natural processes involved. Armed with this understanding, they can solve specific problems of reclamation—optimizing long-term water retention and revegetation, for example, or minimizing sediment production and/or the release of soluble chemical compounds. The most valuable lessons we’ve learned from studies of naturally occurring badlands include the following:

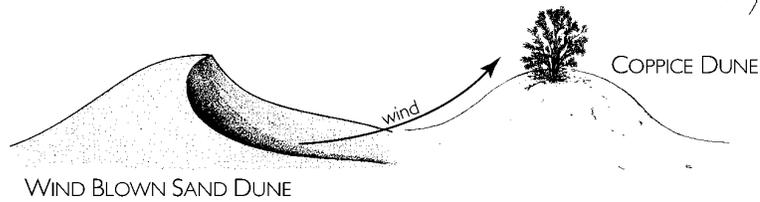
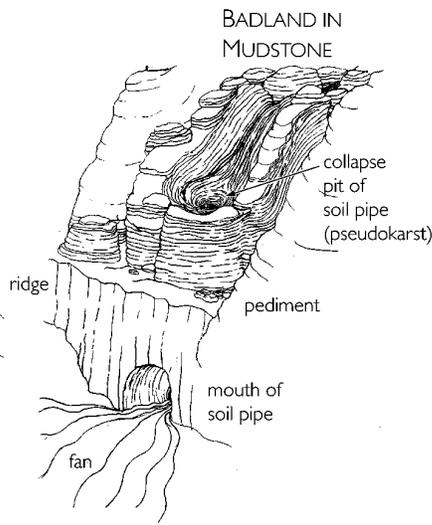
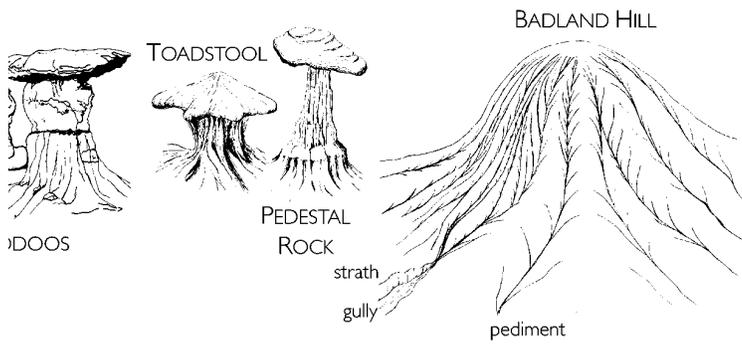
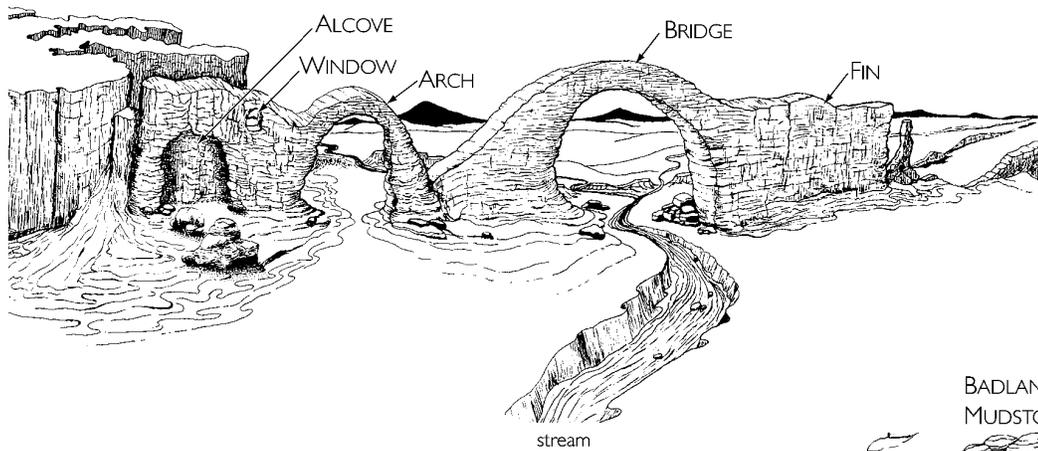
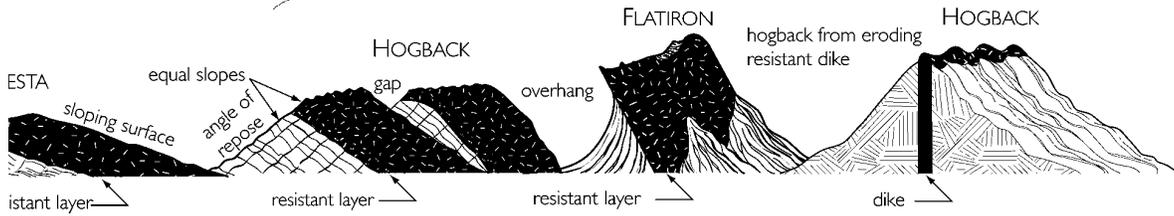
- Badlands illustrate the fastest changing, least stable, most dynamic end of a range in natural rates and processes in the landscape, in contrast to the more stable parts of the same landscape (such as the sand-covered uplands)
- Internal and external environmental influences may alter the flux of materials and energy flow through the natural system
- Badlands demonstrate the importance of thresholds for change when the landscape is subjected to variable magnitudes and frequencies of environmental influences, such as rainfall or grazing pressure
- Badlands reflect the cyclic lowering of landscapes and landforms from higher, larger, and older levels to lower, smaller, and modern levels.
- Badlands and shapes of individual features in badlands may look the same, even though material is slowly being removed from the slopes and added to the valleys below
- Changes in one part of a system may have consequences in adjacent parts of the system
- In a regulatory environment one must consider the larger picture: How may human endeavors fit in with the natural processes that affect the development of landscape?

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### COMMON EROSIONAL FEATURES



Illustrations  
by Leo O. Gabaldon

## All Features Great and Small

Anthropologists use the phrase “name magic” to describe the tendency of people to think that they can understand or control something merely by naming it. It was a rage in geologic and geographic disciplines in the late nineteenth century. Early explorers, mappers, and geologists named hundreds of geographic features and rocks, using new or locally used exotic names, thereby bestowing some impression of enhanced understanding of the feature under scrutiny—and some enhanced status upon the namer.

But does naming a lumpy erosional feature a “hoodoo” or a “yardang” help our understanding of how it formed any more than if we had crawled around it and made careful observations? What if such terms bring with them negative connotations—such as “badlands” or “gully”? As we all know, terms are seldom neutral in their connotations. Today, in extreme cases, names are deliberately changed to conform to current standards of political correctness.

Names tell us something about our past and ourselves. Names applied to features in northwestern New Mexico serve several purposes. Some are descriptive and serve as place names: Standing Rock, The Hogback, Waterflow, Angel Peak. Some are for fun: Beechatuda Draw, Santa Lulu. Some generic terms have both popular and technical definitions: mesa, butte, badland, pedestal rock. The landscape of northwestern New Mexico is described using names for features of various sizes. Erosional features rooted in bedrock range from large to small (see illustrations on facing page). These features are a result of “differential erosion.” Some rock

units resist erosion better than others. Well-cemented sandstone, limestone, and/or lava resist weathering and erosion better than mudstones. Mudstones interbedded with these more resistant rocks are more easily eroded and transported away downstream, leaving the more resistant rocks high on the landscape. The volcanic neck of Ship Rock, the plumbing system for a 25-million-year-old volcano, sticks up 1,700 feet above the surrounding countryside because the surrounding mudrocks have been removed by differential erosion. Surficial deposits may also resist erosion—soils developed with calcium carbonate horizons (caliche) may be difficult to erode. Windblown sand may be so permeable that the small amounts of precipitation that do fall soak in before they have a chance to run off. Gravel deposits may be more difficult to erode than sand or mud and therefore are left behind as terraces along streams. Uncommonly, some deposits are protected from erosion by their proximity to resistant rocks (“bedrock defended”).

**Erosional products** The fragmental products of weathering and erosion are moved away from the underlying bedrock, travel downslope, and ultimately come to rest in new deposits. The most common erosional products seen in badlands and in stream channels in northwestern New Mexico are:

- loose grains of sand, silt, and clay
- textures that range from velvety smooth surfaces to popcorn-like crusts to flat mud-cracked plates on weathered, clay-rich slopes
- slabs or blocks of cemented sandstones, siltstones, or limestones

- concretions and fragments of concretions (rounded or oblong objects formed by concentrated chemical precipitation of cements in preexisting rocks)
- red dog and clinker (red or brown baked, partially melted, and/or silicified mudstones adjacent to burned-out coal seams)
- fossil fragments such as silicified wood, bones, teeth, shells, fish scales, and other fossils
- reworked older clasts (such as pebbles from bedrock formations).

**Features of sediment accumulation** Oddly enough, fewer specific terms have been coined for features or forms that are built up by sediment accumulation. Perhaps ambitious namers are unimpressed with the subtle features developed on areas of lesser topographic relief (“feature challenged”). Instead, the features commonly are tagged with descriptive phrases:

- modern low-gradient washes with adjacent floodplain alluvium
- upland surfaces covered with old alluvium, sand sheets, and eolian dunes
- intermediate slopes with alluvial aprons
- alluvial fans; bajadas
- terraces
- sand sheets, sand dunes, climbing and falling dunes, rim dunes, barchan dunes, parabolic dunes, distended parabolic arms of dunes; longitudinal dunes, star dunes, coppice dunes
- landslides, slumps, debris flow lobes, debris runout fans.



## Uranium in New Mexico

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**U**ranium is a hard, dense, metallic silver-gray element with an atomic number of 92 and an atomic weight of 238.02891. It is ductile, malleable, and a poor conductor of electricity. Uranium was discovered in 1789 by Martin Klaproth in Germany and was named after the planet Uranus. There are three naturally occurring radioactive isotopes (U-234, U-235, and U-238); U-238 is the most abundant.

Most of the uranium produced in the world is used in nuclear power plants to generate electricity. A minor amount of uranium is used in a variety of additional applications, including components in nuclear weapons, as X-ray targets for production of high-energy X-rays, photographic toner, and in analytical chemistry applications. Depleted uranium is used in metal form in yacht keels, as counterweights, armor piercing ammunition, and as radiation shielding, as it is 1.7 times denser than lead. Uranium also provides pleasing yellow and green colors in glassware and ceramics, a use that dates back to the early 1900s.

Nuclear power is important to New Mexico and the United States. Nuclear power plants operate the same way that fossil fuel-fired plants do, with one major difference: nuclear energy supplies the heat required to make steam that generates the power plant. Nuclear power plants account for 19.8% of all electricity generated in the United States (Fig. 1). This generated electricity comes from 66 nuclear power plants composed of 104 commercial nuclear reactors licensed to operate in the U.S. in 2001.

Although New Mexico does not generate electricity from nuclear power in the state, the Public Service Company of New Mexico (PNM) owns 10.2% of the Palo Verde nuclear power plant in Maricopa County, Arizona. PNM sells the generated electricity from Palo Verde to its customers in New Mexico. In 1999 the average cost of electricity generated by nuclear power plants was 0.52 cents/kilowatt hour, compared to 1.56 cents/kilowatt hour for electricity generated by fossil fuel-fired steam plants. Most of the electricity generated from plants in New Mexico comes from coal-fired plants (Fig. 2), and New Mexico sells surplus electricity to other states.

### NUCLEAR FUEL CYCLE

The first step in understanding the importance of uranium and nuclear power to New Mexico is to understand the nuclear fuel cycle. The nuclear fuel cycle consists of ten steps (Fig. 3):

- 1 Exploration—using geologic data to discover an economic deposit of uranium.
- 2 Mining—extracting uranium ore from the ground.
- 3 Milling—removing and concentrating the uranium into a more concentrated product (“yellow cake” or uranium oxide,  $U_3O_8$ ).
- 4 Uranium conversion—uranium oxide concentrate is converted into the gas uranium hexafluoride (UF<sub>6</sub>).
- 5 Enrichment—most nuclear power reactors require enriched uranium fuel in which the con-

Electricity fuel source	Net generation by fuel source (billion kilowatt hours)	Net generation by fuel source (%)	Industry capability by fuel source (megawatts)	Industry capability by fuel source (%)	Fuel Costs (dollars per million Btu)
Coal	1,968	51.8	315,249	38.9	1.2
Petroleum	109	2.9	39,253	4.8	4.45
Gas	612	16.1	97,632	12.1	4.3
Nuclear	754	19.8	97,557	12.0	
Hydroelectric	273	7.2	99,068	12.2	
Other (geothermal, wind, multifuel, biomass, ect.)	84	2.2	162,866	20.0	
<b>Total industry</b>	<b>3,800</b>	<b>100</b>	<b>811,625</b>	<b>100</b>	

**FIGURE 1** Net generation and industry capability of electricity generated by fuel in the United States in 2000 (from Energy

Information Administration, 2001).

Electricity fuel source	Net generation by energy source (%)
Coal	85.5
Petroleum	0.1
Gas	13.7
Duel	—
Nuclear	—
Hydroelectric	0.7
Other (geothermal, wind, multifuel, biomass, etc.)	—
<b>Total industry</b>	<b>100</b>

**FIGURE 2** Net generation of electricity generated at electric power plants in New Mexico in 2000 from Energy Information Administration, 2001.

tent of the U-235 isotope has been raised from the natural level of 0.7% to approximately 3.5%. The enrichment process removes 85% of the U-238 isotope. Some reactors, especially in Canada, do not require uranium to be enriched.

6 Fuel fabrication—enriched  $UF_6$  is converted to uranium dioxide ( $UO_2$ ) powder and pressed into small pellets. The pellets are encased into thin tubes, usually of a zirconium alloy (zircalloy) or stainless steel, to form fuel rods. The rods are then sealed and assembled in clusters to form fuel elements or assemblies for use in the core of the nuclear reactor.

7 Power generation—generate electricity from nuclear fuel.

8 Interim storage—spent fuel assemblies taken from the reactor core are highly radioactive and give off heat. They are stored in special ponds, located at the reactor site, to allow the heat and radioactivity to decrease. Spent fuel can be stored safely in these ponds for decades.

9 Reprocessing—chemical reprocessing of spent fuel is technically feasible and used elsewhere in the world. However, reprocessing of spent fuel is currently not allowed in the United States as a result of legislation enacted during the Carter administration.

10 Waste disposal—the most widely accepted plans of final disposal involve sealing the radioactive materials in stainless steel or copper containers and burying the containers underground in stable rock, such as granite, volcanic tuff, salt, or shale.

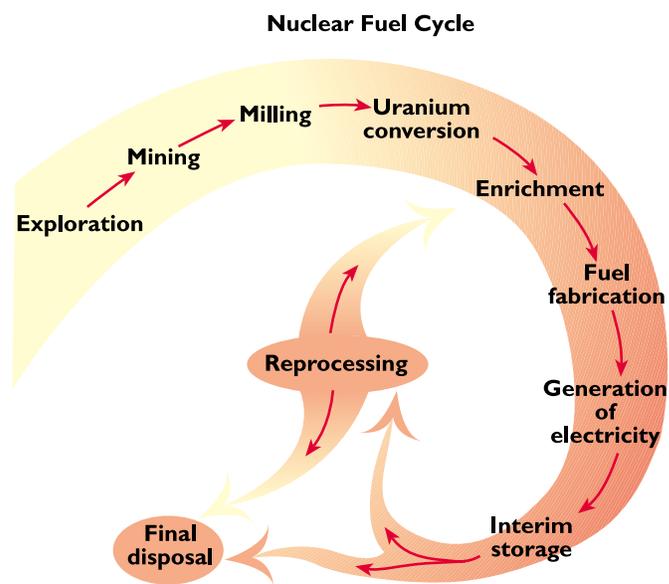
Historically, New Mexico has played a role in three of these steps: exploration, mining, and milling. For

nearly three decades (1951–1980), the Grants uranium district in northwestern New Mexico produced more uranium than any other district in the world (Figs. 4, 5). However, as of spring 2002, all of the conventional underground and open-pit mines are closed because of a decline in demand and price. The only uranium production in New Mexico today is by mine-water recovery at Ambrosia Lake (Grants district). Two companies are currently exploring for uranium in sandstone in the Grants uranium district for possible in situ leaching.

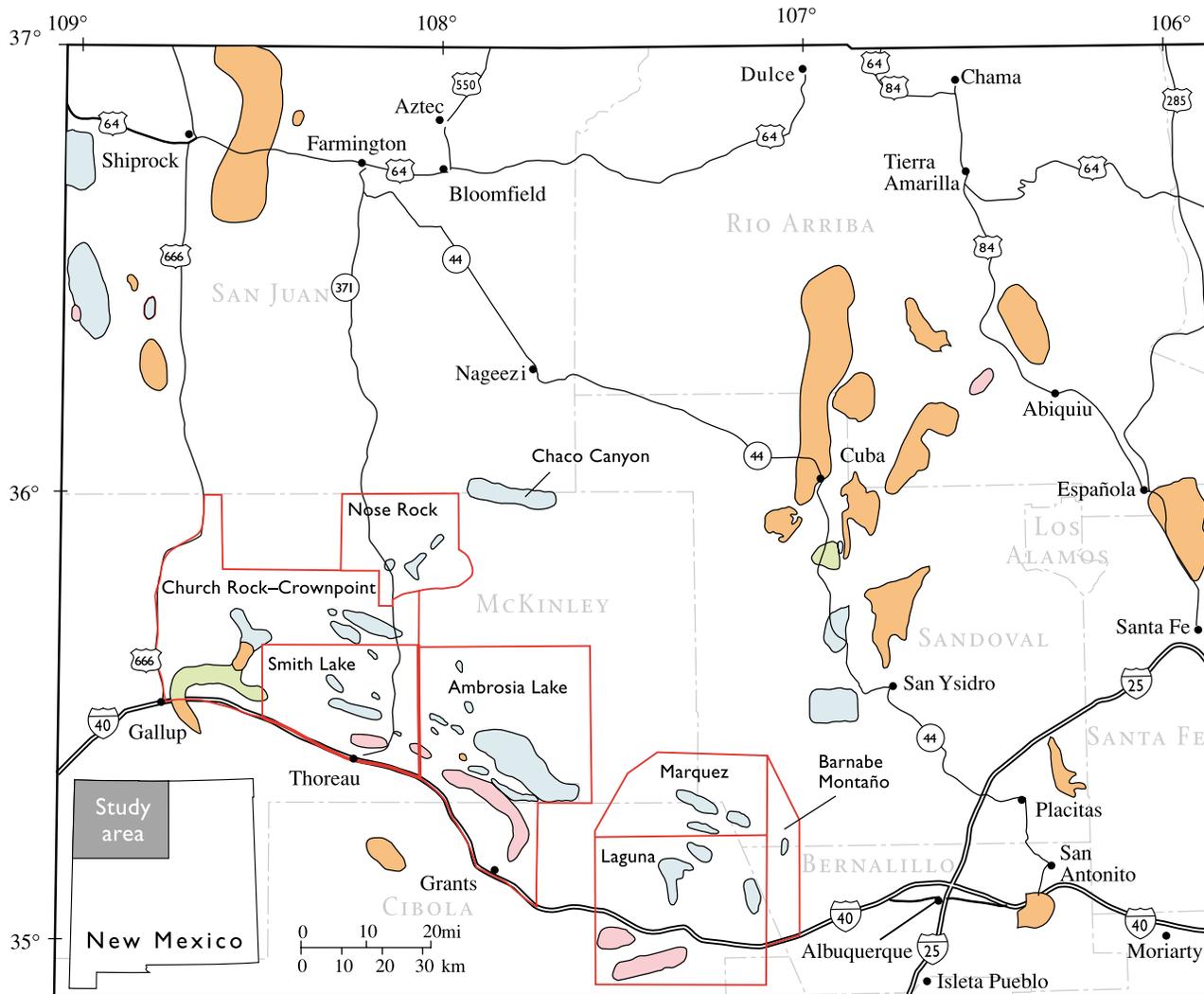
There are six conventional uranium mills licensed to operate in the U.S.; only one is operating (Cotter in Canon City, Colorado), and it will probably close in 2002. The Quivera Mining Company's Ambrosia Lake mill near Grants, New Mexico, is currently inactive and is producing uranium only from mine water.

### TYPES OF URANIUM DEPOSITS IN NEW MEXICO

The Grants and Shiprock uranium districts in the San Juan Basin are well known for large resources of sandstone-hosted uranium deposits in the Morrison Formation (Jurassic). More than 340 million lbs of uranium oxide ( $U_3O_8$ ) were produced from these uranium deposits from 1948 through 2001 (Fig. 5), accounting for 97% of the total uranium production



**FIGURE 3** The nuclear fuel cycle (Uranium Information Centre Ltd., 2000; Energy Information Administration, 2001).



- Morrison Formation (Jurassic) sandstone uranium deposits
  - Other sandstone uranium deposits
- Limestone uranium deposits
  - Other sedimentary rocks with uranium deposits
  - Mining districts

**FIGURE 4** Uranium potential in the San Juan Basin, New Mexico (from McLemore and Chenoweth, 1989).

in New Mexico and 37.8% of the total uranium production in the United States. New Mexico ranks second in uranium reserves in the U.S., with reserves of 15 million short tons of ore at 0.277%  $U_3O_8$  (84 million lbs  $U_3O_8$ ) at \$30/lb (Fig. 6). The Department of Energy classifies uranium reserves into forward cost categories of \$30 and \$50 per lb. Forward costs are operating and capital costs (in current dollars) that are still to be incurred to produce uranium from estimated reserves. All of New Mexico's uranium reserves in 2002 are in the Morrison Formation in the San Juan Basin,

Uranium ore bodies are found mostly in the Westwater Canyon, Brushy Basin, and Jackpile Sandstone Members of the Morrison Formation. Typically, the ore bodies are lenticular, tabular masses of complex uranium and organic compounds that form roughly parallel trends; fine- to medium-grained barren sandstone lie between the ore bodies.

Nearly 6.7 million lbs of uranium oxide ( $U_3O_8$ ) have been produced from uranium deposits in limestone beds of the Todilto Member of the Wanakah Formation (Jurassic). Uranium deposits in the Todilto limestone are similar to primary sandstone-hosted uranium deposits; they are tabular, irregular in shape, and occur in trends. Most deposits contain less than 20,000 tons of ore averaging 0.2-0.5%  $U_3O_8$ , although a few deposits were larger. Uranium is found only in a

few limestones in the world, but, of these, the deposits in the Todilto limestone are the largest and most productive. However, uranium has not been produced from the Todilto Member since 1981, and it is unlikely that any additional production will occur in the near future.

Other uranium deposits in New Mexico are hosted by other sedimentary rocks or are in fractured-controlled veins or in igneous or metamorphic rocks. Production from these deposits has been insignificant (Fig. 5) and it is unlikely that any production will occur from them in the near future.

### FUTURE POTENTIAL

The potential for uranium production from New Mexico in the near future is dependent upon international demand for uranium, primarily for fuel for nuclear power plants. Currently, nuclear weapons from the former U.S.S.R. and the U.S. are being converted into nuclear fuel for nuclear power plants, reducing the demand for raw uranium. In addition, higher-grade, lower-cost uranium deposits in Canada and Australia are sufficient to meet current international demands. Thus, it is unlikely that conventional underground mining of uranium in New Mexico will be profitable in the near future. However, mine-water recovery and in situ leaching of the sandstone-hosted uranium deposits in the Grants uranium district are

Type of deposit	Production (lbs $U_3O_8$ )	Period of production (yrs)	Production per total in New Mexico (%)
Primary, redistributed, remnant sandstone uranium deposits (Morrison Formation, Grants district)	332,107,000 <sup>1</sup>	1951–1989	95.4
Mine-water recovery	8,317,788	1963–2000	2.4
Tabular sandstone uranium deposits (Morrison Formation, Shiprock district)	493,510	1948–1982	0.1
Other Morrison sandstone uranium deposits	991	1955–1959	—
Other sandstone uranium deposits	468,680	1952–1970	0.1
Limestone uranium deposits (Todilto Formation)	6,671,798	1950–1985	1.9
Other sedimentary rocks with uranium deposits	34,889	1952–1970	—
Vein-type uranium deposits	226,162	1953–1966	—
Igneous and metamorphic rocks with uranium deposits	69	1954–1956	—
<b>Total in New Mexico</b>	<b>348,321,000<sup>1</sup></b>	<b>1948–2000</b>	<b>100</b>
<b>Total in United States</b>	<b>922,870,000<sup>1</sup></b>	<b>1947–2000</b>	<b>37.8 of total U.S.</b>

**FIGURE 5** Uranium production in New Mexico (McLemore and Chenoweth, 1989; production from 1988-2000 estimated by the author). <sup>1</sup>Approximate numbers rounded to the nearest 1,000 lbs.

Total U.S. production from McLemore and Chenoweth (1989) and Energy Information Administration (2001).



State	ore (million tons)	\$30 per lb grade (% U <sub>3</sub> O <sub>8</sub> )	U <sub>3</sub> O <sub>8</sub> (million lbs)	ore (million tons)	\$50 per lb grade (% U <sub>3</sub> O <sub>8</sub> )	U <sub>3</sub> O <sub>8</sub> (million lbs)
New Mexico	15	0.277	84	102	0.166	341
Wyoming	42	0.129	110	240	0.077	370
Arizona, Colorado, Utah	7	0.288	41	42	0.138	115
Texas	4	0.079	7	19	0.064	24
Other	7	0.202	29	25	0.107	54
<b>Total</b>	<b>76</b>	<b>0.178</b>	<b>271</b>	<b>428</b>	<b>0.106</b>	<b>904</b>

**FIGURE 6** Uranium reserves by forward-cost category by state, 2000 (Energy Information Administration, 2001). The DOE classifies uranium reserves into forward cost categories of \$30 and \$50 per lb.

Forward costs are operating and capital costs (in current dollars) that are still to be incurred to produce uranium from estimated reserves.

likely to continue as the demand and price of uranium increase in the next decade.

Only one company in New Mexico, Quivira Mining Co. owned by Rio Algom Ltd. (successor to Kerr McGee Corporation), produced uranium in 1989-2001, from waters recovered from inactive underground operations at Ambrosia Lake (mine-water recovery). Hydro Resources Inc. has put its plans on hold to mine uranium by in situ leaching at Churchrock until the uranium price increases. Reserves at Churchrock are estimated as 15 million lbs of U<sub>3</sub>O<sub>8</sub>. NZU Inc. also is planning to mine at Crownpoint by in situ leaching. Rio Grande Resources Co. is maintaining the closed facilities at the flooded Mt. Taylor underground mine, in Cibola County, where primary sandstone-hosted uranium deposits were mined as late as 1989. In late 1997 Anaconda Uranium acquired the La Jara Mesa uranium deposit in Cibola County from Homestake Mining Co. This primary sandstone-hosted uranium deposit, discovered in the late 1980s in the Morrison Formation, contains approximately 8 million lbs of 0.25% U<sub>3</sub>O<sub>8</sub>. Future development of these reserves and resources will depend upon an increase in price for uranium and the lowering of production costs.

## ACKNOWLEDGMENTS

This work is part of ongoing research of mineral resources in New Mexico and adjacent areas currently underway at the New Mexico Bureau of Geology and Mineral Resources.

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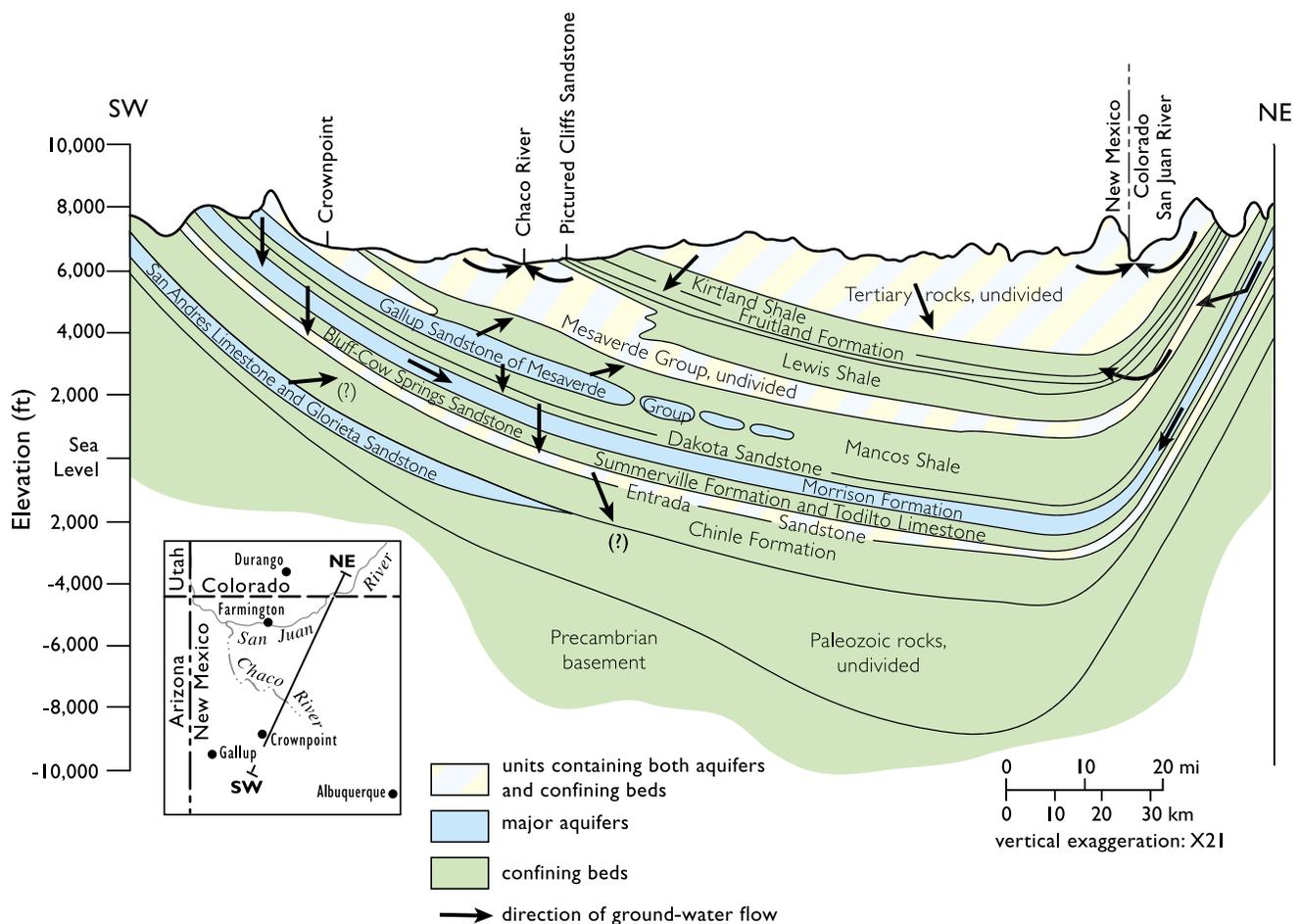
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# Ground Water and Energy Development in the San Juan Basin

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The San Juan Basin is classified as an arid region: most of the area receives less than 10 inches of precipitation a year. Mean annual precipitation in marginal mountainous regions may be as much as 30 inches a year, but surface water is scarce, except for the San Juan River and its tributaries in the northern part of the basin. Most water users, therefore, depend on ground-water supplies. The San Juan Basin contains a thick sequence of sedimentary rocks (more than 14,000 ft thick near the basin center). Most of these are below the water table and therefore saturated with ground water (Fig. 1). Many of these are the very

same strata that contain the energy resources of the San Juan Basin: coal, oil, gas, and uranium. Water plays a key but varying role in the development of each of these energy resources. The purposes of this paper are to 1) briefly describe the ground-water resources of the San Juan Basin and 2) suggest their role in energy-resource development there. Information presented comes from various previous studies done by the New Mexico Bureau of Geology and Mineral Resources, or by New Mexico Tech graduate students funded by the bureau.



**FIGURE 1** Hydrogeologic cross section of the San Juan Basin. Major aquifers are blue; confining beds are green; units containing both are crosshatched.



## WHERE AND HOW DOES THE GROUND WATER OCCUR?

Ground-water occurrence may be described in three ways: the rock unit containing the ground water, the pressure condition under which the water exists, and depth to the ground water. Most of the useable ground water exists in rocks with open space between grains, rather than in fractures. The specific rock units yielding useful quantities of water to wells (aquifers) vary with location. In the northeastern part of the basin, sandstones of Tertiary age are the best targets for ground water. In the western and southern parts of the basin, the most successful wells tap Mesozoic sandstones. Only along the northern flank of the Zuni Mountains, east of Gallup, New Mexico, are productive wells completed in fractured rock (Permian limestone).

Most of the ground water in the San Juan Basin exists under confined (artesian) or semi-confined hydrologic conditions: under pressure, prevented from seeking its own level by an overlying rock unit of low permeability (aquitard). In the Mesozoic rocks of this region, the artesian sandstone aquifers are interbedded with shales that behave as low-permeability, confining aquitards. The Triassic mudrock sequence is the aquitard for the Permian limestone. By contrast, ground water in the alluvium along streams and in the shallow Tertiary sandstone aquifers is generally unconfined: the water is not under pressure, not overlain by an aquitard, and is open to the atmosphere through pores in overlying permeable rocks.

The depth to ground water varies from place to place, because of the slope of the water table and dip of the strata. The depth to water in unconfined aquifers is the depth to the top of saturation or the regional water table, which varies from less than 100 ft to several hundred feet, depending on the aquifer in question and the overlying topography. In the case of confined aquifers, there are two different depths to water: one before it is penetrated by a well, and one after penetration has occurred. Before well construction, the depth to water is the same as the depth to the top of the confined or artesian aquifer. Depths to the top of a specific confined aquifer also vary throughout the basin due to the dip of the strata. Depth to the Tertiary sandstones (for example, Ojo Alamo Sandstone) varies from less than 100 ft to as much as 4,000 ft; depth to the deepest sandstone aquifer widely used (Westwater Canyon Sandstone Member of the Morrison Formation) varies from less than 100 ft to nearly 9,000 ft.

After a confined aquifer is penetrated by a well, water rises above the top of the aquifer. The level to which it rises is called the potentiometric surface. Each artesian aquifer in the basin has its own potentiometric surface. The depth or elevation of this surface also varies across the basin, depending upon the dip of the strata and the pressure of the confined ground water.

## WHICH WAY DOES THE GROUND WATER FLOW?

In the San Juan Basin, as elsewhere, ground water flows from higher elevation recharge areas (mountains), located around the basin margin, toward lower elevation discharge areas (rivers). Northwest of the continental divide, ground water flows toward the San Juan River or Little Colorado River. Southeast of the divide, it flows toward the Rio Grande.

## HOW FAST DOES THE GROUND WATER MOVE?

The rate of water movement in an aquifer depends on its hydraulic properties (porosity and permeability) and the hydraulic gradient (steepness of the water table or potentiometric surface). Thus, the rate of movement varies from aquifer to aquifer. Ground-water modeling has suggested rates for total ground-water inflow and outflow in the basin. These rates are 20 cubic feet per second (ft<sup>3</sup>/s) or approximately 9,000 gallons per minute (gpm) for the Tertiary sandstones and 40 ft<sup>3</sup>/s or approximately 18,000 gpm for the Cretaceous and Jurassic sandstones.

## HOW GOOD IS THE WATER?

Water is of good quality near basin-margin recharge areas, but deteriorates with distance along its flow path as it dissolves minerals. A general measure of water quality is salinity. This is commonly evaluated by specific conductance, a measure of a water's ability to conduct electricity. Values are reported in the strange unit of microSiemens/centimeter (uS/cm). The lower the number, the better is the water quality. Values of less than 1,000 uS/cm generally indicate potable water. Values for valley-fill alluvium are generally less than 1,000 uS/cm in headwater areas and greater than 4,000 uS/cm in downstream reaches, due to discharge of deeper water from bedrock. Specific conductance of water from sandstone aquifers ranges from less than 500 uS/cm near outcrop to almost 60,000 uS/cm at depth.

Bicarbonate content is relatively high in waters hav-

ing specific conductance values of as high as 1,000 uS/cm. Sodium, sulfate, and chloride are major dissolved components in ground water having specific conductance values of as high as 4,000 uS/cm

### HOW MUCH GROUND WATER IS THERE?

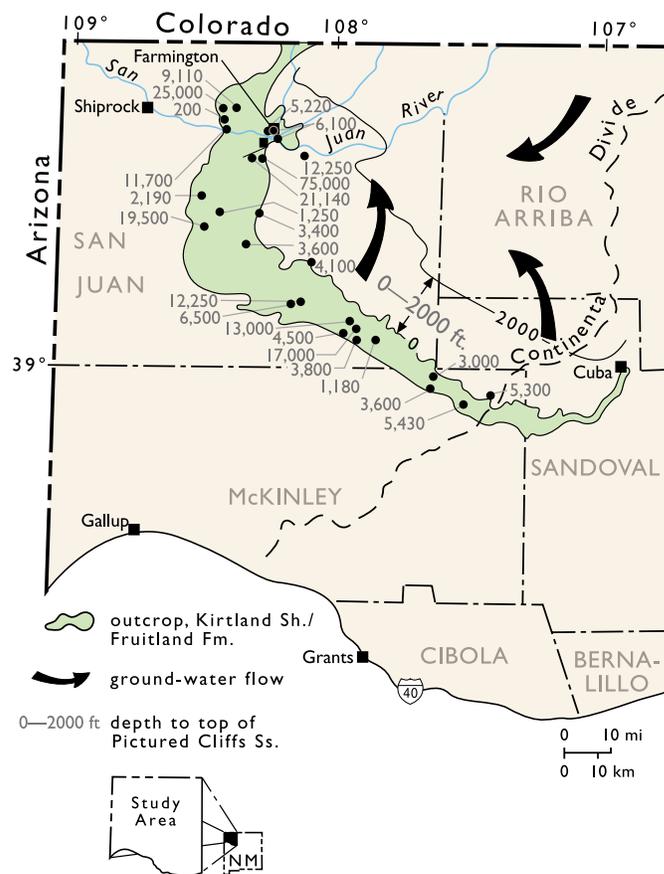
Ground water in most of the region is very old. Studies at the Navajo mine showed the long-term ground-water recharge rate to be very low (0.02 inches/yr). Pumping of aquifers far exceeds this recharge rate and thus results in the depletion of ground-water resources that cannot be replaced in the foreseeable future. It has been estimated that as much as 2 million acre-feet of slightly saline ground water (having less than 2,000 milligrams per liter of total dissolved solids) could be produced from the confined aquifers in the San Juan Basin with a water-level decline of 500 ft. Although that is a lot of untapped water, it is too salty for many uses and installing wells that could handle the anticipated 500-ft drop in water level would be very expensive.

### WHAT ARE THE IMPLICATIONS FOR ENERGY DEVELOPMENT?

Water is an important component in the development of the basin's energy resources. Both water quantity and quality issues must be considered. Is there a sufficient supply of good-quality water for development needs? Does development impact local or regional water quantity and quality? The answers vary from resource to resource.

**Coal** Coal is currently being extracted by strip-mining methods. Water plays a key role in various aspects of such extraction, and water supply is therefore an issue. Large amounts of water are needed for the mine-mouth, coal-fired power plants (for steam generation) as well as for reclamation (especially revegetation). However, quality of water in the principal coal-bearing unit (Fruitland Formation) is poor (Fig. 2). Thus, water for coal-mining needs has historically come from the San Juan River, especially in the northern part of the basin. Irrigation associated with revegetation may flush salts from the unsaturated zone to the first underlying sandstone. Although the quality of ground water in that rock is so poor that it is not being used, it discharges to the San Juan River and may increase salt loads there.

**Oil and Gas** The main issue in petroleum extraction is the potential for contamination of fresh ground-water supplies by produced brine or hydrocarbon spills. On average, six barrels of water are produced



**FIGURE 2** Generalized flow directions and quality of water in the Kirtland Shale/Fruitland Formation, undivided. Units shown are in  $\mu\text{S}/\text{cm}$ .

for every barrel of oil produced. The practice of collecting water and oil in unlined drip pits has been outlawed. However, confined brine may mix with shallower fresh water in older wells where casings and/or seals have deteriorated. The integrity of existing wells should be checked periodically, and abandoned wells should be properly decommissioned to prevent contamination.

**Coalbed Methane** Water is also produced in coalbed-methane development. Unlike the brine associated with petroleum extraction, this water may be fairly fresh. In an arid region like the San Juan Basin, such water should not be wasted by injecting it into a deep saline aquifer, as is often done with brine from oil wells. However, water rights must be obtained from the state engineer before it can be put to beneficial use. Work is under way to clarify this issue and develop a protocol for beneficial use of produced water. However, much more work is needed on the hydrologic system(s) involved, water treatment, technologies



for reducing the quantities produced and markets for beneficial use.

**Uranium** Underground mining of uranium was once intense in the Grants mineral belt. Water supply was not an issue, as the large volumes withdrawn in dewatering (the process of pumping water out of the mine) from the major uranium-bearing unit (Morrison Formation) were of good quality and readily met water needs. Some of the freshest water in the basin is associated with the Morrison Formation (Fig. 3). However, both water quantity and quality were impacted in places. Ground-water modeling showed that had dewatering continued, water-level declines would have been felt all the way to the San Juan River by the year 2000. Dewatering also lowered artesian pressures such that vertical gradients were locally reversed (became downward instead of upward), permitting poor-quality water in one Cretaceous sandstone to flow downward into the underlying Jurassic sandstone aquifer containing good-quality water. Although that mining activity has ceased, sizable reserves of uranium remain in the ground. Such

water-quantity impacts will recur should uranium prices warrant renewed underground mining. However, current interest centers on in situ extraction. The Navajo Nation and environmental groups are still protesting the feasibility of such mining, in view of the potential impact on ground-water quality.

### SUMMARY

Ground water and energy development are intimately related in the San Juan Basin. As a result, there is both good news and bad news.

#### • **The good news:**

- 1 Ground water is associated with the same rocks as the energy resources, so there may be a ready supply.
- 2 Studies have shown that there are large amounts of water of moderate quality in various aquifers, at various depths, in various locations.

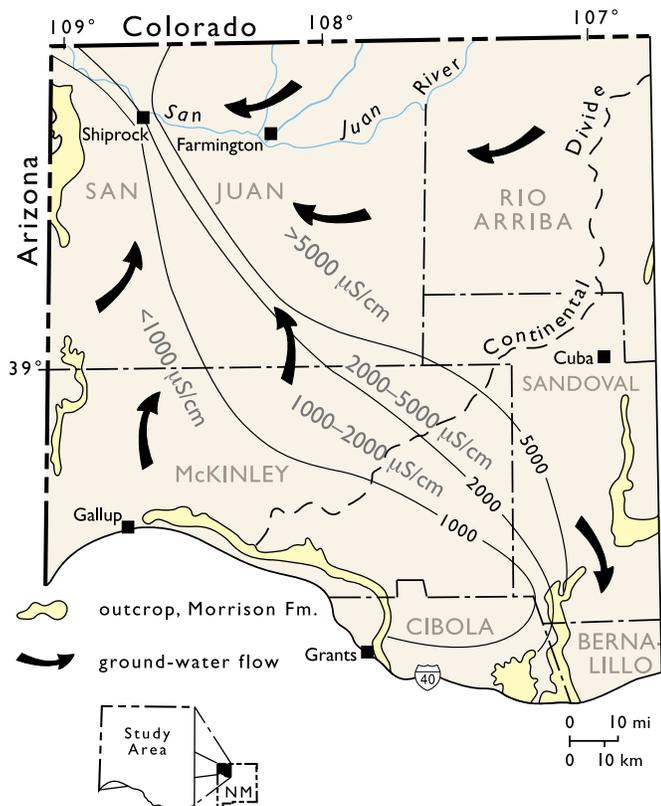
#### • **The bad news:**

- 1 Ground water is associated with the same rocks as the energy resources, so it is vulnerable to quantity and quality impacts.
- 2 Water demands are increasing among the major non-industrial water users, including Indian reservations, municipalities, irrigators, and ranchers.
- 3 As demands of these users along the San Juan River and its tributaries grow beyond their present surface-water supplies, they will have to look to ground-water sources for additional water.
- 4 At that point, energy developers in the San Juan Basin will be in direct competition for ground water with other users.

Thoughtful regional planning and frequent environmental surveillance will be essential for sound management and protection of ground water in this multiple water-use area. Successful energy development will be compatible with regional water-use goals.

### ADDITIONAL READING

- Stone, W. J., 1999, *Hydrogeology in practice—a guide to characterizing ground-water systems*: Prentice Hall, Upper Saddle River, New Jersey, 248 pp.
- Stone, W. J., 2001, *Our water resources—an overview for New Mexicans*: New Mexico Bureau of Mines and Mineral Resources, Information Series 1, 37 pp.



**FIGURE 3** Generalized flow direction and quality of water in the Morrison Formation.

# OIL AND NATURAL GAS ENERGY

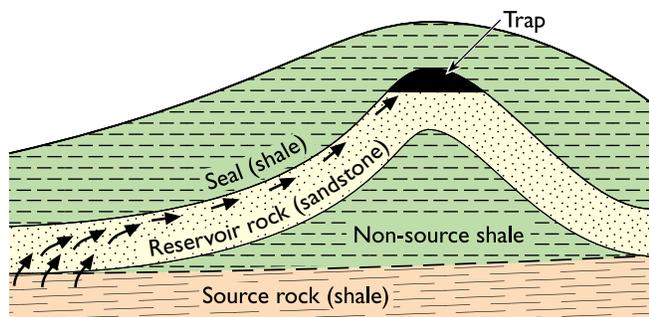
DECISION-MAKERS  
FIELD CONFERENCE 2002  
San Juan Basin



## The Origin of Oil and Gas

Ron Broadhead, *New Mexico Bureau of Geology and Mineral Resources*

We will pass through a number of oil and natural gas fields during this field conference. The oil and gas that are produced from these fields reside in porous and permeable rocks (reservoirs) in which these liquids have collected and accumulated throughout the vast expanse of geologic time. Oil and gas fields are geological features that result from the coincident occurrence of four types of geologic features (1) oil and gas source rocks, (2) reservoir beds, (3) sealing beds, and (4) traps. Each of these features, and the role it plays in the origin and accumulation of oil and gas, is illustrated below (Fig. 1).

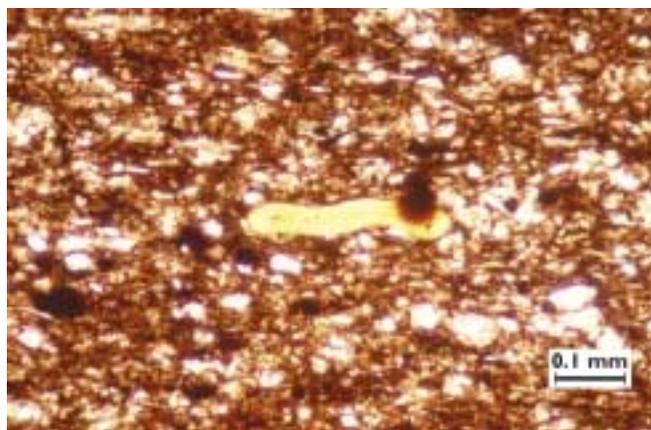


**FIGURE 1** Natural accumulation of oil and gas.

### OIL AND GAS SOURCE ROCKS

Oil and natural gas originate in petroleum source rocks. Source rocks are sedimentary rocks that formed from sediments deposited in very quiet water, usually in swamps on land or in deep marine settings. These rocks are composed of very small mineral fragments. In between the mineral fragments are the remains of organic material (usually algae), small wood fragments, or pieces of the soft parts of land plants (Fig. 2). When these fine grained sediments are buried by younger, overlying sediments, the increasing heat and pressure resulting from burial turns the soft sediments into hard layers of rock. If further burial ensues, then temperatures continue to increase. When temperatures of organic-rich sedimentary rocks exceed 120° C (250° F), the organic remains within the rocks begin to be “cooked,” and oil and natural gas are expelled. It

takes millions of years for these source rocks to be buried deep enough to attain these maturation temperatures. It takes many more millions of years to generate commercial accumulations of oil and natural gas, and for these accumulations to migrate into adjacent reservoir rocks.



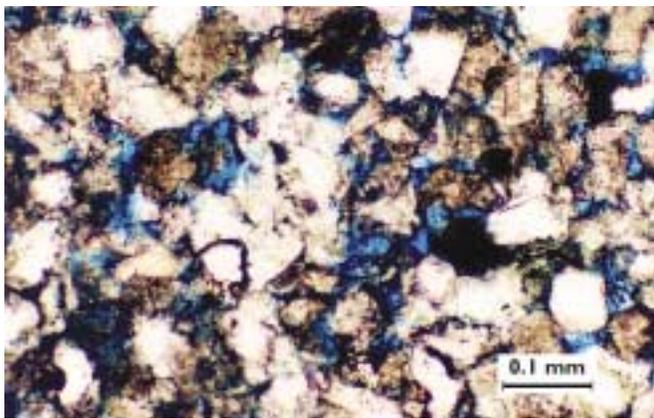
**FIGURE 2** Microscopic image of a source rock with mineral grains (lighter colored material) and organic matter which is mostly algae remains (brown to black and yellow colored material). The source rock will usually act as a seal.

If the organic materials within the source rock are mostly wood fragments, then the primary hydrocarbon generated upon maturation is natural gas. If the organic materials are mostly algae or the soft parts of land plants, then both oil and natural gas are formed. By the time the source rock is buried deep enough to reach temperatures above 150° C (300° F), the organic remains have produced most of the oil they are able to produce. Above these temperatures, any oil remaining in the source rock or trapped in adjacent reservoirs will be broken down into natural gas. So, gas can be generated in two ways: it can be generated directly from woody organic matter in the source rocks, or it can be derived by thermal breakdown of previously generated oils at high temperatures.



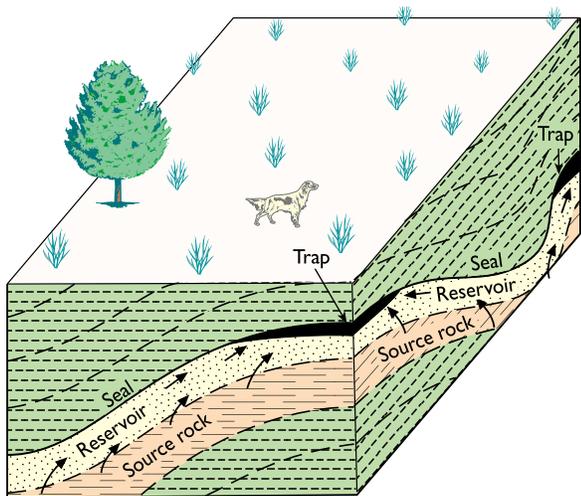
**OIL AND GAS RESERVOIR ROCKS**

Oil and gas reservoir rocks are porous and permeable. They contain interconnected passageways of microscopic pores or holes between the mineral grains of the rock (Fig. 3). When oil and gas are naturally expelled from source rocks, they migrate into adjacent reservoir rocks.



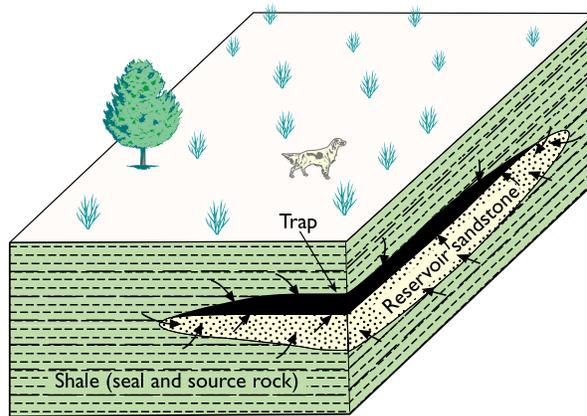
**FIGURE 3** Microscopic image of a sandstone reservoir rock. The pore spaces (blue) may be occupied by oil, gas, or water.

Once oil and gas enter the reservoir rock, they are relatively free to move. Most reservoir rocks are initially saturated with saline ground water. Saline ground water has a density of more than 1.0 g/cm<sup>3</sup>. Because oil and gas are less dense than the ground water (the density of oil is 0.82–0.93 g/cm<sup>3</sup>; the density of natu-



**Structural trap**

**FIGURE 4** Folded strata that form a structural trap.



**Stratigraphic trap**

**FIGURE 5** A discontinuous layer of sandstone that forms a stratigraphic trap.

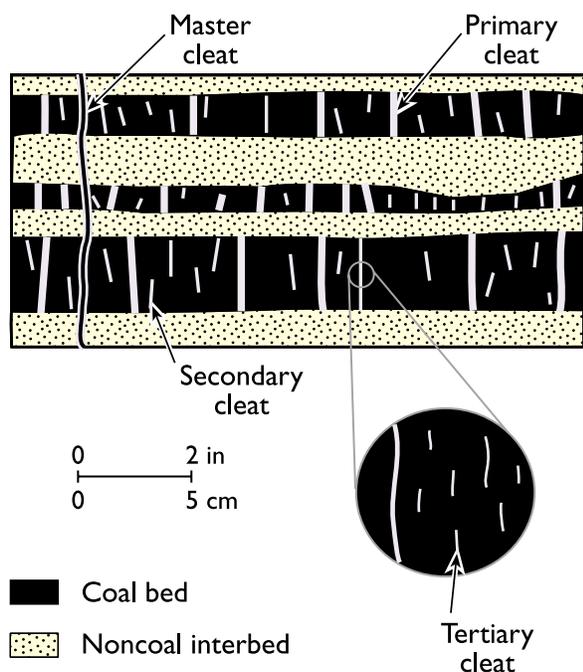
ral gas is 0.12 g/cm<sup>3</sup>), they rise upward through the water-saturated pore spaces until they meet a barrier of impermeable rock (Fig. 2)—a seal. Seals generally are very fine grained rocks with no pore spaces or pore spaces that are too small to permit the entry of fluids.

**OIL AND GAS TRAPS**

Once in the reservoir rock, the oil and natural gas continue to migrate through the pore spaces until all further movement is blocked by the physical arrangement of the reservoir rock and one or more seals. This arrangement of the reservoir and seals is called a trap (Fig. 1).

There are two main types of traps: structural and stratigraphic (Figs. 4–5). Structural traps are formed when the reservoir rock and overlying seal are deformed by folding or faulting. Usually this deformation takes place tens of millions of years after deposition of the sediments that serve as seals and reservoir rocks. The oil and gas migrate upward through the reservoir and accumulate in the highest part of the structure (Fig. 4). If both oil and gas are present, the gas will form a layer (within the pore spaces) that rests above a layer of oil, because natural gas is less dense than the oil. The layer of oil will, in turn, rest upon the water-saturated part of the reservoir.

Stratigraphic traps (Fig. 5) are formed when the reservoir rock is deposited as a discontinuous layer. Seals are deposited beside and on top of the reservoir. A common example of this type of trap, of which there are many examples in the San Juan Basin, is a coastal barrier island, formed of an elongate lens of



**FIGURE 6** Diagram of vertical slice through coal reservoirs, showing vertical distribution of cleats (fractures) in the coal. From New Mexico Bureau of Geology and Mineral Resources, Bulletin 146.

sandstone. Impermeable shales that later serve as seals are deposited both landward and seaward of the barrier island. The result is a porous sandstone reservoir surrounded by shale seals. These same shales may also be source rocks.

### COALBED METHANE

Coal can act as both a source rock of natural gas and a reservoir rock. When this is the case, coalbed methane (“coal gas”) can be produced. The gas is generated from the woody organic matter that forms the coals. At shallow burial depths, relatively low volumes of gas may be generated by bacterial processes within the coals. At greater burial depths, where temperatures are higher, gas is generated thermally (as in conventional source rocks described above). Greater volumes of gas are generally formed by the thermal processes than by the bacterial processes. In the San Juan Basin gas has been formed through both processes.

Most coals are characterized by pervasive networks of natural fractures (Fig. 6). In the deep subsurface, these fractures are filled with water. The pressure exerted by this water holds the gas within the coal. In order to produce gas from the coal, first the water must be pumped out of the fractures. Once this is

done, then the gas moves into the fractures, from where it may then be retrieved. The water that is first produced must be disposed of in a way that complies with existing regulations (see paper by Olson, this volume).

### SUMMARY

Oil and natural gas are generated from the remains of organisms deposited in fine-grained sedimentary rocks along with the mineral grains that make up those rocks. As these source rocks are buried by overlying sediments, the organic matter is converted to oil and natural gas, first through bacterial processes and later by high temperatures associated with burial to a depth of several thousand feet. The oil and gas are then expelled from the source rocks into adjacent porous reservoir rocks. Because the oil and gas are less dense than the water that saturates the pores of the reservoir rocks, they rise upward through the pore system until they encounter impermeable rocks. At this point, the oil and gas accumulate, and an oil or gas field is formed.



## The “Nuts and Bolts” of New Mexico’s Oil and Gas Industry

Brian S. Brister, *New Mexico Bureau of Geology and Mineral Resources*

Since the early 1920s New Mexicans have enjoyed the benefits of a thriving petroleum (oil and natural gas) industry that today provides thousands of jobs and hundreds of millions of dollars in state revenues. However, relatively few citizens of the state have a basic understanding of, or appreciation for, the basic elements of petroleum production, processing, transportation, and distribution systems required for a viable industry. The “nuts and bolts” referred to here are the infrastructure and processes required for the industry to accomplish its job of delivering an end product to the consumer market. It is important to understand that all of the components of the production-through-distribution cycle are necessary in order for the industry to function and provide the fuels and products upon which we rely.

Petroleum industry infrastructure varies significantly depending upon the raw materials produced and the needs of the end user. Production in the San Juan Basin is dominated by natural gas, although crude oil is also produced. Production in the Permian Basin of southeastern New Mexico is dominated by crude oil, but natural gas production is also significant (see paper by Laird Graeser in this volume). End consumers are found all over the Southwest, with California being an important market, particularly for natural gas. This article will focus on infrastructure in the San Juan Basin, but common to the “oil patch” in general.

### WHAT ARE OIL AND NATURAL GAS?

Natural gas and crude oil naturally reside in underground reservoirs. Crude oil, typically liquid at surface temperature and pressure, is a complex mix of hydrocarbon molecules (molecules that contain hydrogen and carbon) and non-hydrocarbon molecules. Crude oil in the reservoir often contains light hydrocarbons in solution that bubble out of the oil as natural gas at the surface (sometimes called “casing-head gas”). San Juan Basin oil reservoirs tend to have a significant amount of associated gas. In fact, today the gas from these wells is more volumetrically and economically significant than the oil. Oil-producing reservoirs in the San Juan Basin are limited to the

flanks of the basin, whereas basin-center reservoirs are gas productive. Both crude oil and natural gas must be refined to yield the varied fuels and petrochemicals that we consume.

Gas in its natural state is somewhat different from the natural gas we consume, and it may or may not be associated with oil. As produced at the wellhead, natural gas is a mixture of light hydrocarbons including methane, ethane, propane, and butane. It also may contain variable amounts of nitrogen, carbon dioxide, hydrogen sulfide, and perhaps traces of other gases like helium. Condensate (a.k.a. “drip gas”) is a light oil byproduct of cooling natural gas as it rises to the surface in the well. More than half of the natural gas produced in the San Juan Basin is from coalbed methane (CBM). CBM is a simpler mix of methane and carbon dioxide. Gas that is transported in major interstate pipelines and sold as burner-tip fuel for heating is almost all methane, with a heating value of 1,000 BTU per mmcf, where BTU stands for British Thermal Units and mmcf stands for million cubic feet of gas. This “standard” gas is what we rely upon as consumers. In order to produce standard gas, non-methane hydrocarbons (that increase BTU value), and non-hydrocarbons (that decrease BTU value) must be removed from the gas stream.

### UPSTREAM AND DOWNSTREAM

The terms “upstream” and “downstream” are often heard, but what do they mean? Upstream operations are those that involve extracting crude oil or natural gas from a natural underground reservoir and delivering it to a point near the well site, such as an oil tank or gas meter. From here it is sold by independent producers to refiners or pipeline companies who may or may not be the ultimate marketers of the product. Downstream operations are those that include gathering, transporting, and processing of the oil or natural gas and distributing the final products, including standard natural gas and refined products like gasoline. A variety of processes and equipment are required in the upstream and downstream industries. Each step of the production-to-distribution cycle tends to create added value and employs skilled workers in well-paying New Mexico-based jobs.

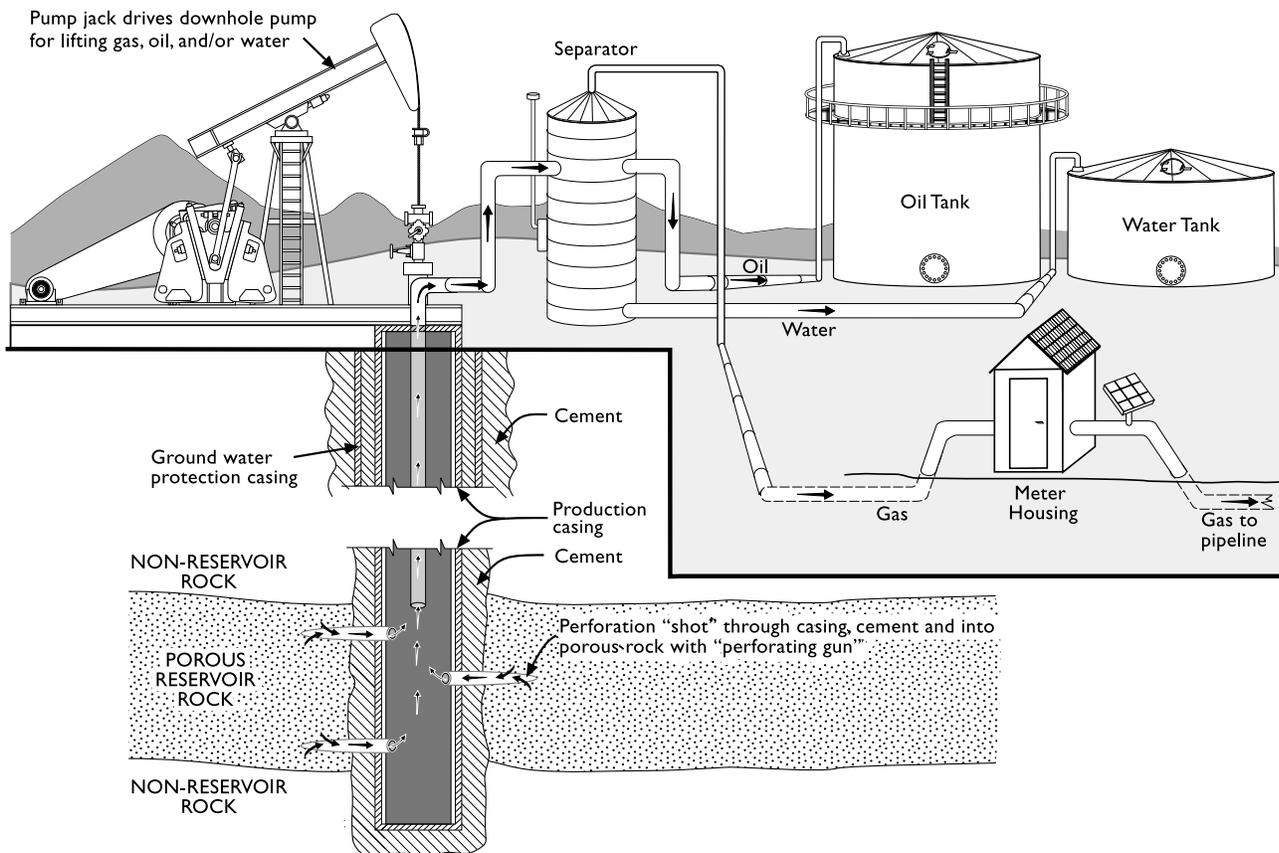
## UPSTREAM INFRASTRUCTURE

Although many companies continue to explore for new reservoirs, New Mexico is generally considered to be a “mature” petroleum province, in that a large number of reservoirs have been found and developed to full production potential. For this reason, there is extensive upstream infrastructure in the producing New Mexico counties. At one time these producing fields were the assets of major integrated oil companies, but today these fields have been largely divested to smaller independent producers, many of whom are headquartered here in New Mexico. Associated with these fields are the easily recognized pumpjacks and tank batteries (row of tanks) that dot our landscape. But there is more there than meets the eye. Figure 1 illustrates typical upstream equipment associated with individual or small clusters of wells.

Below the surface of the ground at each well, there are miles of steel alloy well casing designed to withstand the

heat and pressure encountered in the underground environment, carefully treated to withstand a corrosive environment and remain functional through the predicted life of the field. Two or more casing strings are installed in each well, cemented into the drill hole in order to prevent contamination of fresh water and mixing of fluids between porous formations. Within the production casing is a string of production tubing, which conveys reservoir fluids to the surface. Where gas is produced, the gas flows under its own pressure up the tubing. In wells where liquids are produced, a downhole pump, driven by the pumpjack at the surface alternately raising and lowering a single string of interconnected solid rods, acts as a plunger to lift the liquid to the surface.

At the surface the wellhead caps the casing and tubing and directs the produced fluids toward temporary storage. Wellheads on gas wells, commonly called “Christmas trees,” typically stand tall in order to provide



**FIGURE 1** Upstream infrastructure of oil and natural gas production.

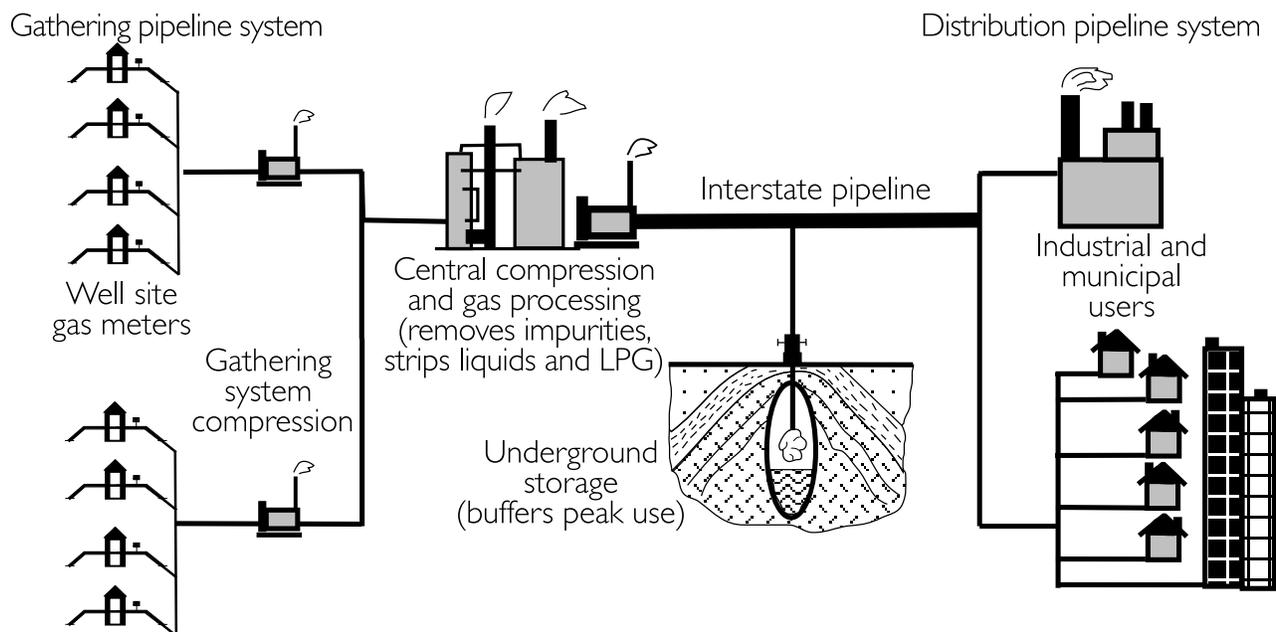


FIGURE 2 Downstream natural gas infrastructure.

working room for servicing the high-pressured well. After leaving the wellhead, the fluids will go to a separator in order to separate gas from oil and/or water that is sometimes produced from the well with the gas. Once separated, the oil flows to an above-ground storage tank, the water flows to a water tank, and gas flows through a meter and into a pipeline. If water is produced, there may be equipment nearby to pump it back into the reservoir to maintain reservoir pressure or the water may be trucked or piped to an approved subsurface-disposal facility.

### DOWNSTREAM INFRASTRUCTURE

Downstream infrastructure includes a complex network of transportation, processing and refining, storage, delivery, and sales networks that span the continent.

In the San Juan Basin, oil is typically collected at or near the well site from the tank battery and trucked to a pipeline terminal, although some 20% is trucked directly to the refinery. Some larger fields may deliver oil directly to a pipeline. Either way, much of the crude oil arrives at a refinery (for example, the Giant Industries, Inc. Bloomfield refinery) via pipeline where it is then temporarily stored in above-ground

tanks in a tank farm. The largest tanks may hold several million gallons.

The refinery processes the oil to create familiar end products such as gasoline, diesel, jet fuel, kerosene, lubricating oil, asphalt, and petrochemical feedstocks. Processes such as distillation and catalysis essentially “crack” the complex and heavy hydrocarbon molecules in the oil to create the various products. The reforming process creates desirable molecules following cracking, generally to increase octane of the gasoline fraction. Unwanted parts of the crude oil, such as sulfur, are removed in the scrubbing process.

The primary product of most refineries is transportation fuel, which is stored at the refinery tank farm awaiting shipment via product pipeline or truck transport to tank farms at distribution terminals near larger cities. These terminals are the hub for truck transportation to retail outlets.

Due to the low dollar value per volume of natural gas, trucking is not a viable option for transporting it; it must therefore be transported by pipeline. The processes and related infrastructure for gas production can be summarized in key components shown in Figure 2. Gas is compressible; as it is stuffed into a smaller space, its pressure rises. On the other hand, as pressure is reduced, it expands. This useful property

provides the mechanism for gas to flow from one point to another (from high to low pressure) through the pipeline system. San Juan Basin gas wells produce relatively low-pressure gas that must undergo several stages of compression (pressure increase) upon leaving the well site gas meter. A gathering system of pipelines transports the gas to a central hub, where the gas is compressed before entering the next pipeline stage.

At strategic points along the pipeline system, but generally before it enters an interstate pipeline, the gas is processed at a gas plant (such as the Williams Field Services gas plant at Lybrook, New Mexico) to separate certain natural components from the standard quality “residue” gas desirable for interstate transport and distribution. The chemical characteristics of the gas produced at the well determine the processing that will take place. For example, if the natural gas is relatively high in carbon dioxide, as is typical for coalbed methane, an extraction facility uses an exothermic (heating) chemical reaction to extract the offending component. In this example, not only is the BTU value of the gas upgraded, but a corrosive component is removed, thus protecting the integrity of the interstate pipeline. Natural gas produced from conventional (non-coalbed methane) reservoirs tends to be rich in ethane, butane, and propane. These hydrocarbons are extracted through a cryogenic (cooling) process. Butane and propane are the components of LPG or liquefied petroleum gas (which stays liquid while pressurized) used as a natural gas substitute in areas not served by the natural gas pipeline system.

Once standard natural gas enters the interstate transportation pipeline system, it may move through several hubs. Along the way, gas may be temporarily stored at strategic places in underground salt caverns or old gas fields in order to meet seasons of peak demand. Gas is eventually delivered to a utility, which then delivers the gas through a distribution pipeline network to the consumer. Typically, natural gas changes ownership multiple times along the gathering, transportation, and distribution system.

### **WHAT DOES THE FUTURE HOLD?**

The role of new and evolving technologies should never be discounted. We are ever more creative in improving the efficiency of our fossil fuel energy infrastructure. Such efficiencies are designed to extract more value from the raw material. Automation, safety improvements, and improved environmental compliance are on the forefront of engineering research. In the future the uses of oil and natural gas will likely change. A new trend is the increasing use of low-emission natural gas turbines to generate electricity during peak demand. Natural gas-based fuel cells powering portable electric motors may one day replace the gasoline-fueled internal combustion engine as the transportation engine of choice. Future improvements in processes and minimization of environmental impacts will ensure that New Mexico’s home-grown oil and gas industry will continue to provide responsibly for the needs of New Mexico and the Southwest for many decades to come.



# The Oil and Gas Industry in New Mexico— An Economic Perspective

Laird Graeser, *Independent Tax Consultant*

It has been said, “if you live in New Mexico, you’re in the oil and gas business.” This “old saw” has traditionally been undeniably true, and is, to this day, more true than generally held. The “oil patch” extends over four counties in the northwest part of the state, four counties in the southeast, and portions of four other counties elsewhere in the state (Fig. 1). The impacts of the industry on air and water quality, the environment, state and local revenues, and the overall state economy are pervasive. The values of crude oil and natural gas production are strongly linked to state-wide employment and the gross state product. Direct and indirect links simultaneously can be demonstrated with respect to state and local revenues – primarily gross receipts tax revenue. However, the purpose of this paper is to present a survey, not a detailed econometric analysis of these linkages.

## PRODUCTION VOLUMES AND VALUES

San Juan Basin (northwest NM)	Permian Basin (southeast NM)	Other
McKinley (gas & oil)	Chaves (gas & oil)	Colfax (gas)
San Juan (gas & oil)	Eddy (gas & oil)	Harding (CO <sub>2</sub> )
Sandoval (gas & oil)	Lea (gas & oil)	Quay (CO <sub>2</sub> )
Rio Arriba (gas & oil)	Roosevelt (gas & oil)	Union (CO <sub>2</sub> )

FIGURE 1 The oil patch in New Mexico (by county).

Note that over a long period of time, there does not appear to be a predictable relationship between gas price and gas volume (Fig. 2a). The lagging price change ten years after changes in volume is clearly spurious and not causal. On the other hand, plotting gas value (volume times price) in logarithmic terms shows that gas price drives the total value of gas, as should be expected (Fig. 2b). The other thing to note is that this strong link between gas value and gas price changed dramatically in 1972, at the time of the first oil embargo. At that time, strong increases in gas price were accompanied by decreases in gas volume, with corresponding modest increases in total value. Earlier—before about 1955—small changes in gas

price caused a relatively strong change in gas value. The production response for the San Juan and Permian Basins is revealing (Fig. 3). It is apparent that the production response in the San Juan—with its current emphasis on the exploration and production of coal seam gas—is very different than in the Permian. In neither basin, however, is the production response clearly dependent on price.

A similar interpretation can be posited for crude oil production and volume. Before the first oil embargo of

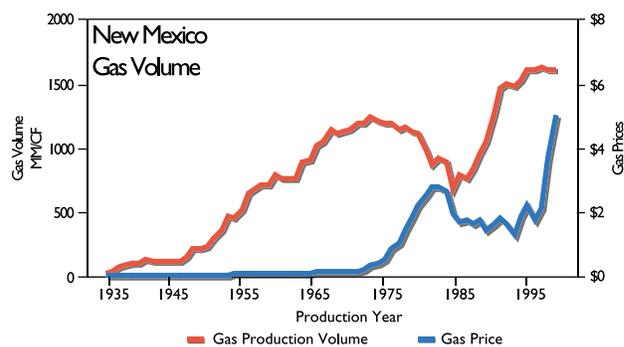


FIGURE 2A New Mexico gas production volume and gas price over time.

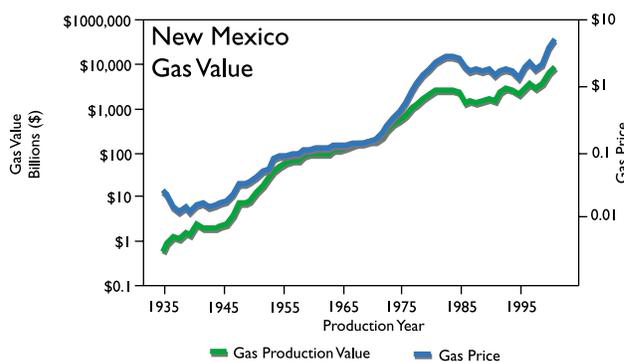


FIGURE 2B New Mexico gas production value and gas price over time.

1972–73, oil volumes were moderately responsive to changes in oil price (Fig. 4). After a decade-long re-equilibration, oil volumes from the early 1980s to the present became quite responsive to price changes.

## STATE AND LOCAL TAX REVENUE

Energy in its various forms—crude oil, refined gasoline, natural gas, and electricity—has been a disproportionate candidate for taxation. Currently, there are six taxes imposed directly on oil and gas extraction and processing (Fig. 5):

- 1 Oil and Gas Severance Tax
- 2 Conservation (and Reclamation) Tax
- 3 Emergency School Tax
- 4 Oil and Gas Ad Valorem Production Tax
- 5 Natural Gas Processors Tax
- 6 Oil and Gas Ad Valorem Equipment Tax

Unfortunately, because of the complexity of deductions and rates, it is difficult to determine an effective tax rate on sales or production value without a great deal of work and assumptions about price. Some of the taxes historically have been specific excises, based on volume, not value. Other taxes are based on sales value, but these allow significant deductions from sales value to determine production (wellhead) value. The two ad valorem property taxes have a complicated rate structure dependent upon location of production. Further complicating the calculation is the recent proliferation of contingent tax rates and economic development incentives expressed in rates and base. The details of the taxes are discussed below.

In addition to the taxes enumerated here, oil and gas well servicing and well drilling are considered construction services and subject to the gross receipts tax. In addition, multi-state and multinational corporations produce and market most of New Mexico's oil and gas. These corporations pay corporate income tax to New Mexico on apportioned net profit.

### 1 OIL AND GAS SEVERANCE TAX

A severance tax is imposed on all oil, natural gas or liquid hydrocarbons, and on carbon dioxide severed from the ground and sold. The tax is based on sales value. The tax rate is 3.75% of the sales price at or near the wellhead on oil, carbon dioxide, other liquid hydrocarbons, and natural gas. An "enhanced oil recovery" tax rate of 1.875% is applied to oil produced from new wells using qualified enhanced-recovery methods. Before January 1, 1994, only carbon dioxide projects qualified. Thereafter any secondary or tertiary method could be used. The lower rate applies to production for the first five or seven years after bringing the enhanced project into production.

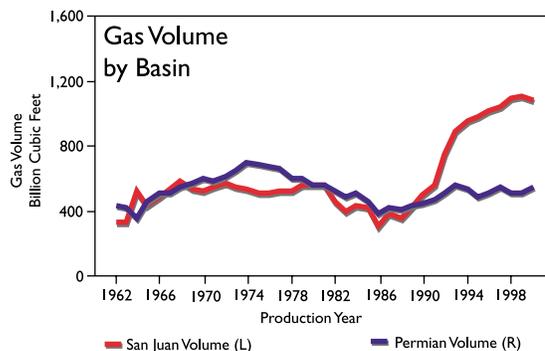


FIGURE 3 New Mexico gas production by basin.

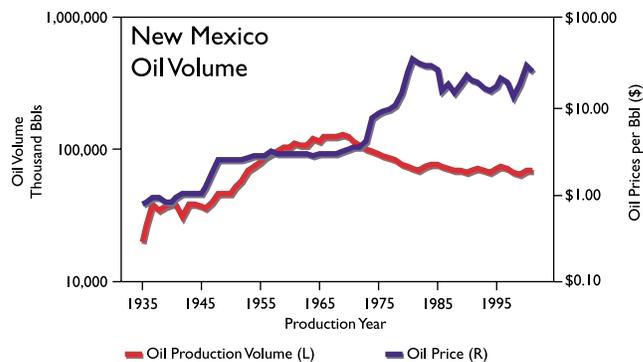


FIGURE 4A New Mexico oil production value and oil price over time.

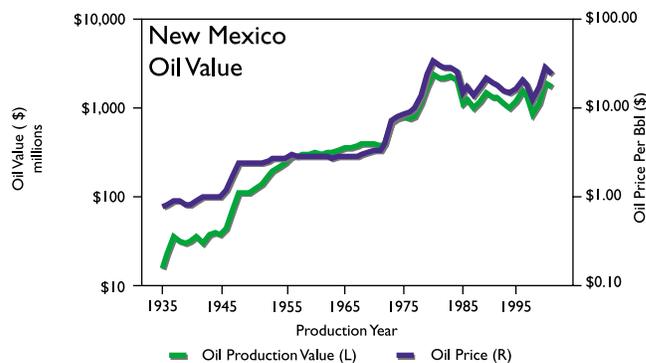


FIGURE 4B New Mexico oil production value and oil price over time.

In 1995 a 50% credit was authorized for projects approved by the Oil Conservation Division that restore non-producing wells to production, or that increase the production from currently producing wells. Originally, qualification for the credit required a



well to have been shut in for a specific two-year period. In 1999 the credit was extended to any well shut in for a period of two years beginning on or after 1/1/93.

In 1995 an “intergovernmental oil and gas tax credit” was enacted to ameliorate dual taxation of oil and gas production on Indian lands. The credit is against state production taxes for taxes paid to Indian tribes on production from new wells drilled on Indian land after June 30, 1995. The credit amount is the smaller of 75% of the Indian production taxes or 75% of the state production tax.

In 1999 several severance tax incentives were provided to oil and gas producers hard hit by a severe oil price slump. The Marginal Wells Conditional Tax Reduction provides either a 50% or a 25% reduction in both oil and gas severance tax and oil and gas emergency school tax to stripper wells when prices are low. Stripper wells are oil wells that have been certified by the Oil Conservation Division to have produced less than 10 barrels per day in the previous calendar year and natural gas wells certified to have produced less than 60 mcf per day in the previous calendar year.

Special price-contingent oil and gas severance tax rates were also enacted in 1999. When prices are at or below \$15 per barrel for oil or \$1.15 per mcf of natu-

ral gas, the oil and gas severance tax rate is 1.875%. A 2.8125% rate applies when prices are more than \$15 but not more than \$18 per barrel for oil or more than \$1.15 but not more than \$1.35 per mcf for natural gas.

The severance tax is distributed to the state severance tax bonding fund, with any excess after meeting severance tax bonding fund obligations being distributed to the severance tax permanent fund.

## 2 OIL AND GAS CONSERVATION TAX

A conservation tax is levied on the sale of all oil, natural gas, liquid hydrocarbons, carbon dioxide, uranium, coal, and geothermal energy severed from the soil of the state. The measure of the tax is 0.18% or 0.19% of the taxable value of products (sales price less deductions for state, federal, and Indian royalties), depending on the balance in the oil and gas reclamation fund. If the balance in that fund is over \$1 million, the lower rate goes into effect. Tax is due on the 25th day of the second month after the close of the month in which the taxable event took place. Since July 1991 a monthly advance payment of conservation tax has been required from high-volume producers. Proceeds from the tax are distributed to the state general fund and the oil and gas reclamation fund.

Fiscal year	1996	1997	1998	1999	2000	2001 est.
<b>OIL:</b>						
Volume (million Bbls)	74.69	74.05	72.43	66.32	67.72	71.04
Value (\$)	\$1,338.30	\$1,571.30	\$1,148.20	\$832.40	\$1,648.30	\$1,390.70
Derived price (\$/Bbl)	\$17.92	\$21.22	\$15.85	\$12.55	\$24.34	\$19.58
<b>NATURAL GAS:</b>						
Volume (Bcf)	1,506	1,575	1,619	1,606	1,628	1,623
Value (\$)	\$2,133	\$3,350	\$3,349	\$2,737	\$4,142	\$6,255
Derived price (\$/mcf)	\$1.42	\$2.13	\$2.07	\$1.70	\$2.54	\$3.85
<b>TAX COLLECTIONS (in million \$):</b>						
<b>Oil &amp; gas:</b>						
O & g severance tax	\$105.91	\$153.34	\$152.15	\$106.36	\$165.13	\$315.58
Conservation tax (o & g only)	\$5.05	\$7.47	\$8.04	\$5.44	\$8.68	\$16.46
Emergency school tax	\$102.22	\$151.36	\$153.68	\$107.85	\$169.51	\$329.03
<b>Ad valorem:</b>						
O & G production tax	\$1.79	\$3.04	\$2.83	\$2.01	\$3.41	\$6.54
General obligation bond fund						
County treasurers	\$26.25	\$39.40	\$38.55	\$27.62	\$45.52	\$83.82
Natural gas processors tax	\$24.57	\$13.89	\$12.84	\$11.28	\$12.26	\$12.11
<b>O &amp; g equipment tax</b>						
General obligation bond fund	\$0.38	\$0.41	\$0.51	\$0.60	\$0.46	\$0.58
County treasurers	\$5.50	\$5.00	\$7.20	\$8.02	\$6.09	\$7.26

**FIGURE 5** Oil and gas tax collections. Source: Taxation and Revenue Department records provided by Tax Research and

Statistics Office.

### 3 OIL AND GAS EMERGENCY SCHOOL TAX

An emergency school tax is imposed for the privilege of engaging in the business of severing oil, natural gas or liquid hydrocarbons, and carbon dioxide from New Mexico soil. A 3.15% rate is imposed on the net taxable value of the products listed, with the exception of natural gas, which is taxed at 4%. Net taxable value is defined as the actual price received for products at the production unit, less federal, state, or Indian royalties and the cost of transporting oil or gas to the first place of market. Tax payments are due on the 25th day of the second month after the close of the month in which the taxable event took place. A monthly advance payment equal to the average monthly payment made in the previous year is required from high-volume producers. The school tax is distributed to the state general fund each month.

In 1999 a non-refundable one-time drilling credit of \$15,000 was made available for the first 600 new crude oil or natural gas wells drilled between January 1, 1999, and June 30, 2000. The Marginal Wells Conditional Tax Reduction, also enacted in 1999, provides either a 50% or a 25% reduction in both oil and gas severance tax and oil and gas emergency school tax to stripper wells when prices are low.

Special price-contingent oil and gas emergency school tax rates were enacted in 1999. When prices are at or below \$15 per barrel for oil or \$1.15 per mcf of natural gas, oil and gas emergency school tax rates are 1.58% and 2%, respectively. When prices are more than \$15 but not more than \$18 per barrel for oil or more than \$1.15 but not more than \$1.35 per mcf for natural gas, oil and gas emergency school tax rates are 2.36% and 3%, respectively.

### 4 OIL AND GAS AD VALOREM PRODUCTION TAX

An ad valorem tax is levied monthly on the sale of all oil, natural gas, liquid hydrocarbons, and carbon dioxide severed from the soil of the state. The ad valorem tax is based on the assessed value of products. The tax rate is the property tax rate for the taxing district in which products are severed. This rate changes annually, effective each September 1. Assessed value is equivalent to 50% of market value less royalties. The tax is due on the 25th day of the second month after the close of the month in which the taxable event took place. A monthly advance payment of ad valorem tax is required from high-volume producers. The ad valorem tax is distributed monthly to the applicable property tax beneficiaries, primarily counties and school districts.

### 5 NATURAL GAS PROCESSOR'S TAX

A natural gas processor's privilege tax is levied on processors based on the value of products processed. Before July 1, 1998, the tax rate was 0.45% of the value of the products processed. In 1998 landmark legislation, the tax was totally revamped, with tax imposition being shifted entirely to the processing plants. Tax is measured by the heating content of natural gas at the plant's inlet, measured in million British Thermal Units (mmbtu). The rate is set initially at \$.0065 per mmbtu but will be adjusted every July 1. The adjustment factor is equal to the average value of natural gas produced in New Mexico the preceding calendar year divided by \$1.33. The rate starting January 1, 1999, will be similarly adjusted. New deductions are added for gas legally flared or lost through plant malfunction. Deductions for the value of products sold to any federal or New Mexico governmental unit or any non-profit hospital, religious, or charitable organization when such products are used in the conduct of their regular functions were repealed.

The natural gas processor's tax is due within 25 days following the end of each calendar month in which sales occurred. A monthly advance payment of processor's tax is required from high-volume producers. Revenue is distributed to the state general fund.

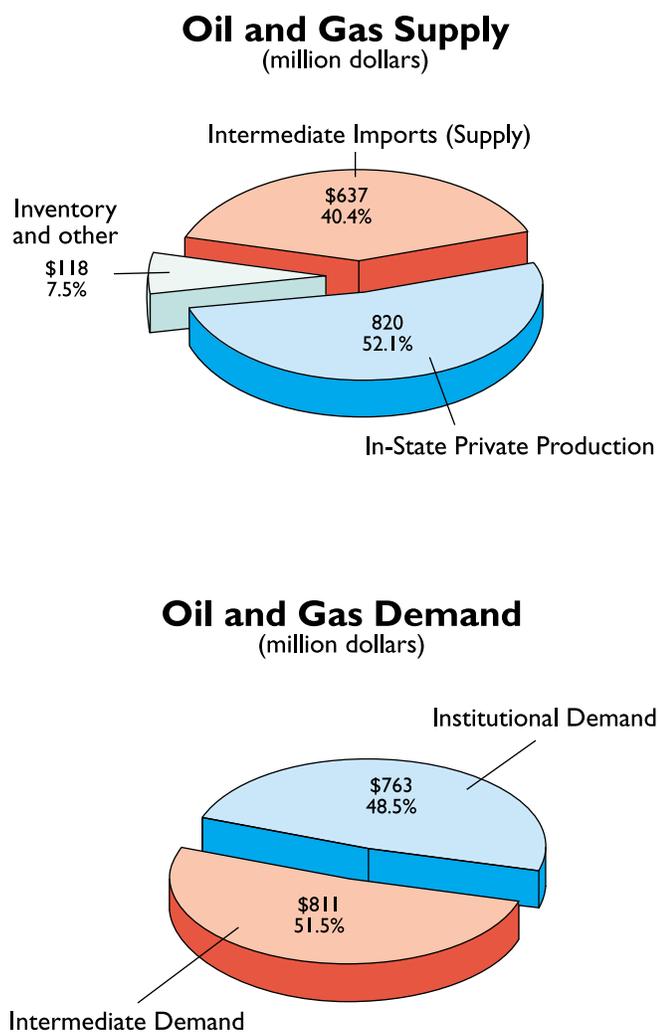
### 6 OIL AND GAS AD VALOREM EQUIPMENT TAX

An ad valorem tax is levied annually on assessed value of equipment used at each production unit. Assessed value is equivalent to 9% of the previous calendar year sales value of the product of each production unit. The tax rate is the certified property tax rate for the taxing district in which products are severed.

The Taxation and Revenue Department is required to prepare a tax statement on or before October 15. Payment is due on November 30. The production equipment tax is distributed to property tax beneficiaries, primarily counties and school districts.

### IMPACT OF OIL AND GAS PRODUCTION ON THE STATE'S ECONOMY

Roughly 6% of New Mexico's Gross State Product (GSP) is attributable to production of oil and gas in the state. Oil and gas production contributes an unusually large amount to Gross State Product with a minimal contribution to value added from wages and salaries (and proprietorship profit). For the average industry, 39% of production value is used to pay



**FIGURE 6** New Mexico oil and gas supply and demand.

salaries and 65% of GSP value added is contributed by wages and salaries paid. For oil and gas production, these percentages are about 18% and 25%. This is certainly not unexpected for primary mineral production, but is interesting nonetheless. The computer equipment industry also is heavily capital intensive, with a ratio of about 17% of production value devoted to wages and salaries, but 50% of contribution to GSP. Apparently, most of the value of computer equipment is retained as implicit or explicit return to capital. The other important export industry in New Mexico is agriculture and other mining. This is also capital intensive with 26% of production and 54% of contribution to GSP in the form of wages and salaries.

Oil and gas production is sold in the state for manufacturing purposes and sold outside the state for energy and subsequent manufacturing. Figure 6 shows

imports, exports and supply-demand balance for oil and gas production. The institutional demand is primarily exports to surrounding states for process and manufacturing uses.

### IMPACT ON REVENUES OF OIL AND GAS PRODUCTION

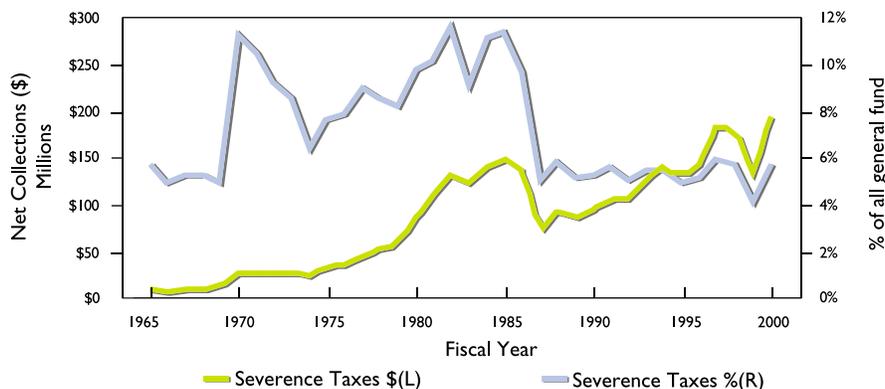
The life of a revenue estimator for the New Mexico state government is interesting. The old Chinese curse says, "may you live in interesting times." This curse is the motto for trying to predict the flow of revenue from the oil and gas industry. During the gas price bubble which lasted throughout fiscal year 2000, gas prices paid to New Mexico's producers exceeded \$5 per mcf. Because the General Fund's sensitivity to an increase in gas price is over \$10 million per \$0.10 change in gas price, these unexpected prices led to soaring revenue collections. Just as abruptly, prices collapsed as California learned how to adapt to a new energy delivery and price regime. Revenue estimates were revised up and down by over \$100 million over the period from first estimates to final collections. Severance taxes have had a variable history in the General Fund. Figure 7 illustrates a modest variation. However, this is only a part of the true impact of oil and gas severance over time. First and foremost, a substantial portion of oil and gas have been produced from state and federal lands in New Mexico. Fifty percent of the royalties and bonus payments from production on federal lands accrue directly to the state general fund. For production on state-owned lands, producers pay royalties in addition to the various severance taxes. These royalties add to the corpus of the land grant permanent fund. The corpus generates income (primarily as interest on corporate bonds). This interest does accrue to the General Fund. For a more complete picture of the importance of oil and gas severance to the state general fund, then, we must sum direct General Fund severance taxes, rents and royalties, and interest paid. Figure 8 exhibits both the direct impact and the total impact measured by the total General Fund. This impact peaked in the "Big Mac" era (1981–82) at 47% of the General Fund. The current level (before the expansion of direct severance revenues during 1999–2000 and 2000–2001) is about 23%. This is money that the state's resident taxpayers do not have to pay for critical government services.

### SUMMARY AND CONCLUSION

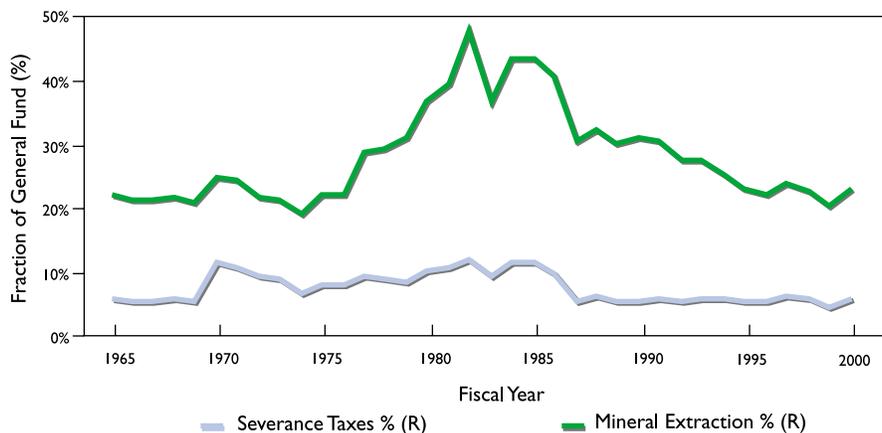
By any measure, the oil and gas extraction industry has been and continues to be an important source of

revenues to state and local governments; an important source of employment, although for a declining number of workers; and a generator of production value

model of energy deregulation, power will be produced in New Mexico with a combination of improved coal burning, base load generating plants and peak load gas turbine plants located close to the source of natural gas. With either variant, New Mexico's place in the energy production future of the western United States is assured. However, state policymakers must constantly check that tax, environmental, and employment laws and regulations to not unduly dampen the apparently bright future for the state.



**FIGURE 7** General Fund Revenues—severance taxes by amount and percent of all general fund revenues.



**FIGURE 8** General Fund Revenues—severance taxes, rents and royalties, interest by amount and percent of all general fund revenues.

helping to sustain New Mexico's economy. There continues to be a great deal of validity to the phrase that opened this paper, "if you live in New Mexico, you're in the oil and gas business." The industry is still pretty healthy and will continue to prosper, no matter what the energy future of the United States. Under a balkanized model of energy deregulation, each of the western states will license a number of high-efficiency natural gas turbines. The operators of these new generating plants will buy all the natural gas the state can produce. New fields are ready to come on line and produce for years to come. Under an energy-province

A number of sources of information have been tapped for this report. In some cases, the data are old and at least partially defective. At minimum, the state should invest whatever money is required to have access to the best, most timely, and accurate data and analysis available. New Mexico's energy future is not so certain that the state can afford to take its eye off the ball.



## Environmental Regulation of the Oil and Gas Industry in New Mexico

William C. Olson, *Oil Conservation Division  
Energy, Minerals, and Natural Resources Department*

The Oil Conservation Division (OCD) is the only state regulatory agency other than the New Mexico Environment Department (NMED) that administers several wide-ranging water quality protection programs. Some of these programs were developed and remain separate from the state's Water Quality Act, which, until the advent of various federal programs, controlled other discharges to ground water. Among the discharges regulated by OCD are surface and underground disposal of water and wastes produced concurrently with oil, natural gas, and carbon dioxide; waste drilling fluids and muds; and wastes at crude oil recovery facilities, oil field service companies, refineries, and natural gas plants and compressor stations. Many of these activities are regulated under the New Mexico Oil and Gas Act, which authorizes the OCD to set requirements for proper drilling, completion, plugging, and abandonment of wells. Additional authority is granted OCD under the New Mexico Geothermal Resources Act, and under administrative delegation as a constituent agency of the Water Quality Control Commission under the New Mexico Water Quality Act. Below is a summary of the impact of these legislative acts.

### OIL AND GAS ACT

When the New Mexico Oil and Gas Act created the Oil Conservation Commission in 1935, it authorized rulemaking for prevention of waste and to protect correlative rights, but it did not specifically address freshwater protection. However, the original act did require that dry or abandoned wells be plugged in such a way as to confine fluids to their existing zones. Under these and other provisions of the statute, the OCD adopted rules regarding drilling, casing, cementing, and abandonment of wells. These activities by themselves provide some freshwater protection.

In 1961 the Oil and Gas Act was amended to allow the OCD to make rules protecting freshwater from the disposal of drilling and production waters. Under the 1961 amendments, the state engineer designates which water is to be protected. Currently, protection is afforded all surface and groundwater having 10,000 mg/l or less total dissolved solids (TDS), and all surface water having over 10,000 mg/l TDS that impacts protectable ground water.

Under the Oil and Gas Act, statewide regulations can be adopted after notice and hearing. Rules specific to a particular practice, operator, or geographic area may also be issued as the OCD orders. When an order is approved for a specific operator, it serves as a permit. Using one or the other of these methods, OCD administers requirements for underground injection of produced waters and nonhazardous production fluids, for surface disposal of such fluids, and for disposal of non-recoverable waste oils and sludges from oil production and treating plants.

### WATER QUALITY ACT

The New Mexico Water Quality Act provides the statutory authority to OCD for environmental regulation of downstream facilities such as refineries, natural gas plants and compressor stations, crude oil pump stations, and oil field service companies. Discharges to groundwater at these facilities are controlled under Water Quality Control Commission (WQCC) regulations. As a constituent agency of the WQCC, OCD has been delegated authority to administer the regulations at these facilities and at geothermal operations. State water quality regulations at other non-oil field facilities are administered by the New Mexico Environment Department.

The New Mexico Water Quality Act specifically prohibits the WQCC from exercising concurrent jurisdiction

Act	Number	Year passed	Year amended
New Mexico Water Quality Act	74-6-1 through 74-6-17, NMSA 1978	1967	1978
New Mexico Oil and Gas Act	70-2-1 through 70-2-38, NMSA 1978	1935	1978
Geothermal Resources Act	71-5-1 through 71-5-24, NMSA 1978	1975	1978

tion over oil and gas production activities that may cause water pollution and are regulated by the OCD through the Oil and Gas Act. The delegation to OCD of WQCC authority effectively eliminates this conflict, because the same staff administer both sets of regulations, applying whichever is applicable to the regulated facility.

### **GEOTHERMAL RESOURCES ACT**

Regulations adopted under the Geothermal Resources Act (71-5-1 through 71-5-24, NMSA 1978) are similar to those of the Oil and Gas Act. Its provisions control drilling, casing, and cementing of geothermal wells. Production volume of geothermal fluids is also regulated so that the geothermal reservoirs will not be depleted or unfairly appropriated by a particular user. The act and its regulations specify that activities be conducted in a manner such that human health and the environment are afforded maximum reasonable protection, and that disposal of produced waters be in such a manner so as not to constitute a hazard to useable surface or underground waters.

Unlike the Oil and Gas Act, the Geothermal Resource Act has a clause allowing concurrent jurisdiction with other state regulatory agencies. This means that WQCC regulations are also applicable. Again, these responsibilities have been delegated to the OCD; in practice only storage and disposal of geothermal fluids is currently being regulated via discharge permits. Other operational aspects (drilling and production) are covered through permits issued under the Geothermal Resources Act.

### **IMPLEMENTATION**

Environmental activities are implemented by the Oil Conservation Division's Santa Fe office and four district offices. In addition to matters related to oil and gas production, the Santa Fe office staff process, approve, or set hearings on applications for (1) surface disposal or underground injection of salt water, (2) water flooding used in secondary oil recovery or pressure maintenance, and (3) surface treatment and disposal facilities. The above activities, with the exception of surface disposal and waste oil recovery/treating plant applications, are performed by OCD's petroleum engineers. Those exceptions are reviewed by OCD Environmental Bureau staff. OCD Environmental Bureau staff also provide valuable input and guidance in the application process, especially with regard to possible impacts on groundwater from production and underground injection.

The OCD Environmental Bureau, formed in 1984, performs water protection activities not carried out under other OCD programs. These activities include permitting of oil refineries, natural gas plants and compressor stations, oil field service companies, brine production wells, and any other oil field-related discharges to ground water. Bureau staff also perform inspections and sample at these facilities, investigate groundwater contamination, sample groundwater at domestic wells and other locations suspected of having contamination, and supervise groundwater cleanup and remedial actions. The Environmental Bureau coordinates OCD environmental programs and responds to information requests from industry, federal and state agencies, and the public. The Environmental Bureau researches, writes, and proposes additional regulations for freshwater protection to the Oil Conservation Commission, and the bureau prepares and updates guidelines to assist industry in complying with regulatory requirements. The Environmental Bureau performs these activities with a staff of seven: two hydrologists, a petroleum engineer, a chemical engineer, an environmental engineer, and two geologists.

Daily activities performed by OCD district staff provide protection for freshwater from field production activities. All permits to drill, complete, work-over, and plug oil, gas, and injection wells are reviewed and approved by district staff, including a district geologist. The review ensures proper casing and cementing programs. Field inspectors witness required cementing and testing of production and injection wells and respond to complaints of possible rule violations. Field inspectors also collect water samples, supervise cleanup of minor spills and leaks, and provide first response to oil and gas related environmental problems.

### **ENVIRONMENTAL CONCERNS**

The state of New Mexico is heavily dependent on groundwater as a public resource. Approximately 90% of New Mexico's population depends on groundwater aquifers as a source of domestic water. Consequently, the OCD Environmental Bureau has concentrated its efforts on preventing the contamination of freshwater by oil and gas operations, and resolving groundwater contamination that results from oil field practices.

New Mexico's reliance on groundwater makes the enforcement of OCD and WQCC rules and regulations an important activity. The costs to the public for loss of freshwater resources, and to industry for reme-



diation of contaminated groundwater, are large. Whereas the costs to industry for preventative measures are not negligible, they are a fraction of those incurred in the remediation of contaminated groundwater. The OCD currently has discharge permits for more than 350 oil field facilities, 55 of which have active ongoing groundwater remediation projects. Roughly 90% of the cases are the result of disposal practices that are no longer allowed under current rules and regulations, such as the use of unlined pits for waste disposal. The remaining 10% of these cases can be attributed to leaks and spills during oil and gas production operations. Notably, there have been no cases of groundwater contamination from a disposal activity permitted under the discharge permit program.

Most of OCD's efforts are in the area of preventing groundwater contamination, partly because of the cost effectiveness of this prevention and partly because of the need to protect groundwater for future uses. Preventative measures are implemented through the enforcement of regulations and rules requiring discharge plans and permits for oil field production activities, gas plants, compressor stations, refineries, crude oil pump stations, and other major potential contaminant sources. The goal of the permitting system is to work cooperatively with industry to keep groundwater contaminants contained, and to provide for early detection and prompt remediation of leaks and spills.

All injection wells, refineries, oil field disposal facilities, gas plants, and most mainline compressor stations have approved discharge plans or other operational permits. The OCD is also bringing smaller scale potential contamination sources under the discharge permit system, including those at field gas compressor stations, crude oil pump stations, and oil field service companies. Refinery and gas plant permitting is difficult and time consuming, due to the age of several facilities and to documented pre-existing contamination at most operating and abandoned sites. Permitting has been facilitated by coordinating remediation activities with other agencies, and by separating issues of past contamination and associated remedial actions from current groundwater protection disposal requirements within the discharge plan.

Groundwater protection measures are also implemented by review and revision of OCD rules related to disposal of produced water and other oil field wastes, as necessary. The first groundwater protection rules were issued in the early 1960s, when the New

Mexico Oil Conservation Commission banned (with some exceptions) disposal of produced water in unlined pits in areas of southeastern New Mexico with protectable fresh waters. Before 1986 no restrictions on direct discharge of oil field-produced water or related wastes existed in the San Juan Basin, due both to the lack of known cases of groundwater contamination, and to the quality of water produced in the basin. Current OCD rules prohibit discharges to unlined pits in areas vulnerable to groundwater contamination in the San Juan Basin.

### SUMMARY

The Oil Conservation Division has an ongoing freshwater protection program staffed by persons knowledgeable in several engineering and scientific specialties needed for proper implementation of the program. The division is cognizant of potential contamination due to oil and gas activities, and enforces and revises state rules as necessary to protect this resource. The OCD will continue to review existing disposal practices and regulations over time and propose regulatory modifications to protect the state's groundwater resources. Current and upcoming issues that the OCD is working on include changes in the hydrogen sulfide rules for protection of public health, drafting of rules for on-site waste management, permitting of all production pits, and a study of aging infrastructure.

Proper staffing is always crucial for successful programs, and OCD, like other agencies, has found that the demands for services by industry and the public are sometimes in conflict with budgetary constraints brought on by the general economic situation of the oil and gas industry and of the state. Since it administers many state oil field regulatory programs, OCD is able to tailor and implement these programs in such a way as to provide maximum effectiveness with available staff, and with a minimum of bureaucratic requirements.

## Foreseeable Development of San Juan Basin Oil and Gas Reservoirs

Thomas W. Engler, *New Mexico Institute of Mining and Technology*

The San Juan Basin is one of the most strategic gas-producing basins in the U.S. because of its annual volume of production and the market it supplies. New Mexico is the third largest natural gas-producing state in the United States. The San Juan Basin contributes approximately 68% of the natural gas produced annually in the state of New Mexico, or 1.048 trillion cubic feet. In addition, 3.2 million barrels of oil have been produced to date from the basin. The value of these commodities in 1999 was \$2.46 billion dollars. The primary market is the southwestern U.S. The San Juan Basin is California's largest single source of natural gas. With the sixth largest economy in the world, California looks to natural gas to fuel its growing need for electric power generation.

Natural gas will continue to be a dominant source of energy and income for the state of New Mexico for the foreseeable future. Figure 1 illustrates the total natural gas reserves by state and region as of January 1, 2000. New Mexico has the third highest reserve base of 15.5 trillion cubic feet (Tcf) of gas, of which roughly 80% (12.4 Tcf) is in the San Juan Basin. Reserve revisions in 1999 added 462 billion cubic feet to the state's resource.

San Juan Basin gas- and oil-producing reservoirs are well defined by the 20,000 wells that have been drilled in this basin. The potential for expansion of pool boundaries is limited; therefore the main emphasis in development is infill drilling (increasing the density of wells) in existing gas reservoirs to increase recovery. Infill drilling is necessary in low-permeability reservoirs where the current spacing between wells is insufficient to efficiently drain the reservoir.

### HISTORICAL DEVELOPMENT OF OIL AND GAS IN NEW MEXICO

Initial development in the region began in the early 1920s. Early oil discoveries in the Paradox Formation and Dakota Sandstone (Fig. 2) on the western flank of the basin were prolific. Natural gas discoveries in the Farmington Sandstone, the Pictured Cliffs Sandstone, and the Mesaverde Group began in the late 1920s. However, there was little development until the late 1940s and early 1950s, because of the lack of market

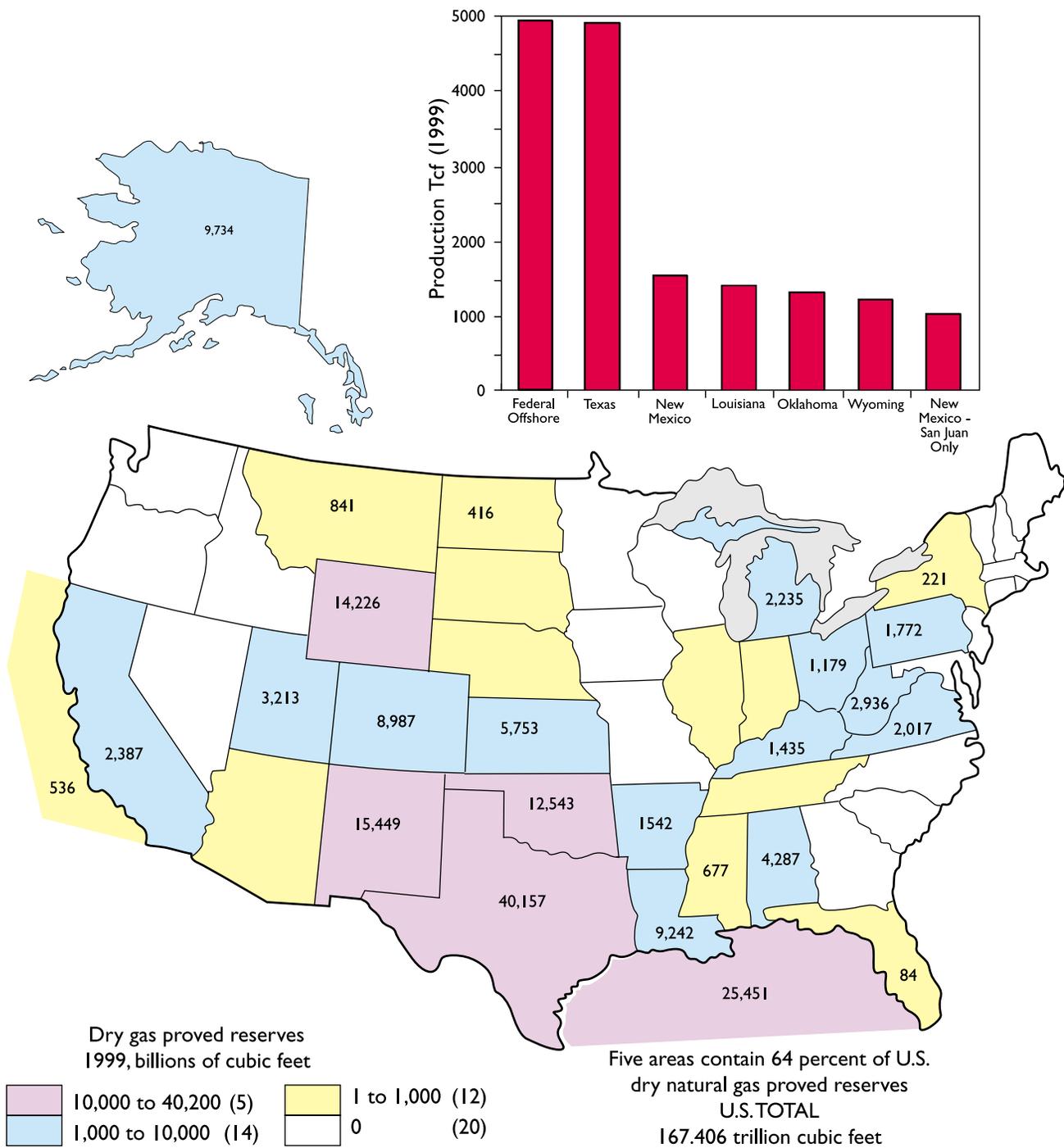
demand. In the late 1940s the Dakota Sandstone was developed as a "deep" major gas reservoir. In 1951 El Paso Natural Gas Company completed an interstate pipeline supplying gas to California markets and thus spurred rapid development, particularly of the Pictured Cliffs and Mesaverde reservoirs. These plays can be categorized as unconventional, because of their low permeability and corresponding low productivity without stimulation treatments, which increase reservoir productivity by improving fluid flow properties. Stimulation has evolved from early completions where nitroglycerin bombs were dropped into wells, to modern hydraulic fracturing technology.

By the middle to late 1970s, stimulation techniques and market improvements had progressed to such a degree that the New Mexico Oil Conservation Division ruled in favor of infill drilling the Blanco Mesaverde pool (1975) and Basin Dakota pool (1979) to 160-acre per well spacing. This resulted in a slight increase in production (Fig. 3). Weak market demand during the 1980s, however, resulted in no significant development. The erratic production history reflects the repetitive shutting-in of wells during periods of sub-economic gas prices.

The Fruitland Formation coalbed-methane play in 1989 had a significant impact on gas production in the San Juan Basin. The daily production rate doubled to 3 billion cubic feet with the successful completion of Fruitland coal wells (Fig. 3). At the same time, both pipeline capacity and market demand were sufficient to sell this additional gas.

In the last several years, reduced well spacing has been considered economically viable. The Blanco Mesaverde pool was approved in 1998 for 80-acre spacing, and the Basin Dakota pool is currently being pilot tested for feasibility of producing at 80-acre spacing. This will capture additional reserves not available in 160-acre spaced development and will improve deliverability from the pools.

The current production rate from the San Juan Basin is approximately 3.0 billion cubic feet per day. Roughly half of this production comes from the Fruitland coalbed-methane pool. Fruitland production has reached a peak and is beginning to exhibit signs



**FIGURE 1** Dry gas proved reserves and production by area (1999). Source: EIA, Office of Oil and Gas. Natural gas pro-

duction by state in trillion cubic feet (1999).

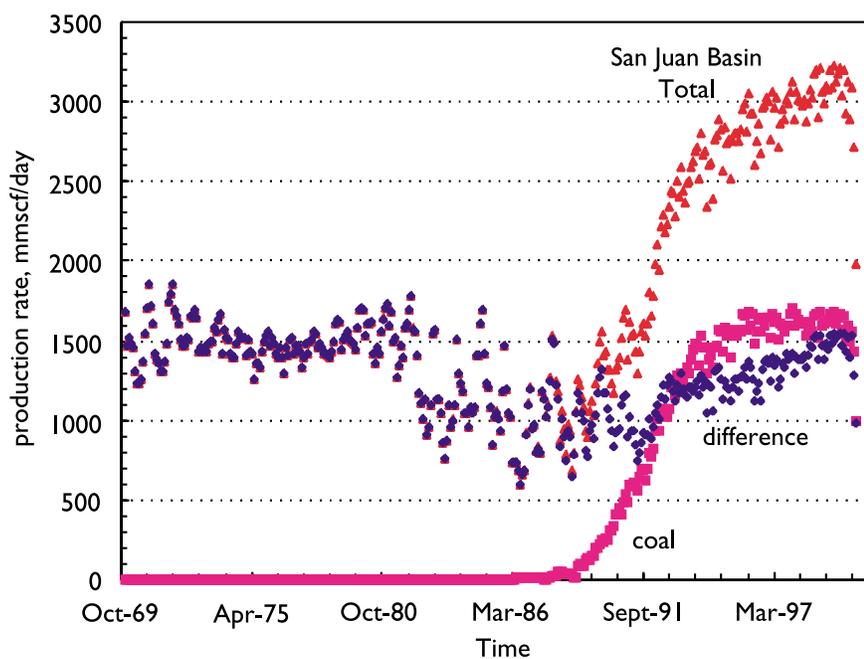
Era	System	Formation	Production	20-year predicted development (no. of wells)	
CENOZOIC	TERTIARY	San Jose Formation	Gas		
		Nacimiento Formation	Gas	100	
		Ojo Alamo Sandstone	Gas		
MESOZOIC	CRETACEOUS	Kirtland Shale Farmington Sandstone	Gas/oil	0	
		Fruitland Formation	Gas	3140	
		Pictured Cliffs Sandstone	Gas	1432	
		Lewis Shale	Gas	4697	
		Mesaverde Group	Cliff House Sandstone Menefee Formation Point Lookout Formation	Gas Gas Gas	
		Mancos Shale	Upper Mancos Shale/Tocito Sandstone Gallup Sandstone/Carlile Shale Greenhorn Limestone Graneros Shale	Gas/oil Gas/oil	300
		Dakota Sandstone	Gas/oil	6846	
PALEOZOIC	JURASSIC	Morrison Formation			
		Wanakah Formation Todilto Limestone			
		Entrada Sandstone	Oil	80	
	TRIASSIC	Chinle Formation			
	PERMIAN	Cutler Formation			
	PENNSYLVANIAN	Hermosa Formation	Honaker Trail Formation Paradox Formation Pinkerton Trail Formation	Gas?	20
		Molas Formation			
	MISSISSIPPIAN	Leadville Limestone			
	DEVONIAN	Elbert Formation			
	CAMBRIAN	Ignacio Quartzite			
PRECAMBRIAN					

**FIGURE 2** Generalized stratigraphy and predicted foreseeable development of the San Juan Basin, New Mexico.



of declining; therefore, alternative sources of gas need to be found to make up the loss. The other major producing reservoirs contribute 0.75 (Mesaverde), 0.35 (Dakota), and 0.25 (Pictured Cliffs) billion cubic feet per day. Further development of the Mesaverde and Dakota reservoirs will yield the best short-term potential for increasing gas recovery and thus maintaining the deliverability out of the basin.

This change in focus from coal to other formations reflects the historical trend in development. During the early 1990s the Fruitland coal dominated the development with approximately 75% of the total activity. This rapid development has declined, and the Mesaverde Group has recently become the major target of activity.



**FIGURE 3** Total gas production (million cubic feet per day) from the New Mexico portion of the San Juan Basin and the contribution of the Fruitland Coal to this total.

### FORESEEABLE DEVELOPMENT

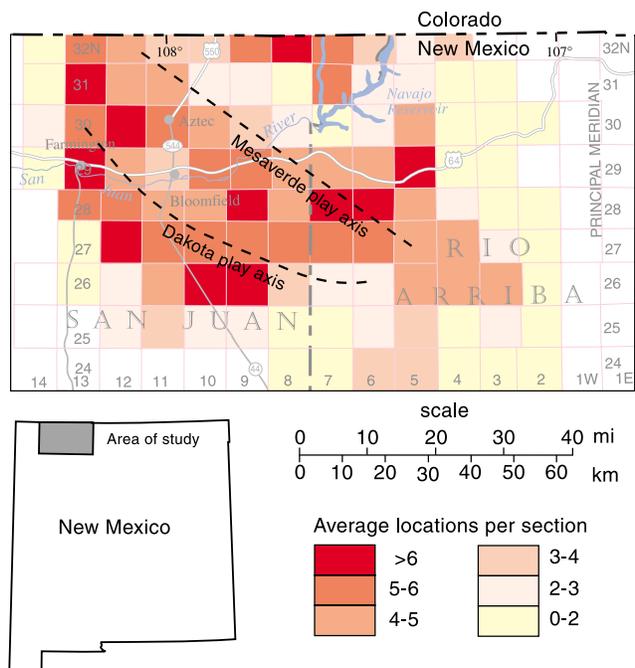
In 2001 New Mexico Tech completed a study for the U.S. Bureau of Land Management to estimate foreseeable development in the basin over the next twenty years. The focus was to determine future reservoir development (drilling and completion of new wells and recompletion of old wells) reasonably supported by geological and engineering evidence, and to estimate the associated surface impact of such develop-

ment. The methods used to make this determination consisted of a review of reservoir characteristics and historical production, predictive engineering production modeling, and presentation of data and conclusions in multiple formats including a report, databases, and GIS-based map displays (Engler et al., 2001).

For the major producing reservoirs, two approaches were used to predict development potential. The first was a survey of companies operating in the San Juan Basin, obtaining their perspective on future development based on current reservoir management practices. The second approach applied engineering techniques developed by the New Mexico Institute of Mining and Technology to predict optimal infill drilling in naturally fractured, low-permeability gas reservoirs of the basin.

The study predicted 16,615 total available subsurface completions in the New Mexico part of the San Juan Basin over the next twenty years. (A completion is defined as the means to effectively communicate the wellbore with the reservoir and successfully obtain hydrocarbons.) These results are subject to three assumptions: (1) sufficient and expanding natural gas take-away capacity of the pipeline system out of the basin, (2) well abandonment rate increases of 5% per year, and (3) minimal impact of future exploration. Figure 2 (last column) shows the results by reservoir and includes both major and minor producing reservoirs, and anticipated emerging and exploratory plays.

A significant reduction in this number of completions will occur as a result of opportunities for commingling and dual completion of wells. Commingling is an allowed practice of combining gas flow from two distinct reservoirs in the same wellbore. Similarly, dual completion produces gas from two distinct reservoirs in the same wellbore; however, the gas streams are not mixed until each can be gauged. With an estimated 25% decrease in wellbores, the total number of locations of surface disturbance becomes 12,461. In other words, multiple completions would reduce the number of locations to be built. This rate equates to an average of 623 wells per year and is consistent with current activity (approximately 640 wells per year average for 1999 and 2000



**FIGURE 4** Distribution map of the average number of total locations (all reservoirs) per square mile averaged over township areas.

combined). This rate assumes continuation of a favorable regulatory environment that supports this level of development.

A location density map (number of wells per 36-square-mile township; Fig. 4) illustrates the anticipated distribution of the total number of completions (12,461) after commingling or dual completing. The trend of highest predicted activity is approximately northwest to southeast and parallels the trend of the Mesaverde and Dakota plays. Federal lands comprise approximately 80% of the leasehold of the San Juan Basin. Consequently, the total number of locations (12,461) affecting federal lands must be reduced proportionately to 9,970. There will also be a need for additional surface facilities, including pipelines, compressors, and processing facilities to recover the gas efficiently and transport it to market.

The role that evolving technology will likely play cannot be over emphasized. We anticipate new and improved drilling and completion technologies—improved techniques to drill directional and horizontal wells, for instance. This would result in increased gas recovery and a reduction in surface disturbance. Improved completion technologies might include advances in stimulation design, equipment, processes,

and materials. Historically, the evolution of stimulation has played a key role in development and well efficiency. Continued advances are anticipated and will benefit both existing and new wells, and may promote the commingling of zones, thereby reducing the number of wells to be drilled.

## CONCLUSIONS

Significant gas resources are available in the San Juan Basin for years to come, but recovery of these reserves will require additional development, primarily in the form of infill drilling. Approximately ten thousand wells will be drilled on federally managed lands in the next twenty years, based on the New Mexico Tech study. This analysis was confirmed by an industry survey, administered by New Mexico Tech and completed concurrently with the geologic and engineering study. The San Juan Basin gas supply is important to the U.S. and to the overall economic health of New Mexico. Industry's continued success in providing large quantities of readily available gas, at a reasonable price, is directly related to decisions made by governmental entities. The challenge is to balance oil and gas development with land use issues and environmental concerns.

## RESOURCES

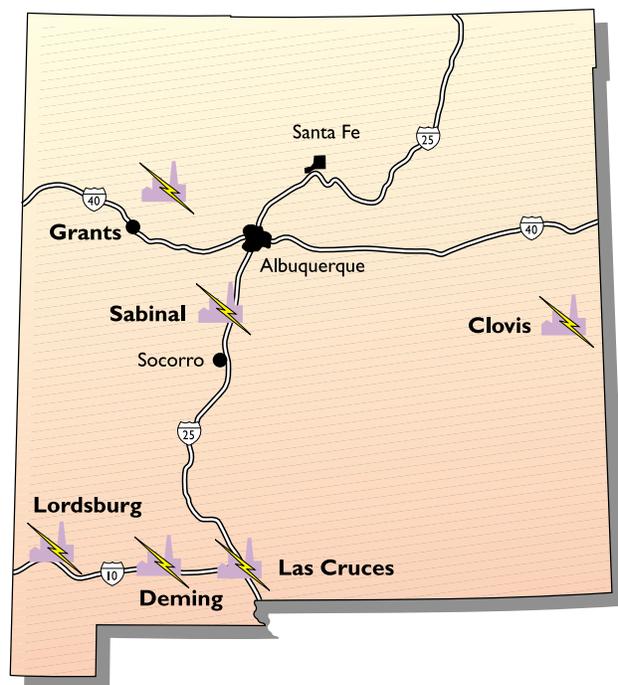
- Engler, T. W., Brister, B. S., Chen, H. and Teufel, L. W., 2001, Oil and gas resource development for San Juan Basin, New Mexico: A 20-year, Reasonable Foreseeable Development (RFD) scenario supporting the resource management plan for the Farmington Field Office, Bureau of Land Management (contact the field office for a copy of the CD-ROM).
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### Planned New Mexico Power Plants

<b>Grants</b>	300-megawatt, coal-fired plant, St. Louis, Mo.-based Peabody Energy
<b>Sabinal</b>	145-megawatt, gas-fired plant, Houston-based Cobisa Corp
<b>Clovis</b>	600-megawatt, gas-fired plant, Houston-based Duke Energy
<b>Lordsburg</b>	80-megawatt, natural gas-fired plant, Public Service Company of New Mexico. 160-megawatt, gas-fired plant, Denver-based Tri-State Generation and Transmission
<b>Deming</b>	560-megawatt, gas-fired plant, Houston-based Duke Energy
<b>Las Cruces</b>	225-megawatt gas-fired plant, Public Service Company of New Mexico

Seven new power plants are currently being planned or are in construction. These plants will meet peaks in local demand and export excess power to the Southwest. Many are natural gas-fired



to take advantage of reduced air emissions, reduced water usage, and New Mexico's abundant natural gas.

# COAL ENERGY AND ELECTRIC GENERATION

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# New Mexico's Coal Industry: Resources, Production, and Economics

Gretchen K. Hoffman, *New Mexico Bureau of Geology and Mineral Resources*

Coal-bearing rocks underlie one-fifth of the state of New Mexico, but most citizens are unaware of the important role coal plays in the economy of the state. Coal mining has been a significant part of our economic development since the 1850s. Today, New Mexico ranks 12th in U.S. coal production (27.34 million short tons), with 1.39 billion short tons of recoverable coal reserves at producing mines.<sup>1</sup> Forty-six percent of the state's total energy needs are met through power generated from coal. The coal industry's contribution to New Mexico's state budget is the third largest source of revenue from mineral and energy production. State tax revenues from the coal industry in New Mexico totaled \$31.8 million in calendar year 2000. In addition, the state receives 50% of all royalties from coal leases on federal lands, and all rents and royalties from state lands. The coal industry in 2000 employed over 1,700 people with a payroll of nearly \$100 million. While the present-day market for coal is dominated by electrical generation, this is just one of the factors that ultimately determine the economic feasibility of mining coal in New Mexico.

## NEW MEXICO'S COAL INDUSTRY TODAY

Six coal mines currently operate in New Mexico; five of them are in the San Juan Basin (Fig. 1). All of these operations mine coal at or near the surface, although the San Juan mine is in the process of converting to an underground operation. Three of those five mines are captive, which means that all the coal produced at those mines is destined for a specific electric power plant. The San Juan and La Plata mines supply coal to the San Juan generating station (operated by Public Service of New Mexico); the Navajo mine supplies coal to the Four Corners generating station (operated by Arizona Public Service). The McKinley mine near Gallup and the Lee Ranch mine northwest of Grants have access to rail transportation and ship their coal to Arizona power plants. Lee Ranch supplies coal to the Escalante generating station (operated by Tri-State Generation & Transmission Association) near Prewitt, New Mexico. The Ancho mine in the Raton Basin delivers high-rank coal by rail to a power plant in Wisconsin; the quality of the coal from the Ancho

mine and the proximity of the mine to rail make it economically feasible to transport the coal out of state.

## ECONOMICS OF COAL

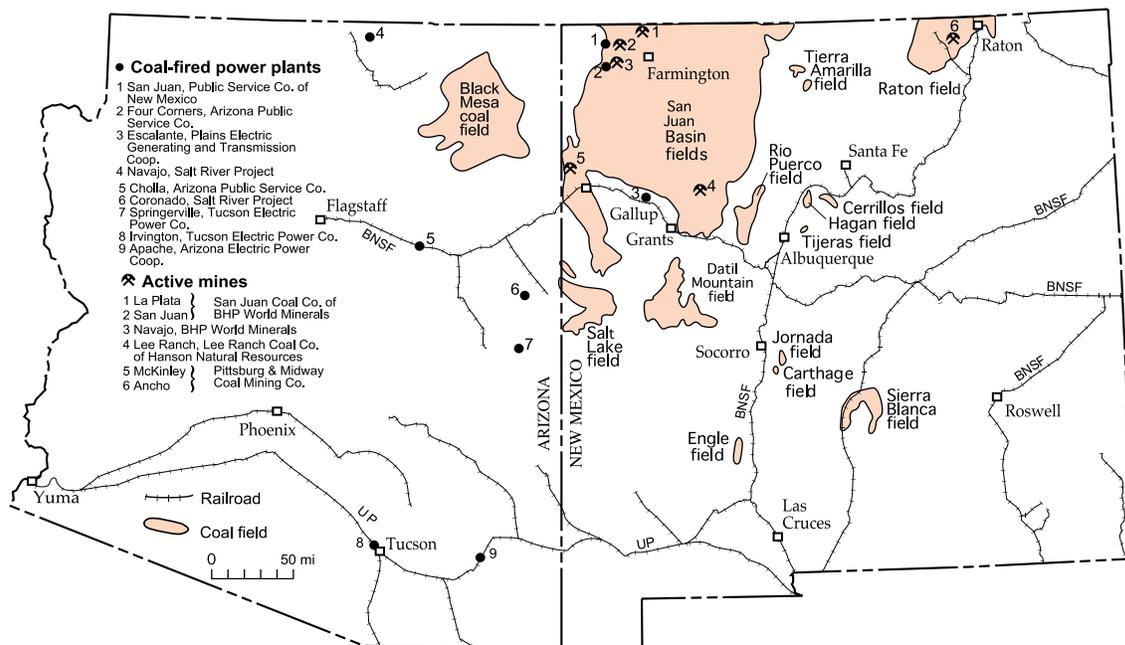
The regional geology of an area determines whether coal is present or absent, and, if present, if the coal beds are thick enough to be considered minable with the available mining techniques. The structure of the coal-bearing deposits—whether the rock units are flat lying, have significant dips, or are faulted—also determines whether a coal bed can be mined with the techniques available.

Coal quality is important as well. There are two important considerations in this regard: sulfur content, which significantly affects the quality of the emissions produced when the coal is burned (how “clean” or “dirty” the coal is), and the heating value, expressed in Btu/lb, which is a measure of how much heat (or energy) can be produced per pound of coal. The relationship between these two factors is the ultimate measure of coal quality.

To meet current standards of the Clean Air Act (as amended in 1990), electric generating stations may not discharge gaseous effluent containing more than 1.2 lb of sulfur dioxide (SO<sub>2</sub>) per million Btu, which translates to about 0.6% sulfur per million Btu. Installing combustion gas scrubbers helps remove sulfur from power plant emissions if a coal has higher sulfur content than the standards allow, but this increases the cost of operations.

Another important quality to consider is the ash content of the coal: the greater the ash content, the greater the amount of combustion byproduct that must be disposed of (see article by Hoffman on fly ash in this volume). Ash is also corrosive to materials used in the combustion chamber, so the greater the ash content of the coal, the higher the cost of maintaining the boiler. Finally, combustion byproducts associated with high ash content must be periodically removed to maintain an efficient and safe operation.

Other factors that affect the economics of coal mining are 1) proximity to available transportation networks, 2) distance to a market and competition within that market, and 3) the technology available for



**FIGURE 1** Coal fields of New Mexico with active mines, coal-fired power plants, and transportation network.

extraction. Throughout the history of coal mining in New Mexico (and elsewhere), the relative importance of each of these factors has changed in response to changes in the end users of the coal produced.

## GEOLOGY

Several areas in New Mexico are defined as coal fields (Fig. 1), but most of the economic coal lies within the San Juan and Raton Basins. Coal-bearing rocks in the San Juan Basin are of Late Cretaceous age (95–60 million years ago) and were deposited in peat swamps in coastal environments. Most San Juan Basin coals thick enough to have economic potential developed from sediments that accumulated as the seas slowly retreated to the northeast, in response to increased sediment supply from the continental highlands to the southwest. This slow and uneven retreat allows for greater buildup of organic material (peat) and for preservation of coal in the rock record. Pressure from the weight of overlying sediments, deposited by rivers, wind, lakes, and seas, compresses the peat. Compaction of the plant material forces out oxygen, hydrogen, and other volatiles, leaving a greater percentage of carbon. This compaction decreases the thickness of the material, as well: an accumulation of 15–20 feet of peat produces a 1-foot thick coal bed.

Heat and time are the most effective elements that

increase the heating value of the coal. Coals in the San Juan Basin do not have great lateral extent. They tend to exist in multiple thin seams within the coal-bearing rock formation, in varying thickness, and typically pinch out laterally. The thickness and extent of coal-bearing strata are important factors in their ultimate economic value.

There are three major coal-bearing rock sequences in the San Juan Basin: the Crevasse Canyon, Menefee, and Fruitland Formations (Fig. 2). The Crevasse Canyon Formation is the oldest unit; coals in this formation are not being mined at this time. The Menefee Formation has two coal-bearing sequences (the Cleary Coal Member at the base and the upper coal member at the top) and is the oldest coal-bearing formation actively mined in the San Juan Basin. Coals in both the Cleary and the upper coal members are thin, averaging 3–5 feet, with some seams as much as 25-feet thick. These coals have limited lateral extent, and there are multiple seams within the coal-bearing sequence at any one location. Surface-minable coal in the Cleary Coal Member is present along the southern edge of the basin and is near the surface on the western and eastern flanks of the basin where the rock units dip steeply. The Menefee Formation coals are low in ash content (inorganic noncombustible material, 7–15%) and are subbituminous in rank

(9,500–11,500 Btu/lb). The sulfur content of the Menefee coals can be over 1% in some areas (which is considered high for New Mexico; New Mexico coals average 0.8% sulfur content). These values limit the economic potential of these reserves. Of the 1.1 billion short tons (st) of surface-minable coal within the Menefee, only 106 million meet Clean Air Act standards of 0.6 lbs sulfur/million Btu. The McKinley and Lee Ranch mines extract coal from the Cleary Coal Member in the southern part of the San Juan Basin (Fig. 1, 2).

The Fruitland Formation is the youngest coal-bearing unit in the San Juan Basin and crops out along the basin's western, southern, and part of its eastern edges (Fig. 2). Some of the thickest coals in the basin are near the base of the Fruitland. Coal seams in the

Fruitland Formation can reach 30 feet in thickness, but 5–10-foot seams are more common. The lateral extent of these coals is limited, but they tend to have greater continuity than coals in the Menefee Formation. Fruitland coals are very high in ash (18–22% by weight), and the sulfur content is variable, depending on the geographic and stratigraphic location, but averages 0.8%. Most of the coals in the Fruitland Formation are of subbituminous rank, but coals near the Colorado border, thermally altered by the San Juan volcanic complex, are of a higher rank (high-volatile bituminous) and therefore have higher heating values (11,500–13,000 Btu/lb). Fruitland coals are mined at the Navajo, San Juan, and La Plata mines west of Farmington (Fig. 1, 2). Demonstrated

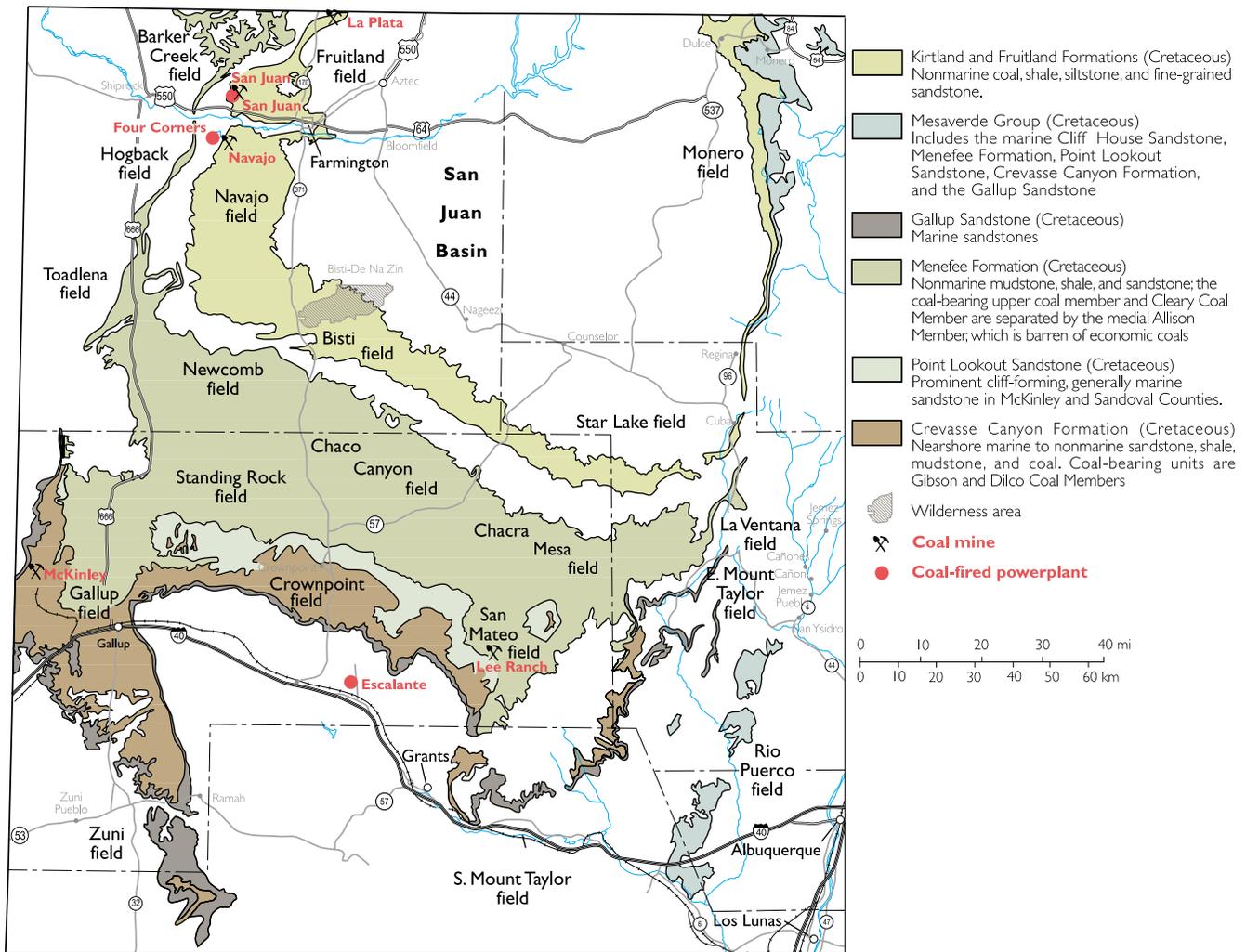


FIGURE 2 Coal fields and coal-bearing rock units within the San Juan Basin.



reserves of compliance coal (coal meeting Clean Air Act standards) within the Fruitland Formation are 883 million short tons (Hoffman, 1996).

## TECHNOLOGY

Throughout the history of coal mining, methods of extraction have changed, becoming more efficient, safer, and less labor intensive. Coal mining in New Mexico began in the 1850s with crude methods (pick and shovel) to mine coal from surface outcrops. Advances were made in underground mining: using explosives to break the coal for easier removal, and employing mules and then battery or electric cars to bring the coal to the surface. With these improvements, along with better ventilation systems, mines increased in size and efficiency. The introduction of large earth-moving machinery, such as large bucket shovels and draglines, made surface mining feasible. Although surface mining began in the 1920s, underground methods prevailed until the 1960s in New Mexico and across most of the nation. The increased mechanization of both surface and underground mining and the use of computers and global positioning systems have increased productivity significantly in the past few years. Although fewer mines are operating in New Mexico now than in the 1980s, production has continued to rise, partly because of technological improvements.

## MARKETS AND TRANSPORTATION

New Mexico coal was first used locally as a home heating fuel. The introduction of railroads to New Mexico Territory spurred the development of many small mines to supply coal to power steam locomotives. Ore smelters in the Southwest provided an additional market for New Mexico coal, particularly coal from the Raton Basin because of its high quality and metallurgical properties. The railroad industry's switch to diesel engines in the 1950s led to the loss of markets for many of the small coal mines and a significant drop in coal production statewide.

Our modern coal industry in New Mexico began in the 1960s, with the increase in population in the Southwest coupled with the demand for cheap electricity. The San Juan Basin was a major area of development because the geology and structure of the area were ideal for surface mining. The Navajo and San Juan mines opened in 1963 and 1973, respectively, to supply coal to adjacent electrical generating stations, built to be near both coal and water. Instead of trans-

porting coal to distant power plants, electricity is generated on site and shipped via transmission lines.

A major restriction for marketing coal from most of the San Juan Basin is the lack of transportation infrastructure (Fig. 1). The lack of railroads is most significant because the only cost-effective way to transport coal is by rail. The only rail line in the northwest part of the state is along the southern edge of the basin, and this line allows the McKinley and Lee Ranch mines to ship coal to power plants in Arizona. Other areas within the San Juan Basin lack coal development in part because of this lack of rail transportation.

In the past, several rail lines have been proposed to provide access to markets, but a major stumbling block has been land access. Although the federal government owns large portions of land in the basin, federal lands are broadly dispersed among tribal, state, and private lands, in checkerboard fashion (see article by Hiles in this guidebook).

The market for New Mexico coal is limited to New Mexico and the greater Southwest, but most of the surrounding states also produce coal. Although New Mexico coal is of a desirable quality that surpasses other coal in the market area—moderate to low sulfur content, high Btu values—transportation and the high cost of mining multiple thin seams has limited the market.

## MINING COSTS

The Clean Air Act of 1970 (as amended in 1990) made the sulfur content of coal relative to its Btu value a major criterion in meeting emission standards. The lower sulfur standard led to a nation-wide shift to low-sulfur coal at generating stations and contributed to the growth of Wyoming's Powder River Basin coal industry, with its vast reserves of low-sulfur coal. The Powder River Basin has 14.7 billion tons of surface-minable, low-sulfur coal compared to the 1.6 billion tons of low-sulfur coal in the San Juan Basin. Development of the Powder River Basin has influenced the entire U.S. coal market. The thick, low-sulfur coal beds in this region allow for very low coal prices, and the extensive rail network in Wyoming allows Powder River Basin coal to be shipped anywhere in the country.

Wyoming coal currently dominates the industry throughout the U.S. The Powder River Basin produces about 30% of the nation's coal. The cost of Wyoming coal in 2000 was \$5.45/short ton at the mine; the average cost of New Mexico coal in 2000 was \$20.29/short ton. The net result is that Wyoming coal

can be shipped far greater distances before approaching the cost of New Mexico coal at the mine.

In addition to extraction costs, reclamation and safety regulations are part of the coal mining economics. The Coal Mine Health and Safety Act (1969) and the Surface Mine Control and Reclamation Act (1977) added many safety and reclamation regulations. Compliance with these regulations increased mining costs and made it difficult for small operators to stay in business. The average price of New Mexico coal in 1974 was under \$5/short ton. Between 1974 and 1981 the price jumped to over \$17/short ton. Smaller companies have gotten out of the coal-mining business, and large corporations now own most of today's operating mines.

The Clean Air Act directly affected the electric generation industry, a major consumer of coal and has had a significant influence on the coal industry. Pollution controls at the San Juan generating station, for instance, account for 35% of the operating costs. Electric utilities consume 87% of the nation's coal production. Approximately 56% of all electricity generated in the U.S. comes from coal-fired generating plants. The dependence on coal to produce electricity varies depending on the region. In New Mexico 46% of the state's total energy needs including electricity, gasoline for cars, and propane for heating is produced from burning coal. The cost of electricity in New Mexico is directly tied to the cost of New Mexico's coal because almost all coal burned at power plants within the state is locally mined. The real price of coal has declined in part because of the greater competition, greater productivity, and the replacement of long-term contracts with reliance on short-term or spot market pricing by utilities. With the pending deregulation of utilities, the coal industry may have to find other ways to cut costs to stay competitive.

## TAXES

The last part of the coal economics equation is taxes levied on coal production. Taxes on coal production are complex and vary from state to state. Most states have four types of tax: sales, corporate income, property, and severance. Royalties are also paid to the owner of the property from which coal is mined, be it state, federal, tribal governments, or private entities. Sales, corporate income, and property taxes are common for an individual or company to pay, but severance taxes are unique to the mining industry. Severance taxes are levied on the value or volume of material extracted from the ground. These taxes may

be levied by percent of value (*ad valorem*) or per unit, or as a combination of the two.

The average effective tax rate (the actual collections divided by output or by gross revenue) in New Mexico is high compared with other western states' tax rates (Fig. 3). Only Montana has a higher tax rate than New Mexico. When calculated by cost per ton, New Mexico is actually the highest in the western states (Fig. 4). Figure 3 shows the breakdown of the different taxes and illustrates where New Mexico has higher tax rates. Neither Utah nor Montana charges sales tax on coal, and Colorado charges a small fraction of a percent. In fact, all states except Arizona and New Mexico provide an exemption on sales tax for coal sold to utilities. These two states levy a sales tax on both electricity and coal, resulting in a double taxation on coal: once as a product from the mine and then again as a component of the price of electricity.

Utah and Arizona do not charge severance tax. The severance tax in New Mexico consists of a severance tax (2.67%) and severance surtax (2.03%). Beginning in 1990, any coal sold under new contract is exempt from the surtax, effectively lowering the total severance tax by 43%. This legislation was renewed in the 1999 legislature until June 30, 2009. The exemption

State	Volume (1,000 tons)	Average Price (\$/ton)	Average Effective Coal Tax Rate (\$/ton)
Arizona	11,787	NA	NA
Colorado	29,989	17.23	0.55
Montana	41,102	8.82	1.34
New Mexico	29,156	20.97	2.54
Utah	26,373	17.33	0.10
Wyoming	337,119	5.38	0.51

**FIGURE 3** Western states coal production and average price for 1999 (EIA, 2001).

	UT	AZ	CO	WY	NM	MT
Sales	0	1.8%	.03%	0.1%	5.3%	0
Severance	0	0	2.6%	4.8%	4.7%	10.5%
Property	0.6%	0.8%	0.5%	4.4%	1.3%	1.0%
Other	0	0%	0%	0%	0.8%	3.7%
<b>Total</b>	<b>0.6%</b>	<b>2.6%</b>	<b>3.2%</b>	<b>9.4%</b>	<b>12.1%</b>	<b>15.2%</b>

**FIGURE 4** Average effective coal tax rates by state—percent of gross receipts. From O'Donnell and Clifford, 1999.

also applies to pre-existing contracts but only to amounts sold in excess of average sales from 1987 to 1989. This legislation has resulted in great savings to the New Mexico coal industry. The prospective elimination of the severance surtax is on the horizon. The surtax will likely be eliminated as present contracts expire. This will remove a \$0.60 charge on each ton of coal produced and reduce the effective severance tax rate in New Mexico to 2.67%.

For many years coal mines operating on the Navajo Nation paid taxes to both the State of New Mexico and the Navajo Nation, but legislation passed in 2001 permits mines operating on Navajo Nation lands and paying taxes to the Navajo Nation to qualify for a credit against gross receipts tax due the state. This new credit means substantial savings for the McKinley and Navajo mines and any new mines to operate on Navajo Nation land. With this legislation and the elimination of the severance surtax, New Mexico's coal taxes will be more in line with those of other western states.

The remaining taxes, property and other (e.g., resource excise, conservation) shown in Figure 3 are low for New Mexico. Property tax constitutes a large percentage of the tax burden in Wyoming, and Montana levies a "coal gross proceeds tax" amounting to 3.7% of the effective tax rate.

## CONCLUSION

If we examine all the factors (geology, transportation, market, and taxes), we can better understand why New Mexico coal is relatively expensive compared to coal from other western states (Fig. 4). Most of New Mexico's coal mines are 20 years old or older, which means the reserves in the mines are deeper and more expensive to mine now than at the beginning of each mine's operation. The San Juan mine switch from surface to underground operations is in response to the increased cost of surface mining. By going underground, San Juan hopes to maintain a competitive product. No new mines have been developed in the San Juan Basin for many years, in part because of the lack of transportation and the inability to reach new markets, as well as the high cost of mining the multiple thin seams characteristic of San Juan Basin coal. Some areas that have potentially economic coal reserves have not been developed because of land access issues. Land access issues are a major stumbling block for new mines trying to acquire land and right-of-ways for transportation. In the 1990s there was no real demand for new coal resources in the New

Mexico market area, but with the recent energy crisis in California there has been renewed interest in coal. The most viable option for new coal mines in New Mexico is captive mines, where coal is shipped directly to a nearby generating station and electricity, not coal, is transported to its destination.

Before electric utility deregulation, the cost of New Mexico coal was not as much of an issue as it is in today's market. Deregulation of the electric utilities would likely bring greater pressure on the coal industry to lower the cost of coal. Recently, several contracts between local coal companies and the utilities have been renegotiated, but more cost-cutting measures may be necessary to maintain a competitive coal industry in New Mexico. Some of these cost-cutting measures may have to come in the form of tax relief. Major reductions in coal production would adversely affect the state's economy, not only in decreased revenues for the state but also in jobs lost within the state.

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## ENDNOTE

- <sup>1</sup>Coal in New Mexico can be divided into resources—the coal that is in the ground—and reserves: coal that is economically producible at this time, given our current technology, the cost of energy, competition from other markets, etc.

## Regulation of the Coal Industry in New Mexico

James O'Hara, *New Mexico Energy, Minerals and Natural Resources Department*

I've heard it said that the coal industry is the most regulated business in America. Having regulated surface coal operations for almost eight years, I think I'd have to agree. But if it's one of the most regulated industries, it is also one of the most environmentally responsible. The dynamic between these two can serve as a model for striking a balance between development and environmental protection.

I'd like to introduce you to coal regulation in New Mexico by briefly summarizing:

- the laws affecting surface coal mining in New Mexico;
- what goes into a surface coal mining permit;
- the role the state of New Mexico plays in the operation of a mine;
- how the coal operators and the state work together, to protect the environment and achieve quality reclamation that will be productive long after the mine is gone.

The regulation of surface coal mining is governed by the federal Surface Mining Control and Reclamation Act (SMCRA), enacted by Congress and signed into law in 1977. The act created a national regulatory authority, the Office of Surface Mining (OSM) that is responsible for permitting, inspection, and enforcement of surface coal mines through regulation (30 CFR 700-7900). Title V of the act allows OSM to transfer regulatory responsibilities for surface coal mining to the states, provided that a state program that is no less effective than SMCRA can be created through statute and regulation.

New Mexico was granted primacy in 1980 with the passage of the Surface Mining Act (NMSA 1979 69-25A-1 *et seq.*) and its implementing regulations, developed through the Coal Surface Mining Commission, 19.8 NMAC. New Mexico's coal program, which is part of the EMNRD's Mining and Minerals Division, regulates federal, state, and private lands, excluding only lands falling within the bounds of Indian reservations, which are regulated by OSM under the federal program.

New Mexico's three hundred pages of coal regulations cover every aspect of mining and the effects it may have on the environment or the public. These

include air quality, protection of surface and ground water, protection of topsoil, and disposal of trash on a permitted mine. More importantly, the regulations set a standard for reclamation of lands affected by mining.

### WHAT'S IN A COAL MINING PERMIT?

There are three main parts of a surface coal mining permit application:

#### 1 *Legal, Financial, Compliance, and Related Information*

An applicant must provide information on who owns the mining company and will conduct mining.

Included is a detailed description of the corporation, affiliated corporations, and the parent corporation.

The federal Office of Surface Mining established the Applicator Violation System, which uses this information to identify "bad actors" and prohibit them from operating a coal mine anywhere in the U.S. This part of the permit also identifies all landowners of surface or mineral estates, any other permits and licenses that may be needed (NPDES, MSHA, etc.), and documentation that the applicant has a right-of-entry or leases to conduct mining.

2 *Background on Existing Environmental Conditions* A permit must contain detailed information about the nature of the site before mining. This includes sections on surface and ground water hydrology, geology, topography, climate, vegetation, soils, fish and wildlife (including threatened and endangered species), and current, pre-mining land use. There are specific requirements for the various types of information listed in each section. For example under vegetation, an applicant must collect:

- A comprehensive listing of species by plant community;
- Information on ground cover, and frequency and constancy values for each species (herbaceous, tree, and shrub);
- Acreages for each community correlated to soils, slope, and aspect;
- Information on the above that is collected over two growing seasons.

3 *A Reclamation and Operations Plan* The purpose for collecting the environmental information is to develop a reclamation plan that will reconstruct as many of the



Mine	Mine location (County)	Permit area (acres)	Acres disturbed	Current bond	Phase released	Amount released	Acres released
Ancho <sup>2</sup>	Colfax	15,909	2,080	\$10,000,000			
Black Diamond <sup>1</sup>	San Juan	249	23	\$89,732	I	\$134,597	23
Carbon No. 2 <sup>1</sup>	McKinley	361	308	\$308,000	I II	\$2,976,687 \$1,676,458	468.4 308
Cimarron <sup>1</sup>	Colfax	5114	54	\$1,102,694			
De-Na-Zin <sup>1</sup>	San Juan	820	172	\$251,402	I II	\$2,815,176 \$1,373,980	170 149.3
Fence Lake <sup>3</sup>	Catron & Cibola	17,702	0	\$7,739,773			
Fence Lake No. 1 <sup>1</sup>	Catron	500	116	\$998,743	I	\$665,829	92.6
Gateway <sup>1</sup>	San Juan	600	144	\$468,742	I II	\$703,113 \$260,811	144.1 144.1
La Plata <sup>2</sup>	San Juan	3,300	1,902	\$56,000,000			
Lee Ranch <sup>2</sup>	McKinley	15,522	4,835	\$75,500,000			
McKinley <sup>2</sup>	McKinley	10,727	4,262	\$44,489,000	Liability Release	\$0	1,745.6
Mentmore Section 33 Industrial Park <sup>1</sup>	McKinley	1,813	1,746	\$1,587,000	I Final	\$0 \$0	618.9 455.7
San Juan <sup>2</sup> NW Pinion	San Juan	18,050	5,127	\$67,000,000	I Final	\$0 \$0	1,832 236.74
York Canyon Surface <sup>1</sup>	Colfax	2,733	1,174	\$2,258,000	I & II	\$5,525,319	1,053
York Canyon Underground <sup>1</sup>	Colfax	4,792	650	\$14,598,577	I & II	\$2,210,019	190

<sup>1</sup>No production, all areas are under reclamation in the 10-year liability period; <sup>2</sup>Currently producing coal, with areas of reclamation in the 10-year liability period; <sup>3</sup>Permitted, but has not begun mining operations.

**FIGURE 1** A summary of New Mexico's surface coal mine operations in 2001.

pre-mining conditions as possible. The reclamation plan includes an approved post-mining land-use and topography, replacement of topsoil, the type of vegetation (seed mix) needed to meet post-mining land uses, and any special mitigation required to prevent toxic or acid-forming materials from affecting the long-term viability of the final reclamation.

The operation plan sets forth a process by which coal will be mined and all the requirements of the reclamation plan will be implemented. Unlike other types of mining reclamation, coal mine reclamation is contemporaneous with the removal of coal. There are strict provisions that limit the amount of disturbance that may take place without corresponding reclamation.

#### **HOW ARE PERMITS APPROVED?**

When an application is received by the Mining and Minerals Division (MMD) it undergoes an in-depth

review to ensure that all of the elements are present, correct, and in the prescribed detail. The Mining and Minerals Division works with the applicant until the application is administratively complete. At that time the public is notified and given the opportunity to review and comment on the application. Public hearings may be held, and additional technical issues are typically addressed.

Upon completion of the public comment period, the director will make a decision on the disposition of a permit. If it is judged to be approvable, the operator must submit a bond that is based on a calculation of what it would cost MMD to complete reclamation should the operator go out of business or not meet the permit requirements. The regulations specify that a bond adequate to carry out reclamation must be held for no less than ten years after the last seeding is completed and specific performance standards have been met, based on a post-mining land use. For example,

criteria for the amount of ground cover, production, diversity, and shrub reestablishment are specified in the permit. Once the bond instrument is in place, the permit can be approved. It can take up to a year or more to process a new application, depending on the quality of the submittal.

One last comment on the permitting process: The regulations include provisions for appealing a permitting decision. This ensures that the public interest is protected.

### **WHAT GOES ON DURING THE LIFE OF A COAL-MINING OPERATION?**

Most of the permitted coal mines have a minimum life of about twenty years for the smaller mines and thirty to fifty years for the larger ones. During this time MMD relies on a series of performance standards and the stipulations of the permit to inspect and enforce all operations; violations can be written on infractions of the rules or the permit. Inspections to review how well the mine is following its operation and reclamation plans are conducted on a monthly basis.

Permits are generally renewed every five years. A renewal is similar to a new application, except that a mine has a right of successive renewal unless an opponent can show the director that the original permit was improvidently issued. The purpose of renewals is to update permits and fine-tune issues associated with operation or reclamation planning. Permits will often undergo minor changes that do not go through a public notice process. MMD completes 50–75 modifications for its mines every year.

### **BOND RELEASE - GETTING CLOSURE**

Since reclamation is contemporaneous with mining, bonds are recalculated every couple of years and adjusted as necessary. As reclamation is completed, permittees can also apply for phased bond releases. Phase I credits completion of backfilling and grading by establishment of an approved post-mining topography. Phase II recognizes revegetation success and evaluates the performance standards for successful revegetation included in the permit. A bond can be reduced upon the director's approval of a bond release application. Final bond release, Phase III, documents that the permittee has waited ten years and demonstrated to the director that the reclaimed lands can support the post-mining land use, which in most cases is grazing. Once the bond is released, the permit is terminated.

### **A SUMMARY OF COAL PERMITS IN NEW MEXICO**

New Mexico has 16 surface coal mines currently permitted (Fig. 1). Ten of these are under the ten-year reclamation liability period and are not in production. Five are under production, producing about 20 million short tons of coal a year. The remaining mine, Fence Lake, is permitted but has not begun operation.

Coal mining continues to be an important element of New Mexico's economy. The regulatory process seeks to strike a balance between the economic and energy needs of the nation and protection of the environment.



## Coal Mine Reclamation in New Mexico

Douglas Bland, *Mining and Minerals Division, New Mexico Energy, Minerals and Natural Resources Department*

The primary goal of coal mine reclamation is the establishment of an appropriate post-mining land use. Regulations require that disturbed areas be returned to the approximate original contour of the land. In this paper I will discuss standard reclamation practices that have been used at most mines in New Mexico. I will also discuss how we address areas that have steep slopes or that require drainages be reconstructed, and special habitat areas where unique reclamation techniques are used to create diversity in landforms and wildlife habitat.

There are differences of opinion regarding the most appropriate post-mining land use for mine sites. In addition, there can be disagreements as to whether the mine should be constructed at all. One reason for opposition to energy development is use of the land for religious purposes. In New Mexico, Native Americans claim that development on certain lands may impede their historic use of the land for religious practice. Such claims can be made even if title to the land is not currently held by the claimant. In 2000 the New Mexico Legislature passed the Religious Freedom Restoration Act to address this issue. At the end of the paper I've included a discussion of the Religious Freedom Restoration Act and its implications for coal mining.

### STANDARD RECLAMATION: PRODUCTIVE SHRUB/GRASSLANDS

Grazing land and wildlife habitat are the most common post-mine land uses for New Mexico reclamation. Creating a diverse, effective, and permanent vegetative cover on all affected lands is the best way to achieve these land uses (Fig. 1).

Standard reclamation practices on coal mines are geared toward maximizing the potential for post-mine plant productivity. All surface or strip coal mines create open pits when the coal is removed. The backfilling and grading operations following coal removal typically result in a gentle, rolling reclamation topography (Fig. 1). Any rock or other material that is toxic or detrimental to plant growth is buried below the rooting zone. Soils are generally more evenly distributed, in

terms of both location and depth, than they were before mining. Native grasses, shrubs, and forbs are seeded; each species is selected for its ease of establishment, adaptation to site conditions, and seasonal forage value. Management of surface water and precipitation runoff is usually better than the pre-mine condition. Finally, careful management is applied to all reclaimed lands during the minimum 10-year bond liability period.



**FIGURE 1** Reclaimed land including a small area depression and productive grasslands at Ancho mine, Colfax County, New Mexico.

The reclamation bond liability period can be thought of as a proving-up time. Livestock grazing is conducted, revegetation is monitored, and wildlife usage is recorded. The quantity and quality of surface and ground water are also monitored. The mine operator is required to demonstrate that reclaimed lands can and do support the post-mine land use, while meeting all approved revegetation and hydrology success criteria, and the bond is not released unless the post-mine land use has been successfully implemented.

The results of these reclamation practices are impressive. Post-mine production of palatable forage is typically double the pre-mine productivity. If the site

was in poor range condition before mining, the post-mine vegetation productivity gains can be much higher. Without question, the essential reclamation mandates are being achieved in New Mexico.

Although reclamation of coal mines has been ongoing since the federal Surface Mining Control and Reclamation Act was passed in 1977, it is an evolving science. The following topics discuss refinements and enhancements to basic reclamation that are being incorporated into reclamation practices in New Mexico.



**FIGURE 2** Complex slopes and drainage construction at San Juan mine, San Juan County, New Mexico.

### STEEP SLOPE AND DRAINAGE CONSTRUCTION

Revegetation can take several seasons to become fully established in New Mexico because of our generally dry climate and the use of perennial species that take more than one year to mature. Erosion can be a problem during the first few years following seeding when surface roughness, mulch, and sparse annual weed cover are the only protection against the forces of nature. Cut-and-fill terraces and rock-lined drains are sometimes used to limit erosion on steeper slopes, but the long-term stability of terraces and drains is a concern. Complex slopes, talus slopes, and substrates with high coarse rock fragment concentrations can be effective alternatives to terraces for steep-slope reclamation. Erosion control is achieved on complex slopes by creating branched drainage patterns. The length of steep slopes is thereby effectively shortened, reducing runoff velocity. Slopes are built with an overall concave longitudinal profile, steeper at the top and flatter at the bottom, so that gradients are reduced as surface runoff accumulates (Fig. 2).

Adjacent undisturbed areas can provide models for drainage construction. Sinuosity within low-flow channels is used to reduce drainage gradients and erosion potential. Rock fragments that do not easily wash away may be used at critical spots in the drainage bottom. Wider flood-stage channels are added in the larger drainages to spread and slow the runoff from major precipitation events.

### SPECIAL HABITAT FEATURES

Special habitat features include badlands and cliffs, small area depressions, and wetlands. The creation of special habitat features is an important component of modern reclamation. Animal and plant species diversity on the reclaimed landscape is dependent on the creation of a variety of appropriate habitats.

The reclamation of badland sites, such as the Gateway mine in the San Juan Basin, present some unique challenges. The Gateway mine is on state trust lands that were used for grazing before mining; grazing is also the post-mining land use. The coal that was mined there provided much more revenue to public schools than badland grazing ever could. The absence of fertile, or even neutral, soil material made it very difficult to establish an effective vegetative cover. Several experimental soil amendments were tried at Gateway to improve reclamation success, including various combinations of wood chips, fertilizer, calcium chloride, gypsum, and phosphorus. However, red scoria gravel, which was salvaged before mining and applied as surface mulch during reclamation, resulted in the best vegetative cover. Forage production on Gateway reclamation, although still sparse, is seven times greater than was measured before mining.

Sandstone-capped plateaus, mesas, and cuestas are common and dramatic pre-mine features that are important both to plant and animal diversity as well as to the aesthetic value of the landscape. Several competent sandstone highwall segments at New Mexico coal mines have been retained as cliff habitat. Recently a raven established a nest on one reclamation cliff while grading operations were still being completed. Rock surfaces concentrate precipitation and enhance soil moisture at the bases of cliffs. The increased moisture encourages the establishment of trees and shrubs, and the depressions created at the bases of cliffs provide seasonal water sources (Fig. 3).

Small area depressions are commonly built on reclamation to furnish temporary drinking water for livestock and wildlife, to control erosion, and to create vegetation diversity. They also provide breeding habi-

tat for insects and amphibians, and foraging sites for predators. Depressions are completely incised and have gentle slopes, and they are re-soiled in a manner consistent with adjoining areas. Depending on the climate of the site and the size of the contributing watershed, small area depressions may vary from western wheatgrass-dominated communities to seasonal wetlands.

Rare plant species are commonly associated with shale and sandstone rock outcrops or springs and seeps. Mitigation is required when mining impacts springs or other wetland habitat, or if the plants are listed as threatened or endangered. Sediment and flood control ponds may be retained as wetlands or developed water resources, with landowner concurrence. Ponds fed by artesian wells have also been used to replace spring-fed wetlands. Outcrop-type rare plant habitat can be provided by simply not re-soiling small areas of reclamation, where the rocky material provides suitable physical and chemical characteristics for the species of concern, and then transplanting the plants and a bucketful of their original soil to the replacement site.



**FIGURE 3** Reclamation cliff at Mentmore mine, McKinley County, New Mexico.

The science of reclamation is evolving. Natural ecosystems are extremely complicated, and as understanding of them expands, so do efforts to address the critical elements of re-creating ecosystems that are both useful and long-lasting.

### **ACKNOWLEDGMENTS**

*Many thanks to Dave Clark, Senior Reclamation Specialist with the Mining and Minerals Division, for his assistance with this paper.*

## The Religious Freedom Restoration Act

Proper reclamation becomes a major issue at a mine site only after mining begins. The decision to begin mining involves successfully addressing any challenges as to whether mining is appropriate for the site. One mechanism that may be used to prevent mining from starting is the Religious Freedom Restoration Act (RFRA), signed into law by Governor Gary Johnson in 2000.

In the 1990s Congress passed the federal RFRA in response to certain court decisions that were perceived by some to unduly restrict certain religious practices. RFRA was intended to change the law in order to provide more religious protection. Subsequently, the federal RFRA was found unconstitutional on the grounds that it was beyond the power of the U.S. Congress, and the court ruled that the states alone could pass such legislation. Many states including New Mexico have since passed their own RFRA. There is currently very little case law on RFRA, because states have just begun to pass RFRA. General First Amendment law will likely be used in RFRA analysis, because RFRA also addresses the protections contained in First Amendment law. To better understand the position courts have taken on such issues in specific circumstances, case law related to the First Amendment should be consulted.

In part, the New Mexico RFRA provides that a government agency shall not restrict a person's free exercise of religion unless:

A the restriction is in the form of a rule of general applicability and does not directly discriminate against religion or among religions; and

B the application of the restriction is essential to further a compelling governmental interest and is the least restrictive means of furthering that compelling governmental interest. RFRA goes on to provide for injunctive and declaratory relief and damages pursuant to the Tort Claims Act.

RFRA analysis requires consideration of several key phrases in order to better understand the statute.

"Substantially motivated" Any analysis of a RFRA issue must begin with the question whether the "free exercise of religion" is involved. Under RFRA, the religious conduct sought to be protected must be "substantially motivated by religious belief." ("Free exercise of religion" means an act or refusal to act that is substantially motivated by religious belief.)

"General applicability" This simply means that a restriction must apply equally across the board to everyone. Any restriction that targets a specific group will be invalid.

"Compelling governmental interest" RFRA does not prohibit every governmental restriction that impacts religious practice. It essentially contains a balancing test, under which the governmental justification for the restriction is weighed against the practice.

Because religious practice is highly protected under our laws, the government bears a heavy burden to justify its restriction with a "compelling governmental interest."

"Least restrictive means" In addition to requiring the government to justify its regulation by compelling interest, the government must show that its regulation is narrowly tailored to achieve its purpose.

The proper forum for a RFRA challenge appears to be the District Court. The legislature provided that RFRA violations may be asserted "as a claim or defense in a judicial proceeding and obtain appropriate relief including injunctive or declaratory relief and damages pursuant to the Tort Claims Act."

"Judicial proceeding" refers to District Court. This may result in a second, separate process being used by challengers to government permits or actions as a sort of citizens suit, in that a challenged decision proceeds through normal administrative appeal channels, while at the same time someone can bring a RFRA challenge in District Court, without going through administrative channels.

Exactly how and under what circumstances New Mexico's newly enacted RFRA will be used is not yet known. However, the clear message is that religious freedom is an important issue to the state legislature and the governor, and it must be properly considered when energy and mineral development is contemplated in areas where this is an issue.



## Coal-Fired Electric Power Generation in New Mexico

Pat Goodman, *Public Service Company of New Mexico*

**M**ost New Mexicans understand that New Mexico is an “oil and gas state.” We are among the nation’s top producers of those energy forms. But many don’t know that New Mexico is blessed with huge coal reserves, as well. In fact, our coal reserve—the amount of coal in the ground—are the fourth largest in the United States. Yet New Mexico takes little advantage of these rich reserves. As a coal producer—actually pulling coal out of the ground—we only rank 13th nationwide.

Why? Rail service from the Four Corners area, site of the state’s largest coal reserves, is virtually nonexistent. Coal in New Mexico is used primarily at power stations built at the mouth of a mine. As a result, coal mined in New Mexico is used primarily for electricity production at two major generating stations: the San Juan Generating Station, operated by Public Service Company of New Mexico (PNM), and the Four Corners Power Station, operated by Arizona Public Service Company.

San Juan Generating Station is the seventh largest coal-fired generator in the western United States. The plant burns between 6.5 and 7 million short tons of coal a year. The nearly 1,800 megawatts of energy produced at the station, located in the northwestern corner of New Mexico, serves PNM’s approximately 369,000 electric customers in Albuquerque, Santa Fe, Las Vegas, Clayton, and Deming. Power produced here but not needed for PNM customers or the plant’s other owners reaches across the West through a transmission network that stretches across 11 western states, two Canadian provinces, and into Baja, Mexico. With eight different owners from as far away as southern California to nearby Farmington, New Mexico, the plant’s product is a vital part of the regional economy.

The nearby Four Corners Power Plant, operated by Arizona Public Service, provides even more energy, at 2,040 megawatts. Together, the two plants produce enough energy for more than 3.6 million homes. Their location on the western grid, with major switching facilities, makes the two power plants key facilities in the Southwest. Despite this, when a unit goes down, power flows across the transmission system from other generators, and PNM customers don’t even notice.

### RELIANCE ON COAL

PNM customers rely on coal for the majority of their electricity. But other resources make up the fuel mix. Nuclear power from Palo Verde Nuclear Generating Station west of Phoenix provides about 24% of the energy PNM customers might use on any given day. Eighteen percent of the energy PNM produces comes from natural gas and oil. Still, coal remains the workhorse fuel, providing 58% of the energy for our New Mexico customers. Nationally, the United States burns coal for about 51% of its electricity generation.

The average PNM customer uses 526 kilowatt-hours of electricity a month. If all this energy came from coal, it would take about 660 pounds of coal each month to generate that amount of electricity. At this writing (January 2002), PNM is exploring renewable resources like wind for investment in our energy future. But today, and into the foreseeable future, PNM and other utilities will continue to rely heavily on coal for meeting our energy needs.

In order for coal to be used far into the future, it must be burned as cleanly as possible. More than 25 years old, the San Juan Generating Station meets all regulations for air emissions. It has also been a zero-discharge plant since 1983, keeping all water discharged on the plant site rather than returning it to the area’s rivers and streams. But strict compliance with environmental law is only part of the station’s focus. The plant has substantially “raised the bar” on emissions and other environmental practices. We’ve made a serious commitment to getting the most out of every ton of coal burned while reducing emissions at the same time.

For example, between 1997 and 2001, we were able to dramatically reduce sulfur dioxide emissions by 50%, even while we burned more coal (Fig. 1). And, the plant has teamed up with BHP Minerals, supplier of the coal the plant burns, to provide cleaner-burning coal at a reduced cost. This kind of innovative thinking will lead to the development of the largest longwall mining operation in North America. And it’s located right in San Juan County.

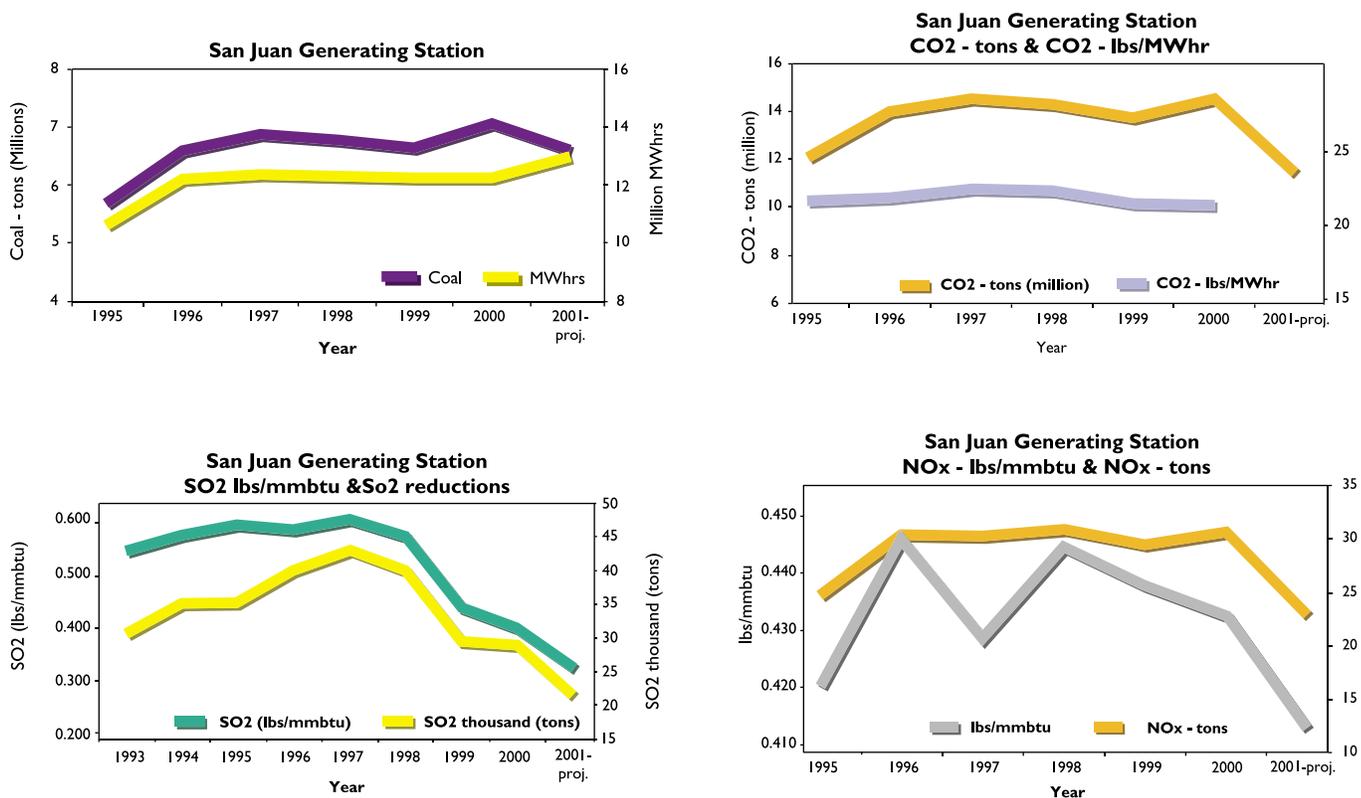


FIGURE 1

**REDUCING AIR EMISSIONS**

Burning coal with less and less emissions is at the heart of PNM’s goals for its coal-fired generation. New Mexico had some of the most stringent state laws for air quality in the nation when the majority of San Juan Generating Station was under construction in the 1970s. To meet those standards, PNM installed a state-of-the-art and very expensive air emissions control system. The system allowed the plant to meet the new air quality laws of the time.

That original Wellman-Lord regenerative sulfur dioxide-removal system was replaced with a new limestone-forced oxidization system in mid-1998. The new system takes gases from the flue, once combustion is complete, and forces them through a spray of limestone slurry in huge absorber cells. The slurry containing the gases becomes calcium sulfate, or gypsum. Once the moisture is removed, the gypsum can be safely returned to the mine to be buried as part of the mine reclamation process.

The new limestone system not only performs better, reducing emissions such as sulfur dioxide by about 50% over the old system, but it also costs much less to run. Operating and capital costs related to the new

system also dropped a significant \$20 million a year for the plant’s owners, helping to keep San Juan power prices competitive in the marketplace and rates low for PNM customers. And the numbers continue to improve with our expanding operating knowledge and experience.

Nitrogen oxide (NOx) is another significant emission associated with coal burning. The plant has installed low-NOx burners and burns coal at slightly lower temperatures to further reduce NOx emissions. The electrostatic precipitators at the plant remove 99.7% of the particulates from the flue gas to ensure cleaner emissions.

**SAN JUAN GENERATING STATION’S ENVIRONMENTAL MANAGEMENT SYSTEM**

Emissions control systems are only part of the solution to burning coal cleaner. In 1999 the San Juan Generating Station took an ambitious step by implementing an Environmental Management System (EMS). And we took it one step farther with our commitment to obtain ISO 14001 certification.

ISO 14001 standards are international standards for environmental management systems that are set by the

International Organization for Standardization in Switzerland. The standards are based on the concept of continuous improvement of environmental performance. In March 2000 an independent auditor certified San Juan Generating Station's Environmental Management System to the ISO 14001 standards.

In December 2000 the San Juan Generating Station was recognized by the Environmental Protection Agency (EPA) as a charter member in its Performance Track Program. The Performance Track Program was developed by the EPA to recognize companies that achieve superior environmental performance and to develop partnerships with these companies. San Juan was one of only two coal-fired generating stations in the United States to be recognized as a charter member in the Performance Track Program.

San Juan's membership in the Performance Track Program includes a commitment to additional reductions in emissions and support of the recovery of endangered species. As part of the Performance Track Program, San Juan Generating Station recently signed a contract with Phoenix Cement to provide fly ash for use in cement products and road building. This represents a significant reduction in solid waste to be buried as part of the mine reclamation process—a reduction of about 300,000 short tons a year.

The plant has served as a model for other power plants PNM operates. The company is committed to implementing an Environmental Management System at all its power plant facilities, from the oldest members of the generating station "fleet," to the newest plants under construction today.

### **A NEW COAL SUPPLY**

Later this year, the coal supply for San Juan Generating Station will come from a new source. BHP Minerals, owner and operator of the mine located next to the plant, is currently making the transition from its surface mining operation to an underground mine.

To mine the coal, BHP Minerals has invested in new "longwall mining" equipment. The technology employs massive hydraulic roof supports and speedy conveyor belts to mine and move large amounts of coal. The underground facility will take advantage of large underground coal seams that could not be reached by surface mining equipment. The coal that is removed will not contain the dirt or other materials often found in the surface-mined coal. As a result, the plant will receive higher grade coal. Switching to an underground mine will allow the mining company to offer a lower-priced and cleaner-burning coal supply,

keeping San Juan Generating Station's future power supply economic and competitive long into the future.

### **FUEL DIVERSITY**

Investing in power plants is capital intensive. San Juan Generating Station represents a total investment of over \$1 billion today. Those costs have been borne not only by utility customers but also by shareholders and other owners in the plant. Selling the plant's excess power when available also helps keep costs down. The end result is competitively priced electricity.

Part of what helps keep prices competitive is the concept known as "fuel diversity." PNM's generation resources represent a mixture of fuels, from coal to nuclear to natural gas and oil. Each source is traded in a larger market for energy. Most consumers are familiar with the volatility of the market when it comes to natural gas for heating their homes. Power plants running on natural gas see the same ups and downs, too.

Newer plants under construction today use clean-burning natural gas as a fuel but the cost to produce that electricity can suffer great price swings. To counter this effect, coal-fired plants offer stable fuel costs over many decades. When managed as a portfolio of resources, power produced by diverse fuel sources offers better protection against price swings over the many decades of service that each plant provides. Each fuel has its strengths and weaknesses. With power plants serving 40 years or more, such decisions have long-lasting effects.

PNM believes that there will still be a place for new coal production in the next generation of power plants. But these new plants will have the advantage of well-developed "clean coal technologies." This new generation of coal-fired plants must address concerns about carbon dioxide and global warming. An integrated gasification combined-cycle approach may prove to offer the benefits of coal while significantly reducing the impacts on the environment.

Utilities like PNM must consider these long-range impacts and develop a clear understanding of how to manage them. At San Juan Generating Station, we have struck a good balance, reducing the effect of burning coal while producing reliable, affordable energy.

### **ADDITIONAL RESOURCES**

For more information on PNM's power plant operations or environmental focus, visit the PNM website: [www.pnm.com](http://www.pnm.com)  
For information on the electric industry in the United States, visit the Edison Electric Institute's website: [www.eei.org](http://www.eei.org)

# Air Quality and the Clean Air Act Amendments

Sandra Ely and Mary Uhl, *New Mexico Environment Department*

**H**aze is caused when light is absorbed or scattered by air pollution. Haze makes the view less clear and diminishes the range of visibility. Air pollutants that are responsible for haze include sulfates, nitrates, organic carbons, soot, soil dust, and nitrogen dioxide. The greater the quantity of these pollutants that are in the atmosphere, the more regional haze will obscure the view. Generally, haze is worse in the summer when there is more humidity; some of the pollutants that cause haze, such as sulfates, grow in size when exposed to water particles. Larger particles are more effective at scattering and absorbing light, so haze becomes worse. There are many sources of the air pol-

lutants that cause haze to form. Electric power generating facilities are large contributors of haze-forming air pollutants. These facilities emit particulates, nitrogen dioxide, and sulfur dioxide. Sulfates and nitrates are formed when sulfur dioxide and nitrogen dioxide are transported long distances. Other sources of air pollution that contribute to haze formation include automobiles, forest fires, windblown dust, and other industrial facilities.

The pollutants that cause haze have major impacts to our health and environment. Small particles of air pollution can be inhaled and reside in the lungs, increasing the risk of respiratory illness, damage to



**FIGURE 1** Map of 156 national park and Wilderness areas protected by EPA's regional haze rule



lung tissue, and even premature death. Sulfates and nitrates are formed from sulfur dioxide and nitrogen dioxide emitted from facilities such as power plants, refineries, and copper smelters. These pollutants cause acid rain. Acid rain damages plants, buildings, and bodies of water. Acid rain may cause lakes, rivers, and streams to become so acidic that there is harm to aquatic plants and fish. Many of the pollutants that cause haze also contribute to the formation of ozone at ground level. Ozone causes respiratory problems and damages plants and ecosystems. Nitrogen dioxide emitted from electric power generating stations and oil and gas facilities can increase the nitrogen loading in lakes, streams, and rivers, upsetting the balance of nutrients in the water and harming plants and fish.

In the western United States, visual range in national parks and Wilderness areas has decreased from an average of 140 miles in the late 1800s to anywhere from 35 to 90 miles today. In the eastern United States, visual range has also decreased. In national parks and monuments, including Grand Canyon, Bandelier, and Yosemite, this decrease in visibility also decreases the quality of the visit for tourists, while increasing the health and environmental problems caused by the haze-forming pollutants.

Congress mandated that the Environmental Protection Agency (EPA) address the problem of haze in our nation's parks and Wilderness areas in the Clean Air Act Amendments of 1990. In 1997 EPA proposed a regulation to reduce emissions that cause haze to form. The rule was issued in April 1999. It requires states to establish quantifiable goals for improving visibility and returning visibility to "natural conditions" in 156 national parks and Wilderness areas (Fig. 1) by the year 2065. The rule requires a coordinated effort between states because tiny particles of air pollution can be transported hundreds of miles by the wind. Each state must develop a plan that addresses the contribution of sources of air pollution to national parks and Wilderness areas within the state and in neighboring states.

New Mexico has nine national parks and Wilderness areas where visibility must be improved under the EPA's new regional haze rule (Fig. 2). These areas are designated as Class I areas, meriting special protection by Congress because of their scenic vistas, wild areas, and historic landmarks. In New Mexico the Class I areas are:

- Wheeler Peak Wilderness
- San Pedro Parks Wilderness
- Pecos Wilderness

- Bandelier National Monument
- Bosque del Apache National Wildlife Refuge
- White Mountain Wilderness
- Carlsbad Caverns National Park
- Salt Creek Wilderness
- Gila Wilderness

These areas attract thousands of tourists to New Mexico each year. Class I areas in neighboring states that may be affected by air pollution from New Mexico include Mesa Verde National Park, Guadalupe Mountains National Park, Weminuche Wilderness, and Chiricahua National Park. In most of these Class I areas, visibility has been improving on the "cleanest" days over the past ten years, but degrading on the "dirtiest" days. Clean days are days when visibility range is greatest; dirty days are days when visibility range is reduced by the greatest amount. EPA's 1997 regional haze rule requires improvement in visibility on the cleanest and the dirtiest days. At most of these Class I areas, acid rain has also increased over the past ten years.

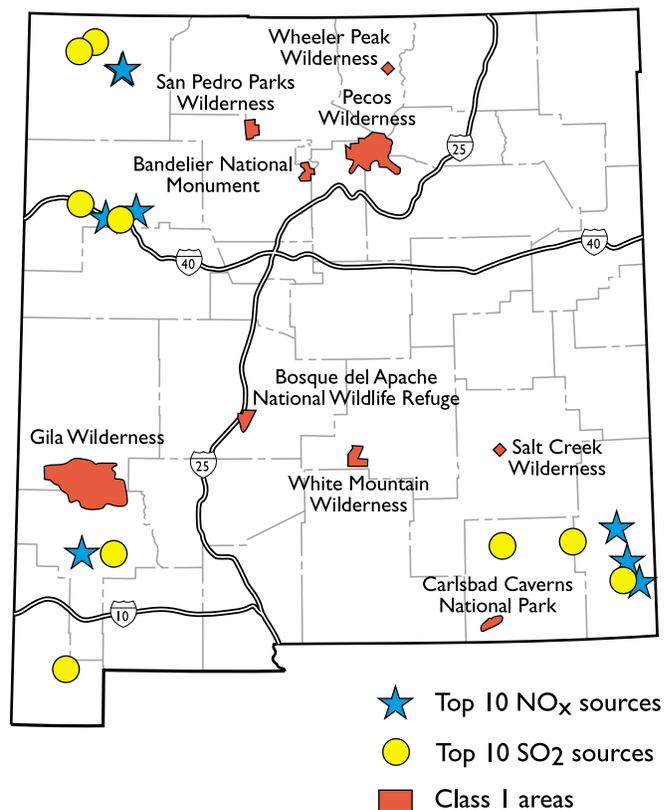
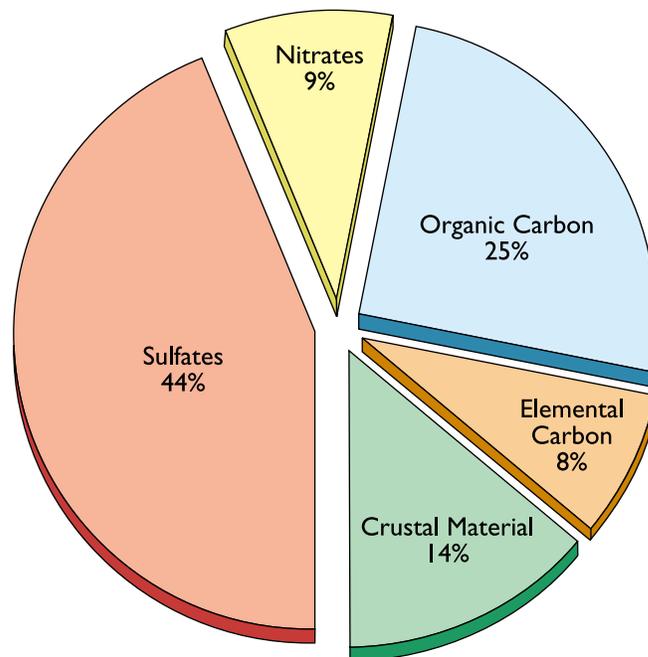


FIGURE 2 Class I areas in New Mexico.

In the San Juan Basin (San Juan, McKinley, and Rio Arriba Counties), there are many sources of nitrogen dioxide and sulfur dioxide pollution. There are electric power generation facilities, oil and gas production and transmission facilities, refineries, other small industrial facilities, automobiles, wind-generated dust emissions, and occasional forest fires. There are currently three large electric power generation facilities in the San Juan Basin: Public Service Company of New Mexico's San Juan plant, Arizona Public Service Company's Four Corners plant, and Tri-State's Escalante plant. These three electric power generating facilities account for a large percentage of the emissions of haze-forming pollutants in the San Juan Basin; they contribute approximately 66% of the nitrogen dioxide emissions and 92% of the sulfur dioxide emissions from industrial facilities in the region.

Transport of air pollution from the San Juan Basin and other areas of New Mexico contributes to the formation of regional haze in Class I areas in New Mexico and in neighboring states. For example, in Bandelier National Monument 44% of the reduction in visibility on the dirtiest days in 1997 was due to sulfates, 9% to nitrates, 25% to organic carbon, 8% to soot, and 14% to soil dust (Fig. 3). In other Class I areas, the reduction in visibility may be due to differing proportions of pollutants, depending on nearby sources and the predominant wind direction for transport of pollutants. Emissions from San Juan Basin facilities do appear to be increasing, however, as monitored ozone concentrations have recently been elevated and are close to the National Ambient Air Quality Standard for ozone.

New Mexico is currently participating in the Western Regional Air Partnership to develop goals and a plan for reducing the emissions that form haze in the West. The Western Regional Air Partnership membership includes other states in the West, such as Utah, Arizona, and Wyoming. This organization is determining which sources contribute most to pollutants that cause haze to form, which pollutants need to be reduced, and how those reductions can be made to achieve the visibility goals established for Class I areas in the western U.S. Because the ultimate goal is to achieve natural visibility conditions by 2065, the states will establish milestones every ten years to ensure that the visibility improves enough incrementally to achieve the ultimate goal. For most of the states in the U.S., visibility goals will be achieved through traditional "command and control" methods. For example, EPA has designated several categories of



**Sulfates-** predominantly from utility and industrial boilers

**Nitrates-** predominantly from automobiles and utility and industrial boilers

**Organic carbon particles-** from sources such as automobiles, trucks, and other industrial processes

**Elemental carbon (soot)-** from diesel, wood, and other combustion

**Crustal material (soil dust)-** from roads, construction, and agricultural activities

**FIGURE 3** Pollutants that contributed to reduced visibility on the worst days in 1997, Bandelier National Monument, New Mexico.

air pollution facilities built between 1962 and 1977 that will be required to install new air pollution control technology in order to reduce pollutants that contribute to the formation of haze. However, several western states with Class I areas on the Colorado Plateau have the option of meeting visibility goals through a combination of voluntary actions and a "cap and trade" program.

The cap and trade program offers flexibility to industry by setting caps on annual emissions. Emissions are tracked annually to determine if voluntary reductions are keeping emissions below the caps. If the caps are exceeded, a regional trading program is initiated, whereby industrial sources trade air pollu-



tion emissions credits to ensure that regional emissions of haze-forming pollutants do not increase further. New Mexico must submit a plan to EPA for improving visibility between 2003 and 2008, depending on whether the state intends to follow the traditional command and control method or the more flexible cap and trade method. Careful analysis of the advantages and disadvantages of both methods is currently underway. The Air Quality Bureau is in the midst of planning several public meetings to ensure comprehensive stakeholder involvement in the decision.

Regional haze goals for Class I areas in the West will require significant reductions in air pollution in New Mexico. Recent degradation in visibility in Class I areas in and near New Mexico will have to be reversed in order to meet the requirements of this federal mandate. Power generating facility emissions contribute a large proportion of industry-generated pollutants that form haze, but the complete picture must be analyzed to determine which emission-reduction and air pollution-control technologies will result in the greatest steps toward visibility goals and the improvement of the health and environment of New Mexico. The EPA's regional haze rule offers an opportunity for the state of New Mexico to examine not only the impacts of air pollution from New Mexico sources, but also the impacts of sources outside of New Mexico. This cooperative program should help to clarify the causes and contributors to haze in New Mexico, with a long-term goal of increasing air quality statewide.

## The Uses of Fly Ash in New Mexico

Gretchen K. Hoffman, *New Mexico Bureau of Geology and Mineral Resources*

One of the natural byproducts of coal combustion is fly ash, the noncombustible particulate matter that remains behind once the organic component of coal is consumed and the volatiles are expelled. Fly ash is composed mainly of minerals and rock fragments that exist naturally in the coal. For many years this byproduct was considered waste and required disposal (the fly-ash industry in the U.S. dates only to the 1960s). But in recent years, fly ash has been determined to have commercial uses and economic value, providing an important resource for other industries and an economic gain to coal-fired power plants. Commercial uses of fly ash include as an admixture to concrete (to improve its strength and durability), in railway construction, as structural fill, and in waste stabilization.

New Mexico coals, high in ash content (from 13% to 27%), create a significant amount of coal combustion byproducts, most of which is fly ash. Of the 28.8 million short tons (st) of coal produced in New Mexico in 1999, over half was delivered to three electrical generating stations in New Mexico. Furthermore, New Mexico coals produce fly ash with high silica and low calcium content, characteristics that make New Mexico fly ash a beneficial admixture for portland cement concrete. The quality of New Mexico fly ash makes it marketable not only in New Mexico but throughout the Southwest.

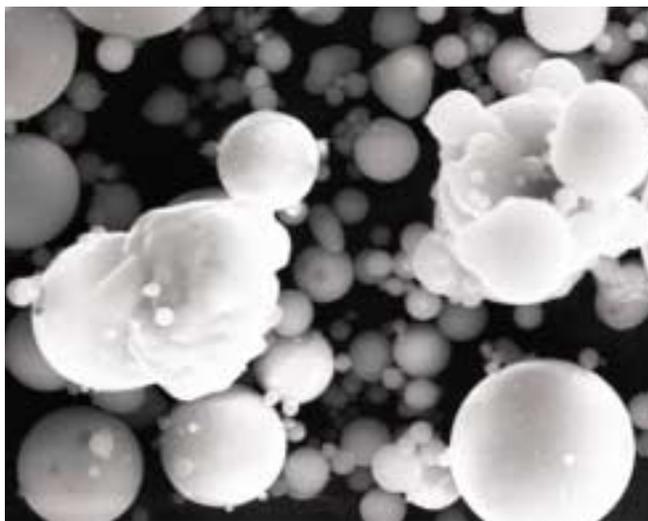
### ORIGIN OF THE ASH IN COAL

The inorganic, noncombustible portion of coal—minerals and rock particles—are introduced either during or after deposition of peat, or during the coalification process. Minerals are transported into the swamp by water or air. Bottom-dwelling organisms in the coal swamp may mix minerals into the peat at the time of deposition. Windblown dust and volcanic ash can both make significant contributions because of the slow accumulation rates of peat in the swamp environment. Swamps downwind of volcanic activity may periodically receive large amounts of volcanic ash. Most (95%) of the mineral matter present in coal is clay, pyrite, and calcite. Clay minerals make up 60–80% of the total mineral content of coal. Clay minerals can be finely dispersed throughout the coal or form layers. During the transformation of peat to

coal, other minerals also precipitate along joints and in voids and may occur as finely disseminated particles or mineral aggregates. Other noncombustibles can be introduced during mining. Small partings are often mined with the coal, and some of the roof and floor, above and below the coal seam, may also be mixed with the coal. This will add to the total content of noncombustible material in the coal, and ultimately to the quantity of ash byproduct.

### A BYPRODUCT OF THE COMBUSTION PROCESS

Coal used for electric power generation is finely crushed, pulverized, and air-fed into a 1900°–2700°-F combustion chamber where carbon immediately ignites. During coal combustion, the volatile matter vaporizes to gas, and carbon burns to heat the boiler tubes. The molten minerals, including clay, quartz, and feldspar, solidify in the moving flue gas stream leaving the combustion chamber. The rapid cooling of the moving particles tends to create spheres, and as much as 60% of fly-ash particles display a spherical shape (Fig. 1). Coarse particles settle to the bottom of the ash hopper, forming bottom ash, and some clings to the sides of the boiler tubes, forming boiler slag. Boiler slag is a problem, because it lowers the efficiency of the boiler tubes and has to be removed periodically.



**FIGURE 1** Secondary electron image of fly ash with glass spheres and masses. End product from Phoenix Cement, Cholla Generating Station. Field of view is 42 microns.



cally. The ratio of fly ash to bottom ash produced by coal combustion is dependent on the type of burner and the type of boiler. Pulverized coal (PC) burners are the most common type used for coal-fired electrical generation, and the fly-ash percentage for these varies from 65% to 85%.

Fly-ash particles consist primarily of glass spheres (often hollow) and spongy masses. Physical characteristics of fly ash include size, morphology, fineness, and specific gravity. Fineness is usually determined by the percentage of the ash retained on a 45- $\mu\text{m}$  (325-mesh) sieve; standards requires that no more than 34% of fly ash be retained. Size distribution can be quite variable, depending on the type of precipitator, and size can vary with coal even when it is from the same source. Fly ash is removed from the flue gas stream by either electrostatic or mechanical precipitators.

#### **OTHER COAL COMBUSTION BYPRODUCTS**

All byproducts of coal-fired electrical generation must be disposed of or used in some application. Coal combustion products (CCPs) include fly ash, bottom ash, boiler slag, and flue gas desulfurization material (FGD). Several factors determine whether these byproducts are marketable: (1) quality of the product—a result of the chemical and physical composition, (2) consistency of product, (3) distance to and economics of the market for these products, (4) transportation network and facilities, and (5) availability and cost of competing materials.

The American Coal Ash Association compiles statistics on the use of coal combustion products in the United States. Of the CCPs, fly ash has the largest production, greatest usage, and widest applications. In 1999, 62.67 million short tons (st) of fly ash were produced in the U.S., and 33% of this was put to use. Cement, concrete, and grout capture over half of the market for fly ash (11.35 million st). Thirty-two percent of bottom ash is used, most of it in structural fill (1.38 million st) and road base/subbase (1.29 million st). Almost all boiler slag (82%) is used in the manufacture of blasting grit, because of its considerable abrasive properties. Only 18% of FGD is used, primarily in the manufacture of wallboard (1.60 million st). Significant amounts of FGD do not meet the purity specifications for wallboard without further processing. The majority of CCPs are disposed of in ponds or landfills. Some generating stations that are adjacent to the coal mine supplying the coal will return the fly ash to the mine for disposal in the pits or for use in reclamation. All disposal methods are regulated, and all cost money.

#### **USE OF FLY ASH IN CEMENT AND CONCRETE PRODUCTS**

Fly ash is used in cement for its pozzolanic nature. A pozzolan is a siliceous or siliceous and aluminous material that in itself is not cementitious—that is to say: it does not in itself act as a cement, but reacts chemically with calcium hydroxide in cement at ordinary temperatures to form compounds possessing cementitious properties. Natural pozzolans have been used for centuries; both the Greeks and Romans were aware that certain volcanic rocks, when finely ground and mixed with lime, yielded a mortar that was superior in strength and resistant to fresh or salt water.

As an admixture, fly ash provides many attractive characteristics to concrete, including strength, durability, and increased workability. The fine grain size enables fly ash to fill void space within the concrete, reducing the need for fine-grained aggregate. The size of the fly-ash particles (0–45  $\mu\text{m}$ ) also improves the packing of cementitious materials and reduces the permeability of the concrete through pozzolanic action. Reduced permeability means the concrete is more resistant to chemical attacks by seawater or sulfate-bearing ground water. The spherical shape of the fly ash increases the workability of the concrete. Use of fly ash lowers the cost of the concrete and saves energy. Cement manufacturing is an energy intensive process, so the savings can be significant. The average cost of cement in the U.S. is \$83/short ton. The average cost of fly ash is approximately \$22/ short ton. The use of fly ash also reduces the mining of other materials for cement. Because fly ash is a byproduct, it has some advantages over other artificial and natural pozzolans. There are environmental considerations, as well; carbon dioxide generated in the manufacture of cement is lowered as much as 50% with the use of fly ash. The primary benefit of fly ash is to the generating station, reducing fly-ash disposal costs and providing additional income through its sale.

#### **OTHER USES**

The most significant use of fly ash is in cement and concrete products, including concrete for large construction projects such as dams. But there are other uses, as well. Fly ash has been used as structural fill, in embankments, highway shoulders, and as load-bearing structural fill. It can be compacted with normal construction equipment and shows little settling compared with conventional fill materials. Fly ash can be used to stabilize hazardous materials by solidifying them into an inert mass.

A minor amount of the total fly ash produced consists of hollow spheres called cenospheres, which have specific high-value applications. Cenospheres float; consequently, they can be collected from the surface of fly-ash disposal ponds. The spherical shape, small size, low density, relatively high-strength in uniform compression, good thermal and acoustical insulating, and dielectric properties allow for a multitude of uses. These applications include fillers for paint, varnishes, and ceramics as well as applications in electronics.

### FLY-ASH PRODUCTION IN NEW MEXICO

Most of New Mexico's coal is used to produce electricity, both here in New Mexico and in Arizona. New Mexico produced 27.3 million short tons (st) of coal in 2000 from six surface operations (New Mexico Energy, Minerals, and Natural Resources Dept., 2001), five of them in the San Juan Basin. New Mexico coal was burned primarily at seven coal-fired electrical generating plants (four in New Mexico and three in Arizona; see Fig. 2). The total estimated fly ash produced in 1999 from these seven generating stations is 4.34 million st, or about 15% of the coal consumed. In that same year, 32% of fly ash produced was land-filled or disposed on site at those plants. (Some of the fly ash from the Springerville and Cholla plants is contaminated by the scrubbers and cannot be used in other products.) The total useable fly ash from New

Mexico coals in 1999 was estimated at about 2.4 million st. Approximately 29% of that was sold for use; the remaining 61% was used in mine reclamation or as fill in mine pits. This is a significant amount, bearing in mind that only 33% of the fly ash produced nationwide is used, and the average usage of all coal combustion products from the western U.S. is 20%.

### MARKETING OF NEW MEXICO FLY ASH

Generating stations burning New Mexico coal sell their fly ash to marketers for resale or admixing (Fig. 2). Marketers, knowledgeable about the fly-ash market, handle the quality control, load-out facilities for transport, technical support, sales, and promotion of the product for all New Mexico fly ash that is being sold. Fig. 2 summarizes the source and ultimate destination of this material.

Several factors make New Mexico fly ash a marketable product. The high percentage (over 60%) of silica in New Mexico fly ash is particularly important, because the alkaline rocks available in the region as aggregate require the use of high-silica ash. As with most industrial minerals, transportation and proximity to markets is crucial. Some plants have rail transportation on site or nearby. Because many of the generating stations in New Mexico and Arizona are not close to large markets, this access to railroad transportation is important. However, because fly ash is a low-cost product

Company	Plant name /State	Coal source	Ash marketer	Transportation	Market area	Major use
Arizona Electric Power	Apache/AZ	McKinley	Boral Material Technologies	Rail and truck	AZ, CA, Mexico	Concrete products
Arizona Public Service	Cholla/AZ	McKinley, Lee Ranch	Phoenix Cement	40% rail, 60% truck	AZ, CA, NM	Concrete products
Arizona Public Service	Four Corners/NM	Navajo	Phoenix Cement	60% by truck to rail head	NM, CO, CA, AZ	Concrete products, backfill
Salt River Project	Coronado	McKinley	Mineral Resources Technology	Rail and truck TX, NM, CA	AZ, CO,	N/A
Tri-State Generation	Escalante/NM	Lee Ranch	Minerals Solutions	Rail and truck	AZ, NV, West TX, NM	N/A
Tucson Electric Power	Springerville/AZ	Lee Ranch	None—fly ash is contaminated by dry scrubbers			
Public Service Company of New Mexico	San Juan/NM	San Juan, La Plata	Phoenix Cement	100% truck	NM, AZ, UT	Backfill

**FIGURE 2** Coal-fired power plants and fly-ash marketers (see Fig. 1 on page 66 for location of mines and plants).



and specialized rail cars are needed, very few marketers send all their fly ash by rail. A unique situation exists at the Four Corners plant (New Mexico) where 60% of their marketed fly ash is shipped by truck to a railhead near Gallup, then shipped to California and Arizona markets. The Arizona Cholla plant ships 40% of its marketed fly ash by rail to California. Having storage facilities at different locations in the market area is also important, particularly with the seasonal fluctuation in the production of fly ash. Most of the marketers of New Mexico fly ash have this capability, which allows them to have product available year round.

### ENVIRONMENTAL CONCERNS

The Environmental Protection Agency (EPA) did an in depth study in 1980 of the use and disposal of fly ash on human health and environment under the Resource Conservation and Recovery Act. Their report to the United States Congress recommended classification of pure stream fly ash, bottom ash, boiler slag and FGD material as nonhazardous. Individual states were left with the responsibility to develop solid-waste programs to deal with coal byproducts (EPA 1988). Early in 2000, the EPA reconsidered this decision. On April 25, 2000, the EPA decided to not reclassify coal combustion wastes as hazardous substances. EPA does plan to develop national standards to address wastes from coal burning plants that are presently either land disposed or used as fill in mining. Had fly ash been regulated as a hazardous material, the economic impact on coal-fired power plants and ash marketers would have been significant. The cost would have included (a) the loss of revenue from sale of a product, (b) the cost of disposal for this combustion byproduct, and, perhaps most important, (c) the cost of handling what might then have been classified as a hazardous material.

### CONCLUSIONS

The use of fly ash as a commercial product has significantly reduced costs associated with what has otherwise traditionally been a combustion byproduct requiring disposal. The birth of the fly-ash industry in the U.S. in the 1960s not only solved this problem, but provided an additional source of income to producers of fly ash. The importance of fly ash as a commercial product, with its many beneficial applications, has allowed the development of a viable industry. The future of that industry will depend upon whether the Environmental Protection Agency continues to view

fly ash as a nonhazardous byproduct. Whatever the future of the fly-ash industry, it will continue to be closely tied to the coal-generated power industry in New Mexico and adjacent states.

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## Can We Achieve Zero Emission Coal Power?

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**F**ossil-energy resources currently provide 85% of all energy consumed worldwide and are readily available. Resource exhaustion could lead to a decline in the use of oil and gas within the next few decades. On the other hand, coal resources in the U.S. and elsewhere could satisfy world energy demand for several centuries. Based on studies by the U.S. Geological Survey, coal resources in the U.S. exceed 10,000 Gigatons (Gt). This number should be compared to an annual carbon consumption of about 6.5 Gt of carbon in all fossil fuels combined. As technologies improve, interchangeability between the various fuels becomes easier. In short, we are not likely to run out of fossil-fuel resources in the foreseeable future. As we discuss below, it is the environmental concerns associated with their use, particularly concerns about air quality, that need to be resolved.

In the 1970s environmental concerns focused on certain air pollutants, particularly heavy metals like lead and mercury, and compounds of sulfur and nitrogen. Regulations were adopted to reduce those emissions. Over the last decade, however, carbon dioxide (CO<sub>2</sub>)—the primary end product of fossil-fuel combustion—has itself become a concern, mainly because of its probable role in human-induced climate change. Unlike other pollutants, CO<sub>2</sub> is harmful not as a single emission, but through its long-term accumulation in the atmosphere. Coal is the most carbon-intensive fossil fuel, producing large amounts of CO<sub>2</sub> as a byproduct of combustion. As governments impose carbon production constraints, both energy producers and consumers will be affected. To be most effective, carbon constraints should aim for zero emissions. A power plant that converts its waste byproducts to reusable or disposable solids and eliminates airborne emissions altogether would be ideal.

Current annual atmospheric CO<sub>2</sub> emissions are increasing at a rate of 1.7 ppm/year (ppm = parts per million), which exceeds 1% of the total pre-industrial carbon content of the atmosphere (280–370 ppm). Given a minimum worldwide population growth of 2% per annum, CO<sub>2</sub> levels in the atmosphere will exceed 500 ppm before 2050, or within the expected lifetime of a coal-fired power plant built today.

Halting the increase of atmospheric CO<sub>2</sub> accumulation requires drastic reductions of emissions. Model cal-

culations suggest that in order to fix the total carbon dioxide level in the atmosphere, yearly emissions will have to fall by a factor of about 3 below those of 1990 in a matter of a decade or two. If, in the coming century, we lower worldwide CO<sub>2</sub> emissions to 30% of what they are today, and given a world population of ten billion sharing equally, the allowable *per capita* emissions would only be 3% of today's *per capita* emission in the United States.

Energy demand will rise rapidly over the course of the next century. In the twentieth century, energy consumption grew by a factor of twelve. In the coming century the remainder of the world may repeat what Europe, Japan, and North America accomplished in the last century in terms of industrialization and energy consumption, but with a population that is billions larger. The importance of energy to the world's economic development should not be underestimated. Figure 1 shows the primary energy consumption per dollar of gross domestic product (GDP) in various countries. In spite of energy efficiency improvements, which already have been dramatic, the amount of energy required for a dollar of GDP is remarkably large. Without access to cheap and abundant energy, further industrial development of the world is limited.

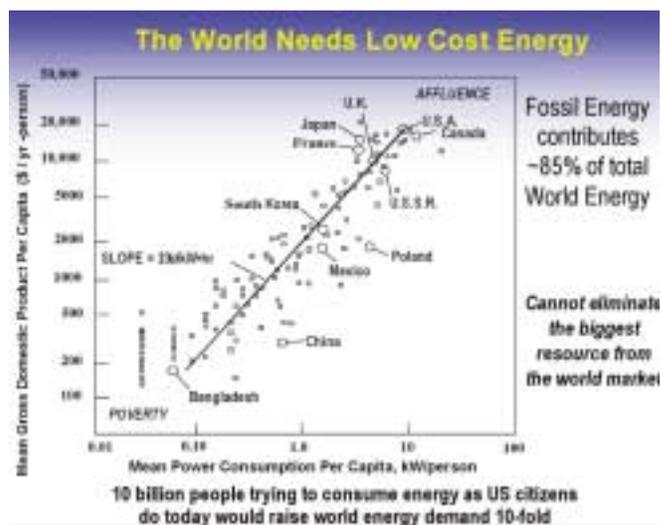


FIGURE 1 Relationship between energy and GDP



Thus, fossil energy must be a major contributor to satisfy the ever-growing energy demand. However, for fossil energy to play such a role in the next century, carbon dioxide emissions, together with all other airborne emissions, will have to be drastically reduced or eliminated. This affects not only coal-based power plants, but also any use of fossil energy. But because power plants are such large and concentrated sources of carbon dioxide, they are also likely initial targets for mandated reductions. In the long run, mandated emissions reductions must apply to natural-gas-based power as well as coal-based power.

Los Alamos National Laboratory (LANL), in collaboration with university, government, and industrial partners, is developing an integrated zero emission process for power plants that is based on a combination of improvements in the power generation process and a method of sequestering CO<sub>2</sub>. Sequestration refers to methods used to temporarily or permanently isolate the CO<sub>2</sub> that is a natural byproduct of combustion from the atmosphere.

### THE POWER GENERATION PROCESS

The goal of current research is to develop a process that will produce hydrogen from coal, hydrogen that will then be used in fuel cells to generate electricity. The multi-stage process gasifies coal, using hydrogen to produce a methane-rich intermediate state (methane is the most common component of natural gas). The methane is subsequently reformed using water and a calcium oxide (CaO)-based sorbent. A sorbent is a compound that removes, in this case, CO<sub>2</sub> from the process. The sorbent supplies the energy needed to drive the reforming reaction and simultaneously removes the generated CO<sub>2</sub> by producing calcium carbonate (CaCO<sub>3</sub>). The resulting hydrogen product stream is split, approximately half going to gasify the next unit of coal, and the

other half being used to generate electricity from solid oxide fuel cells (SOFC). The inevitable high-temperature waste heat produced by the SOFC would in turn be used to convert the CaCO<sub>3</sub> into CaO (which can be reused in the process) and pure CO<sub>2</sub> (which must be sequestered). The SOFC yields an exhaust stream that is largely recycled back to the reforming stage to generate more hydrogen with a slipstream (a small fraction of exhaust flow from the fuel cell) being extracted and condensed. The slipstream carries with it the other initial contaminants present in the starting coal. Overall the process is effectively a closed loop, with zero gaseous emissions to the atmosphere. The process also achieves very high conversion efficiency (about 70%) from coal energy to electrical energy. In addition to our work, several other groups are also employing variants of this process to produce hydrogen from a number of carbon-based fuels.

### THE SEQUESTRATION PROCESS

Sequestration methods that have been proposed and are being studied (Fig. 2) are both temporary and permanent storage in underground reservoirs (such as old oil fields), deep ocean disposal where CO<sub>2</sub> forms a solid hydrate in reaction with cold water, or mineral sequestration where the CO<sub>2</sub> is “locked away” into a new mineral by chemical reaction. We favor the latter, through formation of mineral carbonates from readily available magnesium or calcium silicate minerals. This natural process, which happens spontaneously on geological time scales, is virtually unlimited in its uptake capacity. The difficulty lies in the design of an efficient industrial-scale chemical process. An accelerated mineral carbonation process is now being developed by a collaboration that includes Los Alamos National Laboratory, the Albany Research Center, Arizona State University, and the National Energy Technology Laboratory. Carbon dioxide reacts with magnesium-rich silicate minerals, serpentine or olivine, forming magnesium carbonate, silica, and possibly water. The process would permanently sequester CO<sub>2</sub>, the end products are all naturally occurring, and they can be safely disposed of in landfills.

Available mineral deposits required for this process far exceed humankind’s capacity for generating carbon dioxide. The necessary magnesium silicates exist in vast, rich deposits worldwide. A single deposit in Oman contains over 30,000 cubic kilometers of magnesium silicates, which alone could handle all of the world’s coal. The mining operations to obtain magnesium silicates would be large, but in terms of volumes mined and areas disturbed they are substantially smaller than the associated above-ground coal mines. The mining

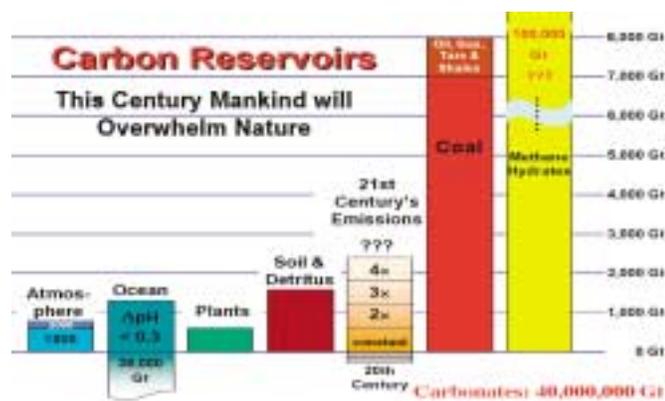


FIGURE 2 Carbon reservoirs.

## The Energy–Water Connection

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LALP-02-7

Energy production requires a reliable, abundant, and predictable source of water, a resource that is already in short supply throughout much of the U.S. and the world. The energy industry is the second largest user of water in the United States. According to the U.S. Geological Survey, electricity production from fossil fuels and

nuclear energy requires 190,000 million gallons of water per day, accounting for 39% of all freshwater withdrawals in the nation, with 71% of that going to fossil-fuel electricity generation alone. Coal, the most abundant fossil fuel, currently accounts for 52% of U.S. electricity generation; each kilowatt hour generated from coal requires 3.3 gallons of water. Coal and nuclear energy account for 72% of U.S. electricity generation and together account for more than a third of all freshwater withdrawals. That means U.S. citizens may indirectly use nearly as much water turning on the lights

and running appliances as they directly use taking showers and watering lawns. According to the Bush administration's 2001 *National Energy Policy*, our growing population and economy will require 393,000 megawatts of new generating capacity (1,300 to 1,900 new power plants—more than one built each week) by the year 2020, putting further strain on the nation's water resources. In summary, the intimate link between clean, affordable energy and clean, affordable water is crystal clear. There cannot be one without the other.

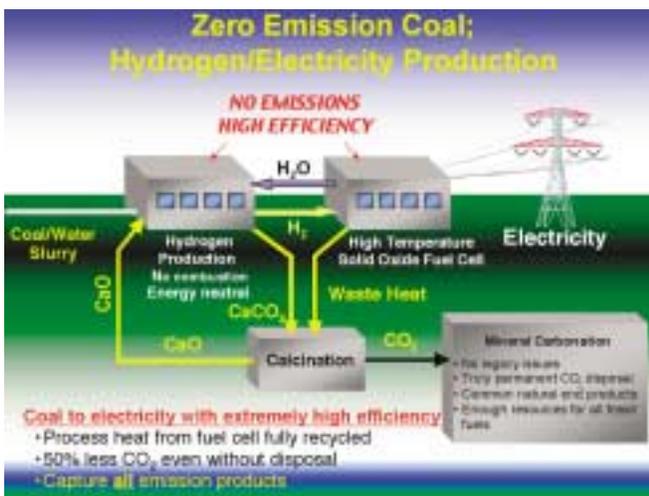


FIGURE 3 Outline of the zero emission coal process.

operation suitable for a large electric power plant is smaller than that for a large open-pit copper mine. The end products from the carbonation process would be used to refill the mine. It is estimated that the mining, crushing, milling, and reclamation costs for this sequestration process are low: around \$7 to \$20 per ton of CO<sub>2</sub>. With a power plant operating at 70% efficiency, this would be about 1¢ US/kWh of electricity.

### COMBINED PROCESSES ELIMINATE ATMOSPHERIC EMISSIONS

The zero emission coal process is illustrated in Figure 3. It combines a high-efficiency, coal-based electric power plant with a process for safely and permanently

disposing of the carbon dioxide generated. What makes the process attractive is the elimination of all harmful airborne emissions. The process has no smokestack, because there is no combustion of coal. The ash from the coal is fully contained, making compliance with ever-tighter restrictions on particle emissions straightforward. A small amount of calcium oxide or calcium carbonate is used to capture the sulfur in the coal. The sulfur is pulled out of the reaction vessels in a solid form, also eliminating hydrogen sulfide or SO<sub>x</sub> emissions. Additionally, the reducing conditions inside the hydrogen production vessel do not lead to the formation of NO<sub>x</sub>, and because there is no combustion involved, NO<sub>x</sub> emissions are eliminated. Finally the CO<sub>2</sub> generated in the hydrogen production is initially extracted as a solid before being converted to a concentrated gas stream. As this is an integral part of the hydrogen production process, no additional expenses are incurred in producing a concentrated stream of CO<sub>2</sub> exhaust. The exhaust will be permanently disposed of by reacting it with abundant, naturally occurring minerals to form harmless, stable mineral solids that will not leave a greenhouse gas legacy for future generations.

In conclusion, coal has an important and even dominant position in the energy future for the world. It is important that the value of this resource be recognized, and that the resource be utilized. We are confident that technological solutions exist that will allow the realization of “green” coal, which can be used to ensure a clean world and a long term, prosperous, healthy, and secure global economy.



## Current Status of Electric Retail Competition

Ernie C'de Baca, *Public Service Company of New Mexico*

The process of deregulating industries has been with us for decades. Deregulation of the airline, railroad, trucking, telecommunication, and even the natural gas industries, all preceded the move to make electric utilities competitive. To a large degree, at least in the electric power business, the impetus came from the large industrial customers who were being forced by market competition to reduce their costs, and who reasoned that there would be significant savings in the bulk quantities of energy they consumed if only they could choose their energy providers. The energy crises of the 1970s resulted in government-encouraged development of independent generators, and of co-generators that produced electric power as a byproduct of some other industrial process. This energy frequently was priced low enough to be attractive to the industrial customer, if only there had been a way for that customer to get around (by deregulation) the locally regulated utility with its franchise protection and higher-cost electricity.

A significant move in this direction was the national Energy Policy Act of 1992. This law permitted federal energy regulators to require utilities, under certain conditions, to open their transmission lines to others who wished to ship (or “wheel” in industry terms) the power across the utility’s lines to get it to the customer. This law was very specific, however. It limited such transactions to wholesale power sales only. This was essentially a market in which utilities sold power to each other. The decision to implement retail competition that would allow the end-user or retail customer to choose their power supplier was left to the states.

### NATIONAL TREND

Many states took up that cause, and by the year 2000 roughly half of the states had either begun some form of retail electric competition or had set target dates to begin doing so. Congress, too, has debated this issue for years because of the interstate nature inherent in modern electric generation and transmission technology. Many proposals have been put forth in Congress, both as comprehensive industry restructuring legislation, and as proposals to deal with individual aspects

of the deregulation process. None had gained wide enough support by late 2001 to become law. Energy policy legislation has now become a high priority, however, as there is growing recognition of the urgency to act, especially following the September 11 terrorist attack. There is increased awareness of the role that a strong power industry plays in our economy and of its importance to national security.

Among the various federal issues are questions concerning transmission planning, coordination, limits on the market power of utilities that own both generation and transmission infrastructure, defining the boundary between state and federal jurisdictions, and the modification or repeal of federal laws that currently discourage competition in the electric power business.

### DEREGULATION VERSUS RESTRUCTURING

So what exactly do we mean by deregulation? Perhaps deregulation is the wrong word. Most people who have studied the matter agree that it is more accurate to speak of “restructuring” the electric industry. In any event, we are not likely to see less regulation, only changes in how the industry is regulated.

To better understand the typical restructure proposal, let’s look at how the traditionally regulated electric utility functions. Since the early twentieth century, utilities have been vertically integrated: a single company owns its own generators to produce the power (or purchases the power on the wholesale market to resell), and it owns the transmission lines to move the electricity over long distances. That same company owns the distribution systems that convert the high-voltage electricity coming over the transmission lines to lower voltages and distributes it to businesses and homes.

Because of the enormous expense of building and operating this system, it has been economically more efficient to build only one such system for a single service territory. For this reason, electric utilities historically have been considered natural monopolies and given franchised service territories. In exchange for this exclusive right (and obligation) to serve, utilities accepted government regulation of their rates and terms of service.

Most restructuring proposals would separate the generation component from the other two services provided by the utility. Utility customers would be allowed to choose the company from which they purchase the electricity. This company might be the local utility, it might be a different utility, or it might be a power generator or marketer from in or out of state. The price of the power would be unregulated, set by supply and demand in the market.

The local utility would continue to own the transmission and distribution systems, but other power companies would be able to send their power across these lines. The transmission and distribution systems would remain regulated by the government, which would set rates for their use. Regulators also would have the responsibility to set rules to encourage competition and ensure fairness for all participants. Consolidating transmission systems into regional transmission organizations that plan, build, and operate transmission systems exclusively, independent from power suppliers, is a concept being pushed at the federal level.

Restructuring proponents argue that retail competition will bring customers lower costs and more diverse services. It remains an open question whether retail competition will lower costs. There has been limited success, at least initially, in some of the first states to deregulate their electric utilities, but one such state – California – has experienced disastrously huge rate increases following its bungled restructuring efforts.

Restructuring the electric utility industry in New Mexico began in earnest with the introduction of several proposals in the 1993 New Mexico Legislature and in following years. Those proposals never got beyond committee debate, but lawmakers did establish a bipartisan study committee every year from 1993 through 1998, which, under the chairmanship of Senator Michael Sanchez (D-Belen) devoted six years to a careful examination of restructuring approaches taken in other states. That effort culminated in New Mexico's Electric Utility Industry Restructuring Act, which became law in 1999.

### **NEW MEXICO'S ELECTRIC UTILITY RESTRUCTURING LAW**

The law, which moved through the legislature as Senate Bill 428, permitted retail electric customers to choose their power supplier, beginning with residential customers, schools, and small businesses, as of January 1, 2001. It permitted choice for all other cus-

tomers as of January 1, 2002. The New Mexico Public Regulation Commission (PRC) was given the authority (which it subsequently exercised) to delay those dates so that choice would become an option for the first group on January 1, 2002, and for all others on July 1, 2002. The law required all investor-owned electric utilities to participate and to file plans for the transition to open access for the PRC's approval. The state's 16 distribution cooperatives are required either to serve as an aggregator for their members, or to choose from three other business models for providing retail service, including open access. Municipal electric utilities may choose to provide open access, but they are not required to do so.

The law eliminates regulation of the price of electricity as a commodity, but state regulation is retained over transmission and distribution. Utilities may (but are not required to) sell off their generation assets. Utilities may keep these unregulated assets, however, only if they are separated from their regulated distribution utility, to prevent cross subsidies and to discourage favoring their own generation over competing power suppliers. Utilities may recover, through rates, at least half of their "stranded" investment in generation before deregulation, and they may recover some or all of the remaining stranded costs, as well as transition costs, with PRC approval.

Other provisions of the law include a "standard offer" service from the native utility for customers who do not choose their power provider, or who wish to return to service from their home utility. The law also funds renewable energy projects, protects customers against "slamming" and other market abuses, and directs the PRC, among other things, to educate consumers about customer choice. All billing and local service issues will continue to be handled through the local utility, although service issues surrounding the energy commodity itself will be the responsibility of the company providing the energy.

### **CALIFORNIA'S EXPERIENCE**

By early 2001 California's dismal experience with electric deregulation forced New Mexico and many other states to reconsider their own plans. At least one state partially repealed its deregulation law. Some states that had authorized competitive retail electric sales, including New Mexico, opted for delay. Three states continue on course with their deregulation plans.

Many in New Mexico, including some of the customers who had advocated most strongly for competition only a year or two before, were fearful that we



would experience California's fate, and they now wanted more time to get ready. Others argued that provisions in New Mexico's law would prevent the lack of generation, which was California's basic problem and which caused dramatic spikes in that state's wholesale energy costs.

Senator Sanchez, sponsor of New Mexico's 1999 law, held public meetings. He concluded that there was strong support for the proposition that, although deregulation might be a good idea and New Mexico's law avoided some of California's problems, the market had changed or not responded as expected; that the market was too unpredictable; and that electric supply in the West was too limited. Therefore, New Mexico should delay its deregulation plans until the market was more favorable.

Sanchez sponsored Senate Bill 266, which passed in the 2001 New Mexico legislative session and was signed by Governor Gary Johnson. It delays the start of electric retail competition in this state for five years, or until January 2007. However, legislators were worried that New Mexico, although it has adequate generation for the near-term, might end up like California if there isn't enough generation for a competitive market in New Mexico by 2007. So the law also permits electric utilities to proceed with developing their holding company structures, and to invest in unregulated generation plants. The PRC is currently considering how to administer this law.

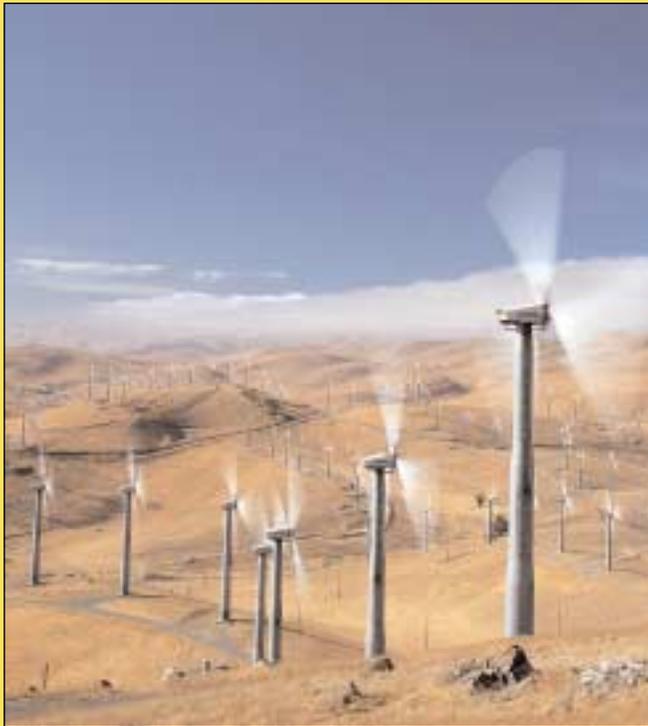
### **UNCERTAIN FUTURE**

However uncertain the future of electric deregulation may be, it is highly likely that we will see some change in the way the electric industry serves customers and how it is regulated. Regulated or unregulated, the power industry, especially generation, is largely dependent on private investors for the enormous capital needed to build infrastructure. There must be certainty in the rules to attract that investment, and there will be no investment if we pursue the notion that we can go to markets when market prices are less than cost, and that we can go to cost – meaning regulation – when cost is less than market.

For the customer, the promise of restructuring this business is not, and never has been, the certainty of lower electric bills, however politically appealing that may be in selling this proposition to the public. Rather, the goal is to establish competitive markets that use resources more efficiently and send proper price signals to customers regarding their usage. This in turn provides incentives to the marketplace to innovate and provide more options from which customers can choose.

# RENEWABLE ENERGY, EFFICIENCY, AND CONSERVATION

DECISION-MAKERS  
FIELD CONFERENCE 2002  
San Juan Basin



Wind turbines at Altamont Pass, California



# Renewable Energy in New Mexico: Current Status and Future Outlook

Chris J. Wentz, *Energy Conservation and Management Division*  
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**R**enewable energy is energy produced from naturally occurring, renewable resources that are virtually inexhaustible. These resources include solar, wind, hydroelectric, biomass, and geothermal. Renewable resources share a number of common attributes that make them attractive for the production of power: reduced environmental impacts, no or low fuel costs, and sustainability of supply. Moreover, renewable energy technologies have improved significantly over the past few decades—some to the point where they are already cost-competitive in certain markets with new conventional power plants (e.g., large commercial wind farms vs. coal-fired generation). Despite these technological advances and inherent environmental benefits, the development and use of renewable energy resources in New Mexico has been minimal. This paper will look at New Mexico's renewable resource base, end-use applications for these resources, their potential as a driver for economic development, and what barriers may be impeding more widespread use.

## BACKGROUND

According to the 2000 census, New Mexico currently has a population over 1.8 million. New Mexico's total electric generating capacity now stands at approximately 5,700 megawatts (MW). Of that total capacity, about 88% is from coal-fired power plants; most of the remainder (10%) is natural gas-fired electrical generation. New Mexico is a net exporter of electricity, consuming only slightly more than half of the electric power it produces. The remaining electricity (43-48% per year on average) is sold out-of-state on the wholesale power market.

The U.S. Department of Energy's National Renewable Energy Laboratory estimates that renewables presently account for 81 MW of our total commercial generating capacity—less than one-quarter of one percent of all electricity produced within the state. This total renewable electric capacity in New Mexico (81 MW) consists predominantly of hydropower (80 MW, 99% of total renewable production), with wind (0.66 MW) and solar photovoltaics (0.08 MW) providing the balance.

## RENEWABLE ENERGY RESOURCES IN NEW MEXICO

New Mexico has a very large and diverse renewable energy resource base. This resource base, which includes solar, wind, hydroelectric, biomass, and geothermal, extends throughout the state and to every county. Much of the following information on our renewable resources was compiled from nationally recognized sources and adopted by consensus among participants in the New Mexico Sustainable Energy Collaborative, a recently formed (2001) renewable-energy advocacy group of diverse organizations and individuals representing private industry, government, electric utilities, national laboratories, trade associations, environmental/public interest groups, and universities.

- *Solar* New Mexico experiences more than 3,200 hours of sunshine per year—substantially more than most other states in the Southwest. Nationally, we rank among the top three states in solar resource potential. As an example of this potential, a photovoltaic (PV) array with a collector area equal to the size of a football field, strategically situated, would be sufficient to power over 122 average homes. Thus, energy from the sun represents a potentially enormous energy resource readily available for both thermal and electrical generation applications within the state.
- *Wind* According to the U.S. Department of Energy, New Mexico ranks 12th in the nation—the upper echelon—in wind energy resources. Ongoing wind monitoring studies by the Energy, Minerals and Natural Resources Department confirm that a number of sites in eastern New Mexico have very good wind speeds (15-20 miles per hour) capable of utility-scale electricity production. Significantly, if New Mexico's total wind potential were developed with large, state-of-the-art wind turbines, the power produced each year would equal approximately 25 times the entire state's electricity consumption. Other states, such as Texas, with comparable potential are currently



adding hundreds of megawatts of wind electric generating capacity. At present, however, total installed commercial wind capacity in New Mexico amounts to less than 1 megawatt from a single wind turbine near Clovis operated by Southwestern Public Service Company/Xcel Energy.

- **Hydroelectric** Hydropower facilities take advantage of the kinetic energy of flowing or falling water to generate electricity. At present, nine commercial hydroelectric plants are in operation in New Mexico, including Navajo Dam on the San Juan River near Aztec (30 MW), Elephant Butte Dam on the Rio Grande near Truth or Consequences (24.3 MW), Abiquiu Dam on the Rio Chama near Los Alamos (15 MW), El Vado Dam on the Rio Chama near Tierra Amarilla (8 MW), and other smaller facilities less than 1 megawatt in size. Although no new large hydropower plants are scheduled for construction in New Mexico, past studies by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers concluded that 18 of the largest undeveloped sites in the state have the potential to generate over 3.5 billion kilowatt-hours of electricity per year. However, numerous constraints limit New Mexico from realizing its full hydropower potential. These constraints include financing, multi-use issues, regulatory barriers, environmental considerations, and economic factors.
- **Geothermal** Geothermal resources exist in at least 20 of New Mexico's 33 counties, with more than 300 thermal springs and wells identified to date. According to the U.S. Geological Survey, our geothermal resource base contains the thermal energy equivalent of more than 100 billion barrels of oil. These geothermal resources have to date not been used for commercial electrical generation but have been tapped for direct-use applications. At present, approximately 50 acres of greenhouse space and an aquaculture facility in southern New Mexico are heated with geothermal energy, as is part of the New Mexico State University (NMSU) campus in Las Cruces; however, no commercial geothermal electric generation is under development or in operation.
- **Biomass/Biofuels** This renewable energy resource is derived from plants or animal waste. New Mexico also has an abundant diversity of biomass resources, including wood or wood

waste, agricultural residues, livestock/dairy manure, sewage sludges, and municipal solid wastes (e.g., in landfills). Energy is derived from these sources by direct combustion or conversion to methane or alcohol. A 1990 study conducted by the Southwest Technology Development Institute at NMSU indicates that the biomass waste generated in 1988 alone had a potential energy content of 35 trillion BTUs—many times greater than our state's total daily energy consumption. At present, municipal sewage plants in Albuquerque, Carlsbad, Las Cruces, Los Alamos and Roswell produce biogas (methane) for generating heat and electricity for their internal consumption. With much forest thinning scheduled over the next few years, coupled with the continuing rapid expansion of our dairy industry, biomass resources have great potential to supply an increasing amount of New Mexico's future energy.

In general, at least one or more of our abundant renewable resources are available to residents and businesses of every county in New Mexico.

#### **RENEWABLE ENERGY TECHNOLOGIES AND END-USE APPLICATIONS**

Renewable resources in New Mexico can be used to generate electricity, thermal energy (heat), or both.

- **Solar *Passive solar*** systems take advantage of building design and natural physical properties to store and transfer heat. Most new home and office construction in New Mexico could use passive solar energy to some extent to reduce heating and lighting costs. **Solar *photovoltaic*** (PV) technologies, which convert sunlight directly into electricity, are commercially available and in use nationwide for such applications as powering residential and commercial buildings, running irrigation pumps, and lighting billboards and mobile highway construction signs. International demand and new building-integrated PV systems hold much promise in the near term for increasing the market penetration of solar photovoltaics. PV power generation costs have decreased substantially to between 15 and 30 cents per kilowatt-hour (kWh) over a typical 25-year system life, but this is still more expensive than the price of electricity paid by most New Mexicans. **Solar *thermal*** technologies—specifically solar air and water heaters, are well-established, reliable technologies whose use could be much more widespread. **Solar *thermal electric*** systems, which use parabolic troughs,

central receiver stations (“power towers”) or parabolic dish/stirling engines to concentrate sunlight to produce heat that is then converted into electricity, are in the early stages of commercialization; yet these technologies are particularly suitable for deployment in New Mexico due to our many cloudless days of sunshine.

- **Wind** Wind energy technologies are currently available for generating electricity for homeowners and businesses or at a utility scale (capacities in excess of 225 kilowatts). Unlike our solar resources, wind is very site-specific and therefore not available in every New Mexico locale. It also is an “intermittent” resource capable of generating electricity only when the wind blows. **Wind turbines** have improved significantly over the past two decades. Increased turbine size, research and development advances, and manufacturing enhancements have all contributed to driving down the installed (wholesale) cost of wind power generation to around 3–4 cents per kWh today for large wind farms. This cost is now on par with electricity produced from new coal-fired generating plants.
- **Geothermal** Geothermal energy can be used to generate baseload electricity and for direct application in space and water heating or other thermal processes. Like wind energy, geothermal is a site-specific resource that must generally be transformed into electricity or used directly where it is found. **Geothermal technologies** for electric power generation have improved considerably to the point where costs presently average 5–8 cents per kWh for existing geothermal plants. Southern New Mexico currently supports a thriving greenhouse and fish farming industry on geothermal resources, and these direct-use applications of geothermal energy are already cost-competitive with conventional resources.
- **Biomass** **Biomass technologies** are many and varied and have the capability of producing electricity and/or thermal energy. They include direct-combustion steam turbine technology, which is the principal process in use today for converting biomass into electricity. Biomass-generated methane can also be co-fired with conventional resources such as coal to extend fossil fuel supplies and reduce air pollution emissions.

## RENEWABLES: A DRIVER FOR FUTURE ECONOMIC DEVELOPMENT

As indicated in the preceding sections, New Mexico has been blessed with significant renewable energy resources. It also has a considerable government presence at the federal, state, and local levels, which collectively represent a sizable load of electrical and thermal energy demand. Facilities in New Mexico, including our two national laboratories (Sandia and Los Alamos), Kirtland Air Force Base, and the state government’s capitol complex in Santa Fe, each have sizable utility bills ultimately paid by New Mexico taxpayers on a recurring basis. In many instances, these utility costs could be lowered over the long term through the targeted, more effective use of renewables. This, in turn, would free up limited government revenues for other pressing needs—including job creation.

New Mexico also has the necessary human resources to develop and support a more vibrant renewable energy industry within its borders. Staff at both Los Alamos National Laboratory and Sandia National Laboratories-Albuquerque are already involved in many renewable research, development, and demonstration projects—activities likely to continue well into the future given the events of September 11, 2001, and the renewed focus they have placed on all forms of domestic energy production. Similarly, existing organizations such as the Southwest Technology Development Institute at NMSU (which has operated the SW Regional Solar Experiment Station in Las Cruces for over 20 years), our colleges and universities, and existing renewable energy businesses together possess a vast reservoir of expertise and experience that could be used to greatly expand the renewables industry in New Mexico.

## RENEWABLE ENERGY BARRIERS AND INCENTIVES

**Barriers.** A number of barriers are usually cited by informed observers as impeding the development and use of New Mexico’s renewable energy resources. Cost-competitiveness persists as one of the primary barriers to the increased market penetration of renewables. Transmission availability and access is another substantive impediment for bringing additional renewable electric generation capacity on-line. Embodied in the transmission issue are applicable standards and corresponding costs for connection of renewable technologies to the existing power grid. The state’s tax structure is another factor identified by commercial developers in recent years as holding back



## Solar Photovoltaic Power A Native American Success Story

David S. Melton

### ***Diversified Systems Manufacturing***

The Native American Pueblo tribes of the Southwest have long realized the power of the sun. Respect for that power was clearly evident in the design and execution of the solar carport located on the premises of the Indian Pueblo Cultural Center (IPCC) in



Albuquerque, New Mexico. One of the important purposes of the solar project was to inform the public of the benefits of renewable energy: economic development, cost reduction of the IPCC energy bill, conservation of natural resources including coal and water, and greenhouse gas reduction.

The solar carport goes beyond meeting the need for shaded parking for the 400,000 visitors the center receives each year. It integrates solar cells that use visible light and other natural electromagnetic radiation from the sun to generate voltage. The carport not only supplies power to the IPCC building, it is also tied to the commercial grid through the process of net metering (see article by Pat Scharff, this volume). It produces 25.5 megawatts of power annually and provides more than three thousand dollars in savings to the IPCC. This renewable energy generator saves an estimated 44 tons of coal and 1 million gallons of water, and it eliminates air emissions that would otherwise be produced in generating that energy through conventional power sources.

Diversified Systems Manufacturing, a Native American-owned and operated firm located at the IPCC, formulated the concept of the solar carport and completed the project using a number of local contractors. Laguna Industries, Inc., owned and operated by the Pueblo of Laguna, manufactured the steel and aluminum components. The Pueblo of Zia granted permission to incorporate the traditional Zia sun symbol in the decoration of the solar carport. The color and texture of the structure complements that of the IPCC.

The project was made feasible by a grant from the New Mexico Department of Energy, Minerals and Natural Resources. Successful demonstration of the technology has stimulated similar projects at Native American facilities at the Pueblo of Laguna and the Southwest Indian Polytechnic Institute (SIPI).

the growth of renewables here. Finally, and perhaps most importantly, the lack of public information, education, and outreach on renewable energy, its applications, costs, and benefits is a formidable barrier in evidence throughout New Mexico and the nation.

*Incentives* In comparison to other states, New Mexico offers virtually no incentives to encourage development of a vibrant renewable energy industry within the state. [Note: When this paper went to press, the New Mexico Legislature had under consideration a number of bills that would provide incentives for renewable energy development.] There is a solar access law on the books (Solar Rights Act); and the New Mexico Public Regulation Commission has a net metering rule (NMPRC Rule 571) in effect that

benefits small (<10 kilowatts) residential and commercial renewable electric systems. In addition, the Electric Utility Industry Restructuring Act establishes a System Benefits Charge/Fund in 2007; it will provide considerable funding (\$4-6 million annually) for renewables projects here. Other proposed incentives that should be reviewed in New Mexico include:

- *Renewable portfolio standards*, which require utilities to build or procure renewable energy so that it constitutes a certain minimum percentage of their total electric generating capacity.
- *Green pricing programs*, whereby electric utilities offer an optional service through which their customers can support a greater level of utility

investment in renewable energy technologies.

- *Tax credits* for renewable energy production and equipment, which help reduce the cost of renewable projects by credits against taxes owed.
- *Tax rebates* for purchase and installation of renewable energy technologies, which also assist in lowering the investment cost of renewables.
- *Demonstration project funding*, particularly for renewable projects at state facilities and in high visibility locations.
- *Funding for public information, education, and outreach on renewable energy.*

### CONCLUSIONS AND RECOMMENDATIONS

New Mexico has the appropriate mix of natural, physical, and human resources to become a national leader in the renewable energy arena. Stimulating growth of the renewable energy industry here will generate both jobs and revenues within our borders, particularly in rural areas. Moreover, increased development and use of renewables will diversify the state's energy supply mix, improve air quality, reduce water consumption from prospective power generation, and enhance our energy security through greater reliance on domestic resources. Given the potential benefits to New Mexico from renewable energy development, one goal is clear: overcoming the barriers that stand in the way of development and implementing industry incentives. Doing so is in the best interests of New Mexico and its citizens.

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# New Mexico's Geothermal Energy Resources

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**G**eothermal energy is rarely mentioned by policy makers and the media as a viable renewable energy source or a cost-competitive alternative to fossil fuels. As a result, this survey of geothermal use and its economic impact in New Mexico may surprise many. Geothermal energy is a prominent (perhaps the leading) renewable resource in New Mexico in terms of economic impact. Given the large geothermal resource base in the state, the potential for future economic benefits is enormous.

## GEOTHERMAL RESOURCES

An accessible geothermal resource base is defined as heat that is stored in the conventionally drillable part of the earth's crust. This heat is continually augmented by radioactive decay of naturally occurring uranium, thorium, and potassium in the earth's crust, and by heat that is conducted into the crust from the even hotter core and mantle below. In other words, the crust acts as a low grade nuclear reactor, with additional heat provided from deeper within the earth. In regions with young and active volcanoes, locally intense heat may be introduced into the crust by magma that rises upward through weaknesses in the crust from partially melted regions of the mantle.

Geothermal resources result from geologic processes that provide a ground-water flow path to concentrate deep-seated heat at economically drillable depths. Elements involved are: 1) a recharge source for the water; 2) a heat source; 3) an upflow zone; and sometimes, 4) a discharge zone. The most porous and permeable upper portions of the upflow zone and the shallow lateral-flow discharge zone are where geothermal resources are most easily exploited.

The shape of a typical geothermal reservoir may resemble a small isolated summer thunder cloud or thunderhead. The anvil or sheared-off top of the thunderhead is analogous to a lateral-flow discharge zone or outflow plume of a geothermal resource, and the rising cauliflower-like bulk of the thunderhead resembles the upflow zone. All currently proven reserves in New Mexico are the result of circulation of ground water that sweeps up heat from deep-seated bedrock. Fault and fracture zones may concentrate and redirect the hot water flow upward. Where these systems intersect the surface, hot springs are

found. Heat from active or young volcanoes is not required for this type of geothermal resource.

## CLASSIFICATION OF USES AND RESOURCES

We classify geothermal resources as high temperature, intermediate, or low temperature. High-temperature resources are those that are greater than 350° F; they are suitable for electrical power generation in excess of 20 megawatts. Intermediate temperature resources are those between 190° and 350° F; they are suitable for small-scale electrical power generation at rates of 3–10 megawatts. Low-temperature resources are those less than 190° F and at least 15°–30° F above the local mean annual surface temperature. Low-temperature resources are the most common and can be used in a variety of "direct-use" geothermal heating applications, including greenhousing, aquaculture, space and district heating, ground-coupled heat pumps, and many industrial uses (such as cooking, curing, or drying) that require large amounts of low-grade heat. High- and intermediate-temperature geothermal resources may also be used in direct-use applications by "cascading" residual heat from power production to lower-temperature applications, enhancing the overall efficiency and economics of use.

## CURRENT GEOTHERMAL USE

**Electric Power** Geothermal-generated electricity is currently being produced at the 32-acre Burgett Geothermal Greenhouse in the Animas Valley near Cotton City (Fig. 1). The Burgett power plant is a model for how geothermal electricity may best be produced in New Mexico. The facility extracts energy in a cascaded system, whereby 230° F water from geothermal wells is first fed into the power plant heat exchangers at a rate of 1,200 gallons per minute; the 185° F outflow from the power plant is used for space heating of the greenhouses. The Burgett power plant is called binary because heat from the geothermal water boils isopentane, whose pressurized vapor drives a turbine. This so-called working fluid powers three modular 0.3-megawatt units, and the electricity is used on location at the greenhouse.

**Geothermal Aquaculture** Geothermal energy offers several advantages for fish culture. Many species have

accelerated growth rates in warm water. Geothermal water can be used as a growth medium, adding to the agriculture receipts in the state without consumptive use of valuable fresh water supply. The AmeriCulture Fish Farm at Cotton City (Fig. 1) raises tilapia, a fish increasingly popular for its taste, from eggs produced on site. AmeriCulture is heated at much lower costs than fossil fuels with a downhole heat exchanger installed in a 400-foot-deep well. AmeriCulture markets tilapia fry to growers and researchers nationwide.

**Geothermal Space and District Heating** The aridity and high elevation of parts of New Mexico creates significant heating loads on cold winter nights. Where shallow geothermal resources co-exist with large heating demands, geothermal space and district heating can compete favorably with fossil fuel. Many of these sites are also suitable for spas.

A district geothermal heating system on the New Mexico State University campus in Las Cruces, in

operation since 1982 uses as much as 260 gallons per minute of 143° F water that is produced from a depth of 980 feet. Geothermal water is passed through a heat exchanger to heat fresh water that is fed into space and domestic hot water loops on campus as needed. The cooled geothermal water is then returned to the reservoir, injected into the reservoir margin beneath the NMSU golf course. Geothermal heat is used to heat dorms, academic buildings, and athletic facilities on the eastern third of the campus. Geothermal heat also provides domestic hot water for showers in the dorms and athletic facilities.

At Gila Hot Springs, a 300-foot-deep flowing well provides 165° F water for geothermal space and district heating of a trailer court, rental cabins, store, and several homes.

**Geothermal Greenhousing** The most important use of geothermal energy in New Mexico is for greenhouses (Fig. 2). Geothermal greenhousing accounts for more than half of the greenhouse acreage in the state. In fact, New Mexico leads the nation in geothermal greenhouse acreage. The success and growth in the geothermal greenhouse industry in New Mexico can be attributed to several factors, including a good climate with abundant sunshine and low humidity, inexpensive land, co-existence of geothermal resources with a supply of fresh water, a good agricultural labor force, and the availability of favorable shallow geothermal resources. Current geothermal greenhouses draw water from wells less than 1,000 feet deep, with resource temperatures ranging from 143° to 240° F

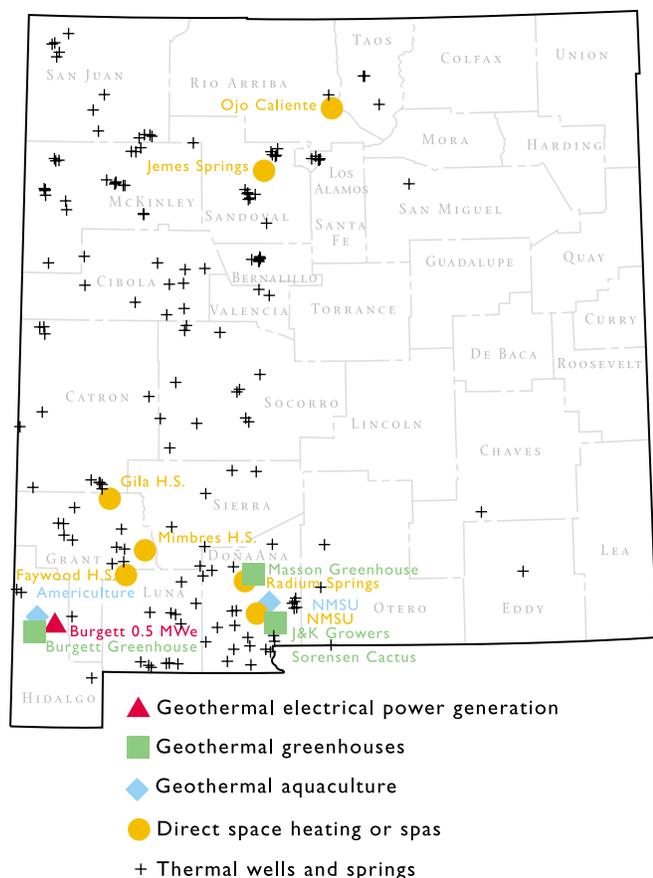


FIGURE 1 Geothermal resources and uses in New Mexico.

## ECONOMIC IMPACT

Figure 2 illustrates the importance of geothermal greenhousing in New Mexico. A total of 52 acres are heated using geothermal energy, representing a capital investment of over \$18 million, a payroll of more than \$6 million, and gross receipts exceeding \$22 million. This places geothermal greenhouse sales among the top ten agriculture sectors in the state. The Burgett Geothermal Greenhouse near Cotton City is the largest employer (and largest business) in Hidalgo County. The Masson Radium Springs Farm geothermal greenhouse is the largest employer in northern Doña Ana County.

## ATTRIBUTES AND POLICY

Geothermal development resembles oil and gas in leasing, royalties, and drilling. Exploration and evaluation of geothermal resources borrow methodologies used in oil and gas, ground water, and mineral exploration.

Geothermal energy is environmentally friendly. Geothermal operations, including electrical power



Site	Location	Product	Size (acres)	Employees/Jobs (persons)	Payroll \$/yr	Capital investment (\$)	Sales \$/yr	Energy Use (MMbtu/yr)	Energy savings (\$/yr)
Burgett Geothermal Greenhouse	Animas/Cotton City	Cut roses	32	256	3,741,696	11,200,000	13,920,000	134,400	403,200
Masson Radium Springs	Radium Springs	Potted plants and flowers	17	136	1,987,776	5,950,000	7,395,000	71,400	214,200
J & K Growers	Las Cruces	Potted plants and flowers	2	16	233,856	700,000	870,000	8,400	25,200
Sorenson Cactus	Las Cruces	Decorative cactus	1	8	116,928	350,000	435,000	4,200	12,600
<b>TOTALS</b>			<b>52</b>	<b>416</b>	<b>6,080,256</b>	<b>18,200,000</b>	<b>22,620,000</b>	<b>655,200</b>	<b>218,400</b>

FIGURE 2 List of current commercial geothermal greenhouses in New

Mexico with acreage, estimated cost attributes, and energy use.

Assumption	Category	Amount	Units
1	Employees per acre	8	persons
2	Average hourly wage w/benefits	\$7.00	\$/hr
3	Annual work hours	2088	hrs/yr
4	Capital investment per acre ~\$8 per sq ft	\$350,000.00	\$
5	Value of sales per acre ~\$10 per sq ft	\$435,000.00	\$/yr
6	Energy use per acre per year southern NM	4,200	MMbtu/yr
7	Energy cost MMbtu geothermal	\$1.50	\$/MMbtu
	natural gas with boiler losses	\$4.50	\$/MMbtu

Cost and energy assumptions used to construct the above table.

production, have a small land-use footprint. Greenhouse gas emissions are typically zero for binary systems. In most cases, spent geothermal fluids are injected back into the reservoir, resulting in minimal impact to fresh-water supplies. With the use of heat exchangers, harmful scaling and corrosion can be controlled, and fluids can be isolated from both the natural environment and surface geothermal equipment.

One impediment to geothermal growth is the initial capital costs associated with resource exploration, testing, and well drilling. However, geothermal energy has the advantage of low operations and maintenance costs, without the volatility associated with fuel costs. Most of the surface equipment used by geothermal operations is “off the shelf” and has well-known engineering characteristics and costs. This is especially true with direct-use installations, such as those outlined above.

Geothermal policy at the federal level and in most of the geothermal industry focuses on electrical power generation. However, in New Mexico more than 5,000 megawatts of electric power is produced by traditional

fossil fuels, and only about 40-45% of this electric power is used in state. The Valles Caldera in the Jemez Mountains is the only resource with proven reserves that exceed 20 megawatts. This is the only resource in the state with magma as a probable heat source. Development of this site by industry is unlikely, as the area has been transferred to the U.S. Department of Agriculture under the Valle Grande/Valles Caldera Preservation Act.

Inferred reserves at other sites in New Mexico are all probably less than 5 megawatts. Small-scale geothermal electric power generation at these sites only makes good sense if it is done in conjunction with cascaded direct use, and the generated power is used on site to assist or augment a direct-use operation. For comparison, the gross receipts or cash flow of an acre of greenhouse that grow potted plants is equivalent to 1 to 2 megawatts of electric power generation with wholesale energy sales of \$0.10 per kilowatt-hour. Federal and state geothermal policy should emphasize direct-use geothermal endeavors in New Mexico over stand-alone electric power generation. Federal royalty rules for direct-use and regulatory requirements for low- and intermediate-temperature drilling on federal lands are impeding geothermal development in the state. These should be modified to provide a realistic framework for future development.

## CONCLUSIONS AND FUTURE POTENTIAL

Geothermal energy is a potentially powerful vehicle for rural economic development in New Mexico. The future of direct-use geothermal energy may include chile and onion drying, cheese and milk processing, additional aquaculture, greenhouses, and district heating. Small-scale electrical power generation is very likely to occur in a cascaded mode with direct-use development. The accessible geothermal resource base is vast, and the options for economic use are many.

## Net Metering in New Mexico

Patrick K. Scharff, *Public Service Company of New Mexico*

In recent years, many electricity consumers have installed small renewable-resource electric generators to offset their consumption of commercial electric power. Often these generators produce power in excess of customer demand. In 1978 the federal Public Utility Regulatory Act (PURPA), in an effort to promote energy efficiency through the use of cogeneration and renewable-resource generators, made provisions for consumers with qualifying generators to sell excess power back to the utilities. Under the provisions of PURPA, and the subsequent implementation of rules by the Federal Energy Regulatory Commission (FERC) and state regulatory agencies, utilities are required to connect with “qualifying facilities” (QFs) and to purchase power generated by them, generally at a wholesale rate. Before the enactment of PURPA, utilities dealt with customer-owned generation on a case-by-case basis. New Mexico implemented the PURPA QF requirements in New Mexico Public Regulation (NMPRC) Rule 570 in 1988.

The purchase and sale agreement between a PURPA qualifying facility and an electric utility requires the use of two meters: one to measure the flow of energy from the utility to the customer and one to measure the flow of energy from the customer to the utility. Any energy that is not consumed by the customer at the time it is produced flows back into the utility grid through the second meter. Under PURPA QF rules, the customer pays full retail price for the energy that flows into the customer’s premises from the grid, and the utility purchases energy flowing out into the grid at the utility’s “avoided cost.” (Avoided cost refers to the utility’s avoided cost of production, although in some states, like New Mexico, a proxy for the wholesale cost of energy is used.) The difference between avoided cost and retail rates can be substantial.

Today consumers who generate their own power through the use of qualifying generators have new and better options available to them. New Mexico is one of 34 states with a “net metering rule” for small renewable-resource electric generating facilities. Net metering rules in effect allow these customers to sell excess electricity back to the utility at retail value, offsetting their consumption over the billing period. Meters literally turn backward when the generators are producing excess energy. Net metering rules are exclusively

state initiatives that are the result of consumers’ desire to resolve the difference between retail and avoided cost rates, and an interest in wider use of renewable resources. A few states implemented single-meter net metering when enacting the provisions of PURPA. Others, like New Mexico, implemented single-meter net metering several years later. Of the 34 states that have net metering, 32 have implemented their rules since 1995.

New Mexico’s net metering rule, NMPRC Rule 571, was implemented by the Public Regulation Commission’s September 1999 order in Docket 2847. PRC Rule 571 is applicable to all renewable-resource generators rated at 10 kilowatts or less. However, as a practical matter, net metering rules in all states are applied almost exclusively to solar electric systems, because of their reliability and consistent performance. One of Public Service Company of New Mexico’s (PNM) net metering customers, however, does have a 400-watt wind generator connected to the grid. New Mexico’s net metering rule allows utilities to choose between paying avoided cost (1 to 3 cents per kilowatt-hour for PNM) or giving kilowatt-hour credits for excess energy at the end of each billing period.

Like other states, New Mexico’s net metering rule is intended to foster and encourage the use of renewable energy resources. However, New Mexico’s net metering rule is different from the rules of other states (and more favorable to the use of renewable resources) in two very important aspects. First, other states have a limit on the total amount of net metering capacity that can be connected to the grid. New Mexico’s rule has no such limit. Second, most other states do not allow kilowatt-hour credits to be carried forward from month-to-month. The few states that do allow kilowatt-hours to be carried forward month-to-month require all credits to be reset to zero at the end of the year with no payment for any remaining balance. New Mexico’s net metering rule allows excess energy credits to accumulate from month-to-month and year-to-year.

The Public Service Company of New Mexico (PNM) provides kilowatt-hour credits for any excess energy at the end of each billing period. These kilowatt-hour credits are applied to future bills when the total energy produced is less than the kilowatt-hours consumed during the billing period. When the kilowatt-hour



State	Utilities	Eligible fuels	Eligible customers	Limit on system size	Limit on overall enrollment <sup>1</sup>
Arizona	IOUs and RECs	Renewables & cogeneration	All customer classes	≤ 100 kW	None
Arkansas	All utilities	Solar, wind, hydro, geothermal, and biomass <sup>2</sup>	All customer classes	≤ 25 kW (residential); ≤ 100 kW (commercial or agricultural)	None
California <sup>3</sup>	All utilities	Solar and wind	All customer classes	≤ 1000 kW	None
Colorado	Individual utilities	All resources	All customer classes	≤ 10 kW	None
Hawaii	All utilities	Solar, wind, hydro, and biomass	Residential or small commercial	≤ 10 kW	0.5% of each utility's peak demand
Idaho	IOUs	Renewables & cogeneration	Idaho Power only; residential and small commercial	100 kW	None
Iowa	IOUs only	Renewables	All customer classes	No limit	None
Minnesota	All utilities	Renewables & cogeneration	All customer classes	< 40 kW	None
Montana	IOUs	Solar, wind or hydro	All customer classes	≤ 50 kW	None
Nevada	All utilities	Solar and wind	All customer classes	≤ 10 kW	100 customers for each utility
New Mexico	All utilities	Renewables & cogeneration	All customer classes	≤ 10 kW	None
North Dakota	IOUs only	Renewables & cogeneration	All customer classes	≤ 100 kW	None
Oklahoma	All utilities	Renewables & cogeneration	All customer classes	≤ 100 kW and annual output ≤ 25,000 kWh	None
Oregon	All utilities	Solar, wind, fuel cell and hydro	All customer classes	≤ 25 kW	No less than 0.5% of utility's historic single-hour peak load; beyond 0.5% eligibility can be limited by regulator authority
Texas	IOUs and RECs	Renewables only	All customer classes	≤ 50 kW	None
Washington	All utilities	Solar, wind, hydro and fuel cells	All customer classes	≤ 25 kW	0.1% of 1996 peak, with no less than half for renewables
Wyoming	IOUs and RECs, Munis exempt	Solar, wind, and hydropower	All customer classes	≤ 25 kW	None

<sup>1</sup>In all cases, energy generation is netted against energy consumption on an equal basis, down to zero net energy use during the designated period. Treatment of "net excess generation" is relevant only when total generation exceeds total consumption over the entire billing period, i.e. the customer has more than offset his/ her total electricity use and has a negative meter reading.

<sup>2</sup>The Arkansas law also extends eligibility to fuel cells or microturbines if the fuel is derived entirely from renewable resources.

**FIGURE 1** Summary of "net metering" programs in states west of the Mississippi River. Portions of this table are reprinted by permission of the Interstate Renewable Energy Council (IREC) and Thomas J. Starrs, Kelso Starrs & Associates, LLC.

Treatment of net excess generation (NEG)	Enacted	Citation/reference
Monthly NEG purchased at avoided cost	1981	Ariz. Corp. Comm. Decision No. 52345
Not specified	2001	HB 2325 (enacted April 2001, effective October 2001)
Customers are billed annually; excess generation is granted to the utility. Also allows bi-directional time-of-use metering	1995	Cal. Pub. Util. Code § 2827 (as amended 1998, 2000, and 2001).
NEG carried over month-to-month	1994	Public Service Co. of CO, Advice Letter 1265; Decision C96-901; and various RECs
Monthly NEG is granted to utility	2001	House Bill 173
Monthly NEG purchased at avoided cost	1980	ID PUC Orders No. 16025 (1980); 26750 (1997)
Monthly NEG purchased at avoided cost	1983	IA Legislature & IA Utilities Board, Utilities Division Rules § 15.11(5)
Monthly NEG purchased at “average retail utility energy rate”	1983	Minn. Stat. § 261B. 164( 3)
NEG credited to following month; at end of annual period any unused credits are granted to utility without compensation	1999	S.B. 409
Annualization allowed; no compensation required for NEG	1997	Nev. Rev. S. Ch. 704
At utility’s option, customer is credited on the next bill for (1) purchase of NEG at utility’s avoided cost; or (2) kilowatt-hour credit for NEG that carries over from month to month.	1999	17 N. M. Admin. Code 10.571
Monthly NEG purchased at avoided cost	1991	N. D. Admin. Code § 69-09-07-09
Monthly NEG is granted to utility	1990	Okla. Corp. Comm. Schedule QF-2
NEG purchased at avoided cost or credited to following month; at end of annual period unused credits shall be granted to low-income assistance programs, credited to customer, or “dedicated to other use” as determined by regulatory authority	1999	Or. Rev. Stat. 757.300
Monthly NEG purchased at avoided cost	1986	Tex. PUC, Substantive Rules, § 25.242(h)(4)
NEG credited to following month; at end of annual period any unused credits are granted to utility without compensation	1998	Wash. Rev. Code § 80.60 (amended 2000)
NEG credited to following month; at end of annual period any unused credits are purchased by utility at avoided cost	2001	WY Legislature, House Bill 195, signed into law February 2001, effective July 2001

<sup>3</sup>The 2001 amendments, which (A) extended eligibility to all customer classes; (B) extended the system size limit to 1,000 kW (1 MW); and (C) eliminated the overall “cap” of 0.1% of each utility’s peak demand applies through the end of 2002 only. Absent further amendment these provisions would revert to the pre- 2001 requirements.



credits are applied to a current bill, PNM's net metering customers receive full retail value for the excess energy they have produced in prior months. When a PNM customer discontinues net metering service all remaining kilowatt-hour credits are purchased at the avoided cost rate.

In terms of tangible capital costs, renewable-resource energy systems are generally quite expensive. They are much more expensive to purchase and install than traditional electricity generating alternatives. However, there are significant advantages. By allowing the meter to turn backward during periods of excess energy production, the net metering customer is effectively using the utility grid as a means of storing energy for use during periods of low or no production. This use of the grid to effectively store energy allows lower-cost grid-connected systems to be constructed without the additional expense of physical batteries to store excess production. A typical one-kilowatt photovoltaic system without batteries costs about \$10,000 and will produce approximately 2,100 kilowatt-hours of electricity per year. Battery energy storage can add 10–20% or more to the installed cost of a photovoltaic system, depending upon the amount of storage needed. With a typical useful life expectancy of only five years, batteries add significantly to the lifetime cost of ownership for a solar electric system. There are obvious environmental advantages to this, as well.

The average PNM residential customer usage is about 6,400 kilowatt-hours of electricity per year. Although net metering helps to offset the 20–35 cents per kilowatt-hour cost of solar electric energy, the high initial cost of photovoltaic systems prohibits their purchase by most consumers. At the end of 2001, PNM had only 14 net metering customers, with a total of 30.4 kilowatts of solar panel capacity and 400 watts of wind power capacity. These systems are installed in Albuquerque, Corrales, and Santa Fe. One of the consequences of single-meter net metering is that the total energy produced by PNM's net metering customers cannot be tracked. However, using the National Renewable Energy Laboratory's PVWatts software, we estimate that a reasonable approximation of the annual energy production of PNM's net metering customers is about 64,000 kilowatt-hours.

To encourage consumer use of renewable energy, several states, most notably California, have implemented financial incentives in addition to net metering. These additional financial inducements include rebates or buy downs for new renewable energy systems and tax incentives. Additional information on

net metering, the specifics of individual state net metering rules, current state financial incentives, and renewable energy technology can be found at the internet Web sites below.

#### **WHERE CAN I GET MORE INFORMATION?**

- 1 Energy Efficiency and Renewable Energy Network (EREN) sponsored by the U.S. Department of Energy at [www.eren.doe.gov](http://www.eren.doe.gov)
- 2 National Renewable Energy Laboratory (NREL) at [www.nrel.gov](http://www.nrel.gov)
- 3 Interstate Renewable Energy Council (IREC) at [www.irecusa.org](http://www.irecusa.org)
- 4 Database of State Incentives for Renewable Energy (DSIRE) at [www.dsireusa.org](http://www.dsireusa.org)
- 5 Solar Electric Power Association (SEPA) at [www.solarelectricpower.org](http://www.solarelectricpower.org)
- 6 A Performance Calculator for Grid-Connected PV Systems (PVWatts) at [http://rredc.nrel.gov/solar/codes\\_algs/PVWATTS](http://rredc.nrel.gov/solar/codes_algs/PVWATTS)

## Renewable Energy Incentives in New Mexico and Bordering States

Benjamin Luce, *New Mexico Solar Energy Association*

**R**enewable energy technology now offers a number of proven and cost-effective options that could greatly benefit New Mexico, both in economic development and in diminishing the environmental impacts of power generation. These include utility-scale wind power and photovoltaics. Utility-scale wind farms (one megawatt and up) can generate bulk power at a cost of 3–5 cents per kilowatt hour (kWh), which makes wind power competitive with other more traditional methods of power generation. Photovoltaics are more appropriate for those highly motivated consumers who are willing to invest in the equipment necessary to contribute through “net-metering,” or for remote applications.

New Mexico is surrounded by states (with the exception of Oklahoma) that currently have aggressive policies and incentives for both utility- and residential-scale renewable energy development. Some of these incentives, mostly financial, have been in place since the late 1980s or early 1990s. More recently, other types of incentives, including mandatory requirements for renewable energy called “portfolio standards,” have been introduced. These standards require public utilities to incorporate renewable sources of power in their energy mix. Such standards have already led to the installation of hundreds of megawatts of renewable electricity generation and are likely to lead to thousands of new megawatts of renewables by the end of the decade. A single megawatt is enough to power roughly 1,000 homes.

The incentives responsible for most of the existing utility-scale generation in neighboring states are:

- Renewable portfolio standards (RPS) adopted by Texas and Nevada, which mandate the addition of renewables to the mix in significant percentages
- Voluntary green pricing programs in Colorado and Texas. These programs allow consumers to choose to buy power generated by alternative means, usually at a higher rate. Such programs rely on consumer demand.

In addition to policy-based incentives, a whole range of financial incentives, including rebates and tax

incentives, are also in place in states bordering New Mexico. These are extremely important for the successful development of residential-scale renewable energy businesses, as well as utility-scale generation. At the time of this writing, the New Mexico Public Regulatory Commission (PRC) is considering introducing a renewable portfolio standard, and several New Mexico state legislators are drafting bills that would create tax incentives for renewable energy.

New Mexico lags significantly in providing these incentives. New Mexico’s deregulation legislation did mandate a systems benefit fund (see below), and made a recommendation that the PRC investigate the possibility of renewable portfolio standards. On this basis, the PRC proposed a portfolio standard rule that mandated 5% renewable energy, which would apply to the “standard offer” option (the default option for customers who opt not to choose). Unfortunately, this standard would be subject to a cap of \$.001/kWh increase on the average utility bill, which could severely limit its impact. Moreover, following the deregulation debacle in California, the legislature has delayed the implementation time for electricity deregulation by five years, and this delay applies to both the systems benefit fund and the portfolio standard as well.

As of this writing, financial incentives for renewable energy generation in New Mexico are simply nonexistent. New Mexico needs, and deserves, aggressive and effective policy incentives to promote renewable energy development now. The New Mexico renewable energy industry will be hopelessly out-paced by out-of-state competitors if effective incentives are not introduced soon.

Figure 1 summarizes incentives in neighboring states and New Mexico. Note that New Mexico is conspicuously lacking in both conventional financial incentives such as tax incentives, and policy incentives such as renewable portfolio standards and systems benefit funds. Figure 2 compares the renewable portfolio standards of states bordering New Mexico in more detail.

Note that, although Arizona’s program has roughly a ten times smaller target figure than the other stan-



Incentive	Arizona	Nevada	Colorado	Oklahoma	Texas	New Mexico
System benefit fund						1-S (delayed)
Disclosure of generation source and related emissions	1-S	1-S			1-S	1-S (delayed)
Renewable portfolio standard	1-S	1-S			1-S	1-S (delayed)
Net-metering	1-S	1-S	1-S, 2-L	1-S	1-S, 1-L	1-S
Line extension analysis	1-S		1-S		1-S	1-S
Solar contractor licensing	1-S	1-S	1-L			
Renewable energy equipment certification	1-S		2-L	1-S	1-S	
Solar & wind access laws	1-S	1-S	1-S, 1-L			1-S
Construction and design policies	1-S, 2-L		1-S, 3-L		1-S, 1-L	
Green power programs						
Green pricing	4-U	1-U	3-U, 6-L		3-U, 3-L	1-U
Green power purchasing/aggregating	1-L		3-L			
Public education/assistance	2-L		3-L		2-L	1-L, 1-S
Demonstration projects	2-L		2-L		2-L	2-L, 2-S
Research and outreach						
Personal tax	2-S					
Corporate tax					1-S	
Sales tax	1-S					
Property tax		1-S			1-S	
Rebates	1-L	1-L	1-S		1-L	
Grants						
Loans	1-S				1-L	
Industry recruiting		1-S			1-S	
Leasing programs	1-U				1-U	
Equipment sales					1-U	

**FIGURE 1** Summary of incentives in place in neighboring states and New Mexico. S = state, L = local, U = utility. Numbers indi-

cate number of incentives.

dards, in terms of total number of megawatts of renewable energy required, more than half of Arizona's renewable energy must be solar, which is about ten times as expensive as wind, geothermal, and other forms of renewable energy. Therefore, Arizona's relatively low standard is quite comparable in cost to the other higher standards.

Green pricing programs, which allow consumers to choose to buy power generated by renewable sources of energy, even if it's at a higher rate, are one of the great successes of the 1990s for renewable energy. Many such programs now exist in the United States. Roughly one in five Americans can now choose to have some or all of their electricity supplied by renewable energy sources. Public support for these programs was established through many surveys of public

opinion. Public Service Company of New Mexico (PNM) has even conducted a small focus group study in Albuquerque, which indicated strong support, comparable to that found in other states. Colorado presently has over 18,000 customers, including many large businesses, participating in green power programs. These programs have been oversubscribed from the start. The DSIRE Web site (listed at the end of this article) has extensive information on many of these programs.

**NEW MEXICO'S WIND RESOURCE**

New Mexico is in the big leagues with respect to wind power, having the twelfth largest resource potential in the U.S. (much greater than California's resource; see Fig. 3). The developable resource is estimated to be

capable of providing roughly 435 billion kWh annually, enough to power 40 million households. Comparing this to New Mexico's total electricity use of about 17 billion kWh/yr, we find that New Mexico's wind resource potential is about 25 times larger than its current consumption of electric power.

Note that New Mexico has approximately one-third the wind resource of North Dakota, the state with the largest resource. Also note that there is a dramatic decrease in wind power resource after New Mexico; Idaho, the next state after New Mexico, has less than one-quarter of New Mexico's resource. That is not to say that wind power cannot be a significant contributor in these states; California is also ranked lower than

New Mexico and is currently producing utility-scale wind power.

### NEW MEXICO'S SOLAR RESOURCE POTENTIAL

New Mexico's solar resource potential is enormous. Assuming 15% efficient solar (photovoltaic or solar thermal electric) collectors, and factoring in the fact that the sun shines strongly roughly eight hours a day, one square kilometer of solar collectors could produce electricity equivalent to a continuous 50 megawatt generator. (The peak power of the sunlight intersecting one square kilometer on a clear day is actually equivalent to 1 gigawatt; we can only capture about 5% because of collector efficiency, spacing considera-

Provisions	Arizona	Nevada	Texas
Total amount of renewable energy electricity production mandated (by percent)	1.1%	15%	(about 3.3%)
Total amount of renewable energy electricity production mandated (in megawatts)	(about 180 MW)		2000 MW
Effective date	3/30/01	1/1/03	1/1/02
Target date for achieving total amount	2009	2013	2009
Trading credits program	Yes	Yes	Yes: administered by state
Eligible technologies	Solar thermal electricity, photovoltaics, wind, biomass, hydro, geothermal electric, waste	Solar thermal electricity, photovoltaics, wind, biomass, geothermal electric	Solar thermal electricity, photovoltaics, wind, biomass, hydro, geothermal electric, wave, tidal, landfill gas
Applicable sectors	Utility, investor-owned utility, publicly owned utility, rural cooperative	Utility, investor-owned utility, publicly owned utility	Utility
Initial minimum	0.2%		400 MW
Year enacted	2000	2001	1999
Existing renewables			880 MW
Penalties	Yes	Yes-administrative fines	lesser of \$50 per MWh or 200% of the average cost of credits traded during the year
Minimum required amount of solar (as a percentage of the renewable contribution)	Solar must make up 50% in 2001, increasing to 60% for 2004 through 2012	Solar must be 0.5% of total electricity delivered, to be achieved beginning 2004 by adding at least .01% annually	Solar must make up at least 5% of the renewable energy generated
Funding for building of new generation	Funding from existing system benefits charges and a new surcharge to be collected by the state's regulated utilities.	Cost of doing business	Cost of doing business

**FIGURE 2** Renewable portfolio standards of states bordering New Mexico.



tions, and the diurnal cycle.) The fact remains, with our current technology, solar energy could provide for all of New Mexico’s electricity needs.

Many studies have confirmed that, with existing technology, an area roughly 100 miles by 100 miles (an area less than one-third of 1% of U.S. land area) could in principle supply all of the current electricity demand of the United States. Preliminary results of a study by RDI Consulting<sup>1</sup> confirms that an area roughly ten times this size exists in western states alone with suitable solar resources, taking into account well-buffered land exclusions for military bases, national forests, parks, and Wilderness, cropland, highways, waterways, urban areas, lakes, and altitudes greater than 9,000 feet. This clearly establishes the sunbelt of the U.S. as a potential “solar Saudi Arabia.”

Rank	State	B kWh
1	North Dakota	1,210
2	Texas	1,190
3	Kansas	1,070
4	South Dakota	1,030
5	Montana	1,020
6	Nebraska	868
7	Wyoming	747
8	Oklahoma	725
9	Minnesota	657
10	Iowa	551
11	Colorado	481
12	New Mexico	435
13	Idaho	73
14	Michigan	65
15	New York	62
16	Illinois	61
17	California	59
18	Wisconsin	58
19	Maine	56
20	Missouri	52

**FIGURE 3** The top twenty states for wind energy potential as measured by annual energy potential in the billions of kWh, factoring in environmental and land use exclusions for wind class of 3 and higher.

In summary, we should note that many European countries implemented incentives and standards similar to those described above in the 1990s, slightly before today’s low-cost wind-power technology was perfected. This directly enabled the development of the now multi-billion dollar European wind-power industry, which currently dominates the market. Due to the solid base of U. S. government-funded research and development on various solar power technologies, New Mexico and other western states presently have a short window of opportunity to develop a similar lead in utility-scale solar power, an option that was simply not available to most European countries because of their weather. Western states stand to benefit enormously from their vast wind-power resources, as well. Together, the potential benefits of developing these renewable energy resources includes significant economic development, job creation, and a more secure energy infrastructure, in addition to a cleaner environment. Adoption of incentives by New Mexico like those described above would greatly help our state to make these potential benefits a reality.

**FOOTNOTES**

<sup>1</sup>The RDI Study was conducted by Dr. Arnold Leitner, Senior Consultant with RDI Consulting, 720-548-5415, arnold\_leitner@platts.com. It was commissioned by the Western Governor’s Association and Congress and extensively critiqued by representatives of fossil fuel industries.

## Some Renewable Energy Policy Organizations in New Mexico

**N***ew Mexico Solar Energy Association* ([www.nmsea.org](http://www.nmsea.org)): Educationally oriented. The NMSEA SunChaser2 Education program takes renewable energy technology and concepts to schools and events, reaching 7,000 students and 3,000 adults each year). Home design competition, solar home tours, workshops, Large Solar Fiesta Event (exhibits and workshops), Taos Solar Village (exhibits). Makes various equipment available upon request (giant SunOven, courtesy of Sandia Labs, etc.).

*Coalition for Clean Affordable Energy* ([www.cfcae.org](http://www.cfcae.org)): A coalition of eight environmental groups:

- New Mexico Solar Energy Association ([www.nmsea.org](http://www.nmsea.org))
- Rio Grande Chapter of the Sierra Club ([www.sierra.nm.org/](http://www.sierra.nm.org/))
- Conservation Voters Alliance ([www.earthwaves.net/nmcva/](http://www.earthwaves.net/nmcva/))
- NM Citizens for Clean Air and Water (<http://members.aol.com/nmcit/>)
- Southwest Research and Information Center ([www.sric.org/](http://www.sric.org/))
- National Parks Association ([www.npca.org/home.html](http://www.npca.org/home.html))
- Land and Water Fund of the Rockies ([www.lawfund.org](http://www.lawfund.org))
- New Mexico Public Interest Research Group ([www.nmpirg.org](http://www.nmpirg.org))

Many of these groups are directly involved in renewable energy policy work, outside of the coalition. CCAE lobbies the legislature, files comments at the PRC, participates on press releases on energy issues. Broad scope: concerned with all consumer and environmental issues related to energy. CCAE played a role in crafting New Mexico's deregulation legislation, and in several of the rules promulgated by the PRC based on that legislation.

*Energy Conservation and Management Division of the New Mexico Energy, Minerals and Natural Resources Department* (<http://www.emnrd.state.nm.us/ecmd/>): Provides testimony, public education and information, conducts research related to energy conservation, efficiency, and renewable energy. The current Director, Chris Wentz, chairs the New Mexico Sustainable Energy Collaborative (see below). The division also funds many projects by groups such as NMSEA, Rebuild New Mexico, and others.

*New Mexico Sustainable Energy Collaborative* (e-mail [Chris Wentz: cwentz@state.nm.us](mailto:cwentz@state.nm.us)): A large, informal collaboration between utilities, advocacy groups, solar businesses, and others, which formed following the Alternative Energy

Symposium initiated by PNM in December 2000. The collaborative includes many of the organizations listed here, including NMSEA and CCAE. The general purpose of the collaborative is to promote renewable energy in New Mexico by formulating comments, draft regulations, and draft legislation that enjoys a broad consensus among stakeholders. The first official act of the collaborative was to file comments on renewable energy in response to the recent Notice of Inquiry from the NM PRC.

*New Mexico Solar Industries Association* (contact [Chuck Marken](mailto:Chuck Marken) at 505-243-4900): A collection of New Mexico solar companies that occasionally pursues policy work.

Note: An excellent source of information on renewable energy incentives is the Database of State Incentives for Renewable Energy (DSIRE), which can be accessed online at <http://www.dsireusa.org>.



## Using Energy Wisely: Increasing Energy Conservation and Efficiency for the Consumer

A Report of the National Energy Policy Development Group

*What follows is a modified excerpt from "Reliable, Affordable, and Environmentally Sound Energy for America's Future, the National Energy Policy, May 2001." The full report is available at <http://www.whitehouse.gov/energy/>.*

**E**nergy efficiency is the ability to use less energy to produce the same amount of lighting, heating, transportation, and other energy services. For a family or business, conserving energy means lower energy bills. For the country as a whole, greater energy efficiency helps us make the most of U.S. energy resources, reduces energy shortages, lowers our reliance on energy imports, mitigates the impact of high energy prices, and reduces pollution. Improvements in efficiency can be particularly effective in reducing energy demand when energy is most expensive.

Conservation and energy efficiency are important elements of a sound energy policy. Improved energy efficiency is the result of many decisions, including those of individual consumers; manufacturers of cars and appliances; home builders; and state, federal, and local government officials. The federal government can promote energy efficiency and conservation by including the dissemination of timely and accurate information regarding the energy use of consumers' purchases, setting standards for more energy efficient products, encouraging industry to develop more efficient products, and searching for more innovative technologies that improve efficiency and conservation through research and development.

Since 1973 the U.S. economy has grown nearly five times faster than energy use (126% versus 26%). Had Americans continued to use energy as intensively as in 1970, the U.S. would have consumed about 177 quadrillion Btus of energy last year, compared to about 99 quadrillion Btus actually consumed. [A Btu (British thermal unit) is the amount of heat required to raise the temperature of one pound of water (about one pint) one degree Fahrenheit at sea level. Put another way, it is approximately the same amount of energy contained in a wooden match head.]

Gains in energy efficiency over the last three decades

were built on a combination of technological improvements, better management practices, and learning to put these technologies and practices to their best use in automobiles, homes, offices, factories, and farms. In many areas the results have been quite impressive. New home refrigerators use about one-third of the electricity they used in 1972. Compact fluorescent lights use about 25% of the electricity of the incandescent bulbs they replace. Automobiles use roughly 60% of the gasoline they did in 1972 per mile driven.

### CONSUMER CHOICES

The two most important factors in consumers' decisions about purchasing an energy efficient product are price and the life of the product. When energy prices are high, consumers tend to weigh energy efficiency more heavily. Unless consumers are informed about the price of energy, they may not have the incentive to select the most energy efficient product. As an example, consumers do not receive timely signals about rising electricity costs in order to make adjustments to their energy use and efficiency. When consumers' peak costs are averaged with off-peak costs, the higher cost of peak electricity supplies is masked. As a result, consumers may not recognize the benefits of investing in technologies that best target peak consumption. Some energy efficiency improvements are easiest and most cost effective to undertake when first building new factories, cars, equipment, appliances, and buildings. Some energy-using equipment, like computers, are used for only a few years before being replaced. Other equipment is used from five to twenty years, such as home appliances, home electronics, and lighting systems. Buildings can last a half a century or more.

In a typical U.S. home, appliances are responsible for about 20% of the energy bills. Refrigerators, freezers, clothes washers, dryers, dishwashers, and ranges and ovens are the primary energy-using appliances in most households. Taking steps to save energy while using these appliances, and replacing old inefficient appliances with modern ones can save money.

The federal government established a mandatory program in the 1970s requiring that certain types of new appliances bear a label to help consumers compare the energy efficiency of various products. Under this program, all refrigerators, freezers, clothes washers, and dishwashers are sold with yellow Energy Guide labels to indicate their energy efficiency. These labels provide an estimated annual operating cost of the appliance, and also indicate the cost of operating the models with the highest annual operating cost and the lowest annual operating cost. By comparing a model's annual operating cost with the operating cost of the most efficient model, you can compare their efficiencies. This labeling program ensures that consumers have the information they need to make the right decisions when they purchase major home appliances. However, Energy Guide labels are not currently required for some products, such as kitchen ranges, microwave ovens, clothes dryers, on-demand water heaters, portable space heaters, and lights.

The federal government not only ensures that consumers have information on the energy efficiency of major home appliances, it also promotes the most energy efficient products through the Energy Star program, a joint program run by the Department of Energy and the Environmental Protection Agency. Energy Star is only awarded to appliances that significantly exceed minimum energy efficiency standards. The Energy Star program does not extend to all products. Energy efficiency would be further promoted if the Energy Star program were expanded to a broader range of products.

Energy efficiency can also be improved by the establishment of minimum energy efficiency standards. Congress enacted legislation in 1987 and 1988 to establish minimum energy efficiency standards for many major appliances. These standards apply to manufacturers, not consumers. Appliance manufacturers must produce products that meet the minimum level of energy efficiency. These rules do not affect the marketing of products manufactured before the standards went into effect, and any products made beforehand can be sold. The new standards will stimulate energy savings that benefit the consumer, and reduce fossil fuel consumption, thus reducing air emissions.

These laws established minimum energy efficiency standards for many appliances, including refrigerators, refrigerator freezers, freezers, room air conditioners, fluorescent lamp ballasts, and incandescent reflector lamps, clothes dryers, clothes washers, dishwashers, kitchen ranges, and ovens, pool heaters, and water heaters. The Energy Policy Act of 1992 added stan-

dards for fluorescent and incandescent reflector lamps, plumbing products, electric motors, and commercial water heaters, and heating, ventilation, and air conditioning systems. Under current law, the Department of Energy can raise the minimum energy efficiency standards for these appliances if certain criteria are met, such as cost, technological feasibility, and the impact on competition among appliance manufacturers. In addition, the Department can set energy efficiency standards for appliances not covered by these laws.

### **RESIDENTIAL BUILDINGS**

There are significant opportunities to improve the energy efficiency of buildings and homes through technologies and better practices. For existing homes, immediate options for improving efficiency include reducing air infiltration with caulking and weather stripping, installing modern thermostats, sealing ductwork, and adding insulation. These steps can reduce the 40% share of residential energy bills that go toward heating and cooling. Additional savings are possible when efficient appliances are purchased or major home renovations are undertaken. Installing a new, more efficient gas furnace can save up to 20% annually on natural gas. New buildings offer the greatest energy efficiency opportunities and can be designed to be both more comfortable and more efficient, cutting heating and cooling costs by close to 50%.

### **TRANSPORTATION**

Transportation plays a key role in a growing U.S. economy, comprising 16% of GDP in 1998, 10.5% of total employment, and 27% of total U.S. energy consumption. Trucks and automobiles account for over three-fourths of the sector's petroleum use, with the remainder attributable to rail, ship, air, and pipeline systems. Mass transit ridership has increased by 21% since 1996. Automobiles today use roughly 60% of the gasoline they did in 1972 per mile driven, due in part to new technology, such as better engine and design controls, improved transmission, weight reduction, and improved aerodynamics. Despite the adoption of more efficient transportation technologies, average fuel economy for passenger vehicles has remained relatively flat for ten years and is, in fact, at a twenty-year low, in large part due to the growth and popularity of low-fuel-economy pickup trucks, vans, and sport utility vehicles.

Opportunities for reducing oil demand in the transportation sector include increasing conservation, vehicle efficiency, and alternative fuels. Conservation can be improved by car pooling, telecommuting, and



increasing transit choices. For example, an increase in the average fuel economy of the on-road vehicle fleet by three miles per gallon would save one million barrels of oil a day, or about half of the global shortfall between supply and demand that triggered the oil price increases since 1998. In addition, fuel conservation can be further improved by technologies to reduce congestion.

A recent analysis indicates that the fuel economy of a typical automobile could be enhanced by 60% by increasing engine and transmission efficiency and reducing vehicle mass by about 15%. Several promising efficiency technologies are being presented to the U.S. market. For example, some automobile manufacturers have already introduced hybrid vehicles, and others have announced that they will introduce hybrid vehicles within the next several years. Advanced lightweight materials offer up to 6% improvement in mileage for each 10% reduction in body weight. Although promising, it may be many years before hybrids become a substantial part of the automotive fleet.

The average car now lasts fourteen years, and newer cars have even more longevity. Vehicle efficiency improvements require significant technological changes. Development of new-car production models requires at least three to four years, which limits the rate at which new technologies can enter the market. Making fundamental changes, such as switching to the use of a fuel cell, would take even longer. Once those new vehicles are in the showroom, it then takes several more years before they constitute any sizable percentage of total vehicles.

Because of the large economies of scale in automobile manufacturing, new technologies with limited early production runs often enter the market at higher initial costs. In this highly competitive international market, higher initial production costs can be a significant impediment to the introduction of new technologies. Unless U.S. automakers can remain competitive with their overseas counterparts, it is unlikely they will invest in new, more efficient technologies. Vehicle efficiency technologies, such as advanced engines, fuel cells, and cutting-edge electronic drive-train technologies, will become widely available only when component costs are reduced or demand is increased.

**CONSUMER CHALLENGES**

Consumers face certain challenges that could be addressed by Decision Makers in government and industry:

- **Insufficient Information** Monthly energy bills

generally report only total electricity or natural gas used, leaving families and businesses unsure about which energy services are most responsible for their energy use, and which investments could best help them reduce their costs. In addition, consumers may be unsure about the credibility of the energy saving claims of individual manufacturers, salesmen, and designers. This incomplete information causes imperfections in the marketplace that hinder purchases of efficient technologies that would actually save families and businesses money.

- **Lack of Availability** Frequently, the most energy efficient products cost more and are not widely available, especially in smaller communities. Builders who would like to construct more efficient homes and businesses face the same problem at the wholesale level. For example, to keep costs down, builders are less likely to install top-of-the-line, highly efficient products. The less expensive and generally less efficient products are heavily stocked and deeply discounted due to volume ordering. The decisions made about the energy efficiency of buildings and homes are not usually made by the consumer who will ultimately pay the energy bills. The incentive is for the builders to choose the material that poses the least cost to the builder, which is not necessarily the most energy efficient choice.

- **Lack of Automation** People often walk out of their offices and homes with the lights on and the air conditioner running. Turning off unused appliances, electronics, and lights is not always easy. Lack of automation (e.g., daylight sensors) means that conservation mostly depends on people turning off switches. Some appliances and electronics, such as stereos, video tape players, and televisions, continue to use electricity even after they are turned off.

- **Higher Initial Costs** Efficient products often cost more than less efficient versions, especially when they are first introduced to the market. Unless consumers can verify the resulting savings, they may be reluctant to pay the additional costs. Businesses that adopt labeling programs that spell out energy savings may be more successful in selling a more efficient, yet initially more expensive product. Higher initial costs can be particularly difficult for the purchaser or builder of a new home or office building.

## Energy Efficiency Programs in New Mexico

Harold Trujillo and Louise Martinez, *Energy Conservation and Management Division, New Mexico Energy Division, New Mexico Energy, Minerals and Natural Resources*

**E**nergy efficiency technologies improve the way we use energy, and they have the potential to extend our energy resources to accommodate future generations and the inevitable growth of New Mexico's economy. Effective technologies are designed to reliably save energy over the life of the product. The word "conservation" applied to energy use typically describes a conscious effort or behavioral habit adopted to reduce consumption. Examples are turning off electric lights and lowering thermostats. Conservation requires a continual application of effort in order to be effective. However, energy efficiency programs achieve the same goals without the required diligence on the part of individuals. Both energy efficiency and conservation are important methods for improving human comfort, preserving the environment, and increasing New Mexicans' disposable income, and they should be part of New Mexico's energy portfolio.

The Energy Conservation and Management Division (ECMD) of the New Mexico's Energy, Minerals and Natural Resources Department is responsible for planning and administering energy efficiency and renewable energy technology programs, including development and use of solar, wind, geothermal, and biomass resources, as well as alternative fuels transportation. In addition, ECMD provides technical assistance and information in these areas to government agencies, Indian tribes and pueblos, educational institutions, and the general public.

The U.S. Department of Energy (DOE) also implements a number of energy efficiency programs in New Mexico. These include the Federal Energy Management Program (FEMP), targeted at achieving energy savings in federal buildings; and the Building America Program, which works directly with contractors to improve residential construction techniques to save energy. Some DOE programs, such as Rebuild America, are administered by ECMD and other New Mexico state agencies.

The state energy program, funded by DOE, is a major collaboration between DOE and the State of New Mexico. The Energy Conservation and Management Division of EMNRD is charged with the responsibility of administering the program in New

Mexico. It is the umbrella program that is used to help all economic sectors in New Mexico. The state legislature provides funds for salaries and benefits. All funds used to implement projects throughout the state are provided by DOE through a basic grant and then supplemented with competitive DOE grants. Each year we compete with 13 other states to get about a half million dollars of DOE funds for special projects. Those special projects include DOE efforts such as Rebuild America, Codes and Standards, Alternative Fuels, Clean Cities, Pollution Prevention, Distributed Generation, Renewable Energy Assessment, Million Solar Roofs, Energy Smart Schools, and now Building America. We can also participate in FEMP projects. All the work done by New Mexico relating to energy conservation is based on the comprehensive plan we put together for DOE.

### RESIDENTIAL SECTOR PROGRAMS

The adoption of new energy codes improves the energy efficiency of all new construction over the life of the building. Between 1977 and 1984, improved energy codes for residential buildings reduced energy consumption from 81,700 Btu/ft<sup>2</sup> (British thermal units per square foot) down to 75,000 Btu/ft<sup>2</sup>. ECMD is currently working with the New Mexico Construction Industries Commission to update the codes to the 2000 International Energy Conservation Code. ECMD provides technical assistance to contractors and homeowners. Several grants have been obtained from DOE to assist with training, and the development of compliance materials. In addition to ECMD programs, the New Mexico Mortgage Finance Authority administers the Weatherization Assistance Program (WAP). WAP, formerly administered by ECMD, helps low-income New Mexicans improve the energy efficiency of their dwellings, saving both energy and money.

### COMMERCIAL SECTOR PROGRAMS

- *Public Facility Energy Efficiency and Water Conservation Act of 1993* This act has made it possible, since its inception, to implement over \$25 million worth of projects, with annual savings of over \$3.9 million, 77.5 million kilowatt-hours of



electricity and 4.7 million therms of natural gas. Part of the energy savings is used to recoup the cost of the project. The advantage of the act is that an energy service company provides the energy audit, design, installation, and up-front financing, including the guaranteed performance bond. Since 1993, 29 public schools, Torrance County, cities of Portales and Tucumcari, New Mexico Highlands University, and Eastern New Mexico University have implemented energy performance contracts. ECMD has statutory responsibility to review all proposals to ensure that the savings are reasonable and accurately estimated.

- *State Government Energy Management Program* Under Executive Order 99-40 (November 1999), Cabinet-level state agencies were directed to reduce their energy consumption by 4% by June 30, 2002. Preliminary results show that as of June 2001 energy consumption was reduced by 17% over the 1998 fiscal year base. These savings represent enough electricity to operate over 1,000 New Mexico homes for one year and enough natural gas to annually heat over 1,800 New Mexico homes. As lead agency, ECMD provides technical and financial assistance in improving the energy performance of over 1,000 state-owned and -operated buildings, maintaining a state utility bill database that contains nearly 1,700 accounts from 30 utilities. The database provides important feedback for agencies to evaluate the results of their efforts as shown in Figure 1. The utility bills for 13 cabinet-level

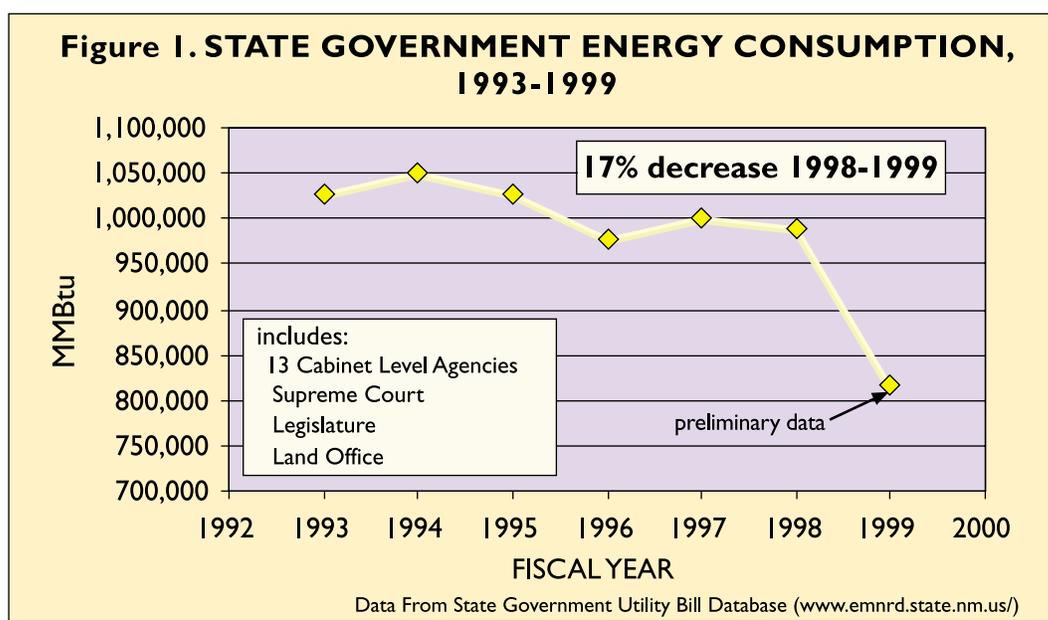
departments during fiscal year 1998 totaled \$8.9 million. Several agencies have exceeded expectations for reducing energy consumption and costs. For example, the Health Department—New Mexico's largest state agency—reduced its energy usage by 39.1%.

Southern New Mexico Correctional Facility completed a lighting retrofit project in December 1999 that resulted in a savings of \$35,410 per year. The project cost \$89,920 and paid for itself in 2.5 years. The project replaced 3,389 magnetic ballasts with electronic ballasts, and new energy efficient lamps were installed. The entire project was completed in four months, using inmate work crews.

The New Mexico Highway and Transportation Department (HTD) established a comprehensive energy management plan for its headquarters building that resulted in over \$600,000 in savings as of June 1998, compared to the 1992 fiscal year base. The lighting system was renovated with electronic ballasts and 32-watt lamps.

More than 30 patrol buildings in Districts II, III, IV, and V were upgraded with energy efficiency lighting, ceiling and wall insulation, and infrared heating systems. HTD spent \$540,143 (of which ECMD provided \$388,858). HTD leads all other state agencies in savings over the last five-year period.

- *Public School Construction Plans Review* ECMD reviews construction plans as required by the



State Department of Education for minimum energy efficiency requirements. In 2001 ECMD reviewed 94 plans representing \$139 million in construction expenditures.

- *Rebuild America/Rebuild New Mexico* This program provides information, training, and technical assistance to private commercial building owners and local government participants. Over 59 participants, with more than 42.4 million square feet of building space, are improving their energy efficiency. Energy audits have identified potential savings of more than \$750,000 per year. In partnership with the Youth Conservation Corps, 31 at-risk youth in Albuquerque and Taos Pueblo have been trained to make energy efficiency improvements.

### TRANSPORTATION SECTOR PROGRAMS

- *Energy Policy Act /Alternative Fuels Conversion Act* Increasing public concern about the cost of pollution, environmental impacts, and national security issues prompted the federal government to enact the Energy Policy Act of 1992 (EPACT). It requires accelerated acquisition of alternative fuel vehicles by federal, state, and fuel-provider fleets.

In 1992 New Mexico enacted legislation known as the Alternative Fuels Conversion Act [Sections 13-1B-1 to -7, NMSA1978] and developed an energy policy goal to meet EPACT requirements, to meet state mandates, and to increase use of alternative fuels derived from New Mexico's own abundant energy resources. There are many types of alternative transportation fuels, including compressed natural gas (CNG), liquefied petroleum gas (propane), ethanol, and electricity. New Mexico's Alternative Fuels Transportation Program is managed by ECMD and funded by the U.S. Department of Energy. DOE established the Clean Cities Program, a voluntary program that works to develop partnerships that promote commitments to using alternative fuels as a substitute to gasoline and diesel. This program facilitates the implementation of EPACT and promotes the use of alternative fuels by providing special funding under the state energy program.

New Mexico school districts have been using CNG school buses since the mid-1990s. The Los Lunas, Belen, and West Las Vegas School Districts continue to operate CNG buses. ECMD provides funding for the purchase of these alternatively fueled buses, as well as

incremental costs for purchasing CNG buses for the University of New Mexico's Park-and-Ride shuttle.

To reduce congestion and to help improve air quality, funding is also provided to develop ride-share and park-and-ride programs that encourage commuters to use carpools, vanpools, and public transportation to get to their destinations. The city of Las Cruces has reported that in the year 2000 a total of 1.012 million gallons of gasoline were saved by carpools and vanpools operating in that area.

### INDUSTRIAL SECTOR PROGRAMS

- *Oil Industry* Opportunities exist to save energy in the production of oil and gas. Measures that reduce operating costs range from simple low-cost maintenance such as proper lubrication to higher-cost items such as replacement of electric motors. Operating costs are critical to producers when oil prices are low. ECMD contracted for the publication, Pollution Prevention Best Management Practices Manual, tailored to the New Mexico oil and gas industry to address energy savings. Training was provided to over 80 industry personnel.
- *Pollution Prevention Programs* ECMD continues to provide technical support to the Green Zia Environmental Excellence Program, which facilitates and publicly recognizes pollution prevention and energy efficiency efforts; the program is administered by the Environment Department. ECMD also coordinated with the Waste-Management Education and Research Consortium (WERC), a consortium for environmental education and technology development based at New Mexico State University, in funding and establishing a Pollution Prevention Technical Resources Center in Albuquerque to provide such assistance.

### BENEFITS OF ENERGY EFFICIENCY PROGRAMS

- *Competitive Edge* Energy is an operating cost of production. Any price increase will cascade through the nation's economy. Businesses that improve their energy efficiency are in a better position to compete in the world market, even during high-cost periods. From experience, energy service companies find conservation opportunities that reduce energy bills by 20–25% on average. Businesses can increase their profit margins, and government entities can reduce costs passed on to the taxpayer.



- *Imported energy* Energy efficiency can reduce our reliance on imported oil and reduce our trade deficit.
- *Life Safety* Energy efficient buildings are safer and can prevent losses to life and property. According to the Risk and Insurance Management Society Inc., energy-efficient windows are more resistant to breakage by fires, thieves, or wind-storms. Insulated pipes reduce the potential for freeze damage.
- *Economic Development* Energy efficiency and conservation efforts generate revenues for New Mexico. For example, energy service companies have implemented over \$21 million of infrastructure improvements that were financed by the private sector and paid for from energy savings; the taxpayers did not have to pay for these improvements.
- *Air Quality* The United States, with 5% of the world's population, produces 23% of the world's greenhouse gases. Energy efficiency improvements help to reduce emissions of pollutants and greenhouse gases.
- *Resource life* Through changes in production, design, and technology, energy efficiency can extend natural resources. Energy efficiency helps to sustain our economy, environment, and community over the long term for future generations.
- *Demand Stress* One way to provide for resource diversification and a hedge against the price volatility of conventional fuels is energy efficiency. Demand/price stress is reduced on our current resources. Efficiency also allows time to develop cost-effective renewable and fuel cell technologies.

# Low-Temperature Fuel Cells: Revolutionizing Energy Use

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**F**or many years Los Alamos National Laboratory has been engaged in an extensive research and development program in low-temperature fuel cells. Fuel cells can produce electricity and heat from hydrogen, natural gas, petroleum fuels, and fuel gases derived from coal and biomass. Fuel cells use fuels without combustion. Instead, they work by using chemical reactions, converting the chemical energy in a fuel into electric energy with reduced emissions of both greenhouse gases and noxious pollutants. Fuel cells have the potential to radically change energy use with worldwide impact.

Fuel cells have been around since 1839, but it took 20 years of research for NASA to demonstrate potential applications of fuel cells to provide power during space flight. Industry soon recognized the commercial potential of fuel cells but encountered technical barriers and high investment costs; fuel cells were not economically competitive with existing energy technologies. Since 1984 the Office of Transportation Technologies at the U.S. Department of Energy has been supporting research and development of fuel cell technology, and as a result hundreds of companies around the world are now working toward making fuel-cell technology pay off.

## HOW FUEL CELLS WORK

A fuel cell is an electrochemical energy conversion device. It is two to three times more efficient than an internal combustion engine in converting fuel to power. The fuel cell produces electricity and heat, using fuel (there are several options) and oxygen from the air. When the fuel is hydrogen, the only emission is water. One common low-temperature type of fuel cell is the polymer electrolyte membrane (PEM) fuel cell. In the PEM fuel cell, hydrogen flows into the fuel cell, and a platinum catalyst facilitates the separation of the hydrogen gas into electrons and protons. These then pass through a membrane and, again with the help of a platinum catalyst, combine with oxygen and electrons to produce water. The electrons that cannot pass through the membrane become electric current. The current travels through an external circuit and powers an electric motor.

## TYPES OF FUEL CELLS AND FUELS

There are five types of fuel cells (Fig. 1). For each, it is the electrolyte that defines the type. Polymer electrolyte membrane (PEM) fuel cells (described above) are low-temperature, direct hydrogen fuel cells that hold much promise for portable fuel cells. Known drawbacks are (1) that they must run on hydrogen fuel, and (2) they can operate only within a narrow temperature range, because they contain and produce water, which cannot be allowed to freeze or boil. The cost of polymer membranes is high (\$100 per square foot), which inhibits their widespread use today.

In addition to the direct hydrogen fuel cell, research is currently underway to develop a fuel cell system that can operate on various types of common hydrocarbon fuels such as gasoline or natural gas. In such a fuel-flexible system, called a reformat/air system, a PEM fuel cell is fueled with hydrogen generated by an onboard reformer that converts hydrocarbon fuels into hydrogen-rich mixtures. Technical challenges lie in the reforming process, which requires high temperatures (700°C to 1,000°C). The reforming process also generates sulfur and carbon monoxide that can poison the fuel cell catalyst. Such a system lacks the zero emission characteristics of pure hydrogen systems, but it is still an improvement over the internal combustion engine (whose emissions are higher still), and the necessary fuels are readily available.

Direct methanol fuel cells use liquid methanol rather than hydrogen as a fuel. The advantage with these is that the fuel is liquid and can be distributed in a way that is familiar to consumers. In addition, the system does not require a reforming subsystem or a hydrogen storage subsystem. This technology is still relatively new, and several challenges remain. In particular, a great deal more platinum is required than for direct hydrogen fuel cells, and some methanol fuel crosses through the membrane, decreasing and wasting fuel.

## APPLICATION OF LOW-TEMPERATURE FUEL CELLS

The low-temperature technologies being developed at Los Alamos are particularly attractive for applica-



Fuel cell	Electrolyte	Operating temp. (°C)	Applications	Advantages	Disadvantages
Polymer electrolyte/membrane (PEM)	Solid organic polymer Poly-perfluoro-sulfonic acid	60–100	Electric utility Portable power Transportation	Solid electrolyte reduces corrosion and management problems Low temperature Quick startup	Low temperature requires expensive catalysts High sensitivity to fuel impurities
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90–100	Military Space	Cathode reaction faster in alkaline electrolyte —so high performance	Expensive removal of CO <sub>2</sub> from fuel and air streams required
Phosphoric acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175–200	Electric utility Transportation	Up to 85% efficiency in in co-generation of electricity and heat Impure H <sub>2</sub> as fuel	Platinum catalyst Low current and power Large size/weight
Molten carbonate (MCFC)	Liquid solution of lithium, sodium and/or potassium carbonates, soaked in a matrix	600–1000	Electric utility	High temperature advantages*	High temperature enhances corrosion and breakdown of cell components
Solid oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria as added	600–1000	Electric utility	High temperature advantages	High temperature enhances breakdown of cell components

\* High temperature advantages include higher efficiency and the flexibility to use more types of fuels and inexpensive catalysts as the reactions involving breaking of carbon-to-carbon bonds in larger hydrocarbon fuels occur much faster as the temperature is increased.

**FIGURE 1** Types of fuel cells.

tions with multiple start-stop cycles, such as battery replacement, portable power, vehicular propulsion, and residential energy systems. Every major automobile manufacturer in the world is currently developing fuel-cell vehicles. The modular nature of fuel-cell power systems enables the generation of heat and power for small-scale residential applications. PEM fuel cells offer the advantage of minimal maintenance, because there are no moving parts in the system. The potential for utility-scale systems is currently being studied (see paper by Berger et al., this volume).

**RELATED RESEARCH AT LOS ALAMOS NATIONAL LABORATORY**

Los Alamos National Laboratory has worked with industry on fuel-cell and related technology since the mid-1970s, through both the government-funded core research program and through cooperative research and development agreements with private industry. The Los Alamos research program ranges from fundamental investigation of ion transport and electrochemistry through materials development and component opti-

mization. In addition to fuel cells, current research and development includes supporting technologies such as hydrocarbon fuel reforming to generate a hydrogen-rich gas stream on demand, gas-cleanup technologies to make such streams compatible with PEM systems, and advanced sensors and controls. Theory and model development will further enable knowledge-based innovation; current research goals include cost reduction, durability, and performance improvement.

# MULTIPLE LAND USE

DECISION-MAKERS  
FIELD CONFERENCE 2002  
San Juan Basin



## Love of Land May Offer Control of Its Destiny

Frank Titus, *New Mexico Bureau of Geology and Mineral Resources*

If you love the Southwest, you'll love the San Juan Basin. Drive through this wild and desolate land. It is Jim Chee and Joe Leaphorn country. Its bigness is breathtaking. Here you learn self-reliance — or you leave. But at the human level, below its haunting geography, a tempest brews. It is about competing interests. It is about people getting along with people.

Although the land may seem boundless, its boundaries, social as well as physical, are real, embedded in hearts and minds, tradition and law. Although the land may seem timeless, its socioeconomic structure has been built on change. Grazing, the Navajo Nation, oil and gas, coal, irrigation, power generation—each has grown from a small beginning. All, except the birth of the Navajo Nation and grazing, are within the memory of someone still living. And still, the future holds change.

This is a land of rugged individualists and small tight-knit groups living within a common landscape, provided with common natural resources. Has any one yet offered a vision of how in their common arena they might work together to achieve a set of mutually beneficial goals? Cannot the puzzle pieces of a future be assembled in win-win format?

In his seminal article *The Tragedy of the Commons*<sup>1</sup> Garrett Hardin argues that in any commons—and the San Juan Basin is in his sense a commons—humans inevitably will tend to overtax the resources. Here are his words.

*The tragedy of the commons develops in this way. Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.*

*As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility to me of adding one more animal to my herd?" This utility has one negative and one positive component. 1. The positive...[is] one animal. Since the herdsman receives all the proceeds from the sale of the additional animal the positive utility is nearly +1.*

*2. The negative...is...the additional overgrazing created by one more animal. Since...the effects of overgrazing are shared by all the herdsmen, the negative...for him...is only a fraction of -1.*

*Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit in a world that is limited.*

Hardin's several examples of "commons" in this country today include public lands (mining, overgrazing), the high seas (overfishing), national parks (overcrowding), public waters (overconsumption), and the atmosphere (polluting).

In an interesting further analysis, however, Hardin goes on to argue that an appeal to the conscience of the community to protect the commons is inevitably self-defeating. People vary, he says. Confronted with appeals to protect any commons, some people will respond to the plea more than others. By this means, those concerned with the welfare of the commons may restrain themselves for the common good, whereas those willing to focus exclusively on their own mission become the dominant players. Therefore, he concludes, protection of the common interest depends on some form of coercion. Hardin says:

*To say that we mutually agree to coercion is not to say that we are required to enjoy it, or even to pretend we enjoy it. Who enjoys taxes? We all grumble about them. But we accept compulsory taxes because we recognize that voluntary taxes would favor the conscienceless. We institute and (grumblingly) support taxes and other coercive devices to escape the horror of the commons.*

Well, that's one way. But must we agree that there is only one way, and it's coercion? In fact, below are examples of spontaneous, citizen-generated efforts that have worked yet conflict fundamentally with this view of Hardin's.

On January 19 of this year I attended the first annual meeting of an upstart organization named The Quivira Coalition. Some 300 people packed the grand ballroom of La Posada de Albuquerque hotel. I came away simply amazed at the coalition's success in fulfilling its audacious purpose of getting ranchers, environmentalists, and land managers to unite in deciding what would be

good for improving western range land, and then DOING IT — a ranch, a grazing allotment, a farm, a critical habitat at a time. The speakers were people who live and work outdoors, intimately knowledgeable with both the land and their topics, and to a person they spoke in rangeland idiom. They were the people on the ground. Quivira membership is equally divided among the three interest groups. But, having decided that the threat to their way of life was too great if they failed to cooperate to grow more grass on the range; if they failed to cooperate to protect the riparian vegetation along stream courses crossing their lands; if they failed to cooperate to not damage the critical habitat of threatened or endangered species, they found ways to accomplish these things and more. Nobody made them do it. Maybe it was the looming consequences of inaction that got them started; maybe it was a new generation and education. Anyway, they have done it, on their own, and they continue to do it.

Now another example: I participated for five days between Christmas last and New Years in a private, citizen-started, 30-some-person discussion group in Santa Fe that focused on the future of northern New Mexico. One of the daily discussion leaders, Carl Moore, who specializes in negotiating difficult decisions in groups of individuals with divergent opinions, talked at length about a standing committee of citizens in Catron County. They have become effective at negotiating the most difficult and stressful considerations within their own membership, and are nearly always successful in reaching a mutually acceptable stance. They simply keep talking until they can reach common ground. This seems a central reason for their success: their agreement to keep talking until they can agree on something. They've faced many issues. One of the hottest has been over reintroduction of the Mexican Gray Wolf into areas close to the ranchers' grazing land — a hot issue if ever there was one.

The third, and a final example, is a citizen committee in the Pecos River valley. The New Mexico state engineer announced a tough plan to solve the problem of the state's likely inability to deliver enough water to Texas to meet the mandate of the Pecos River Compact between New Mexico and Texas. The committee is looking for alternatives. Drought and decreased runoff in the river for more than two years have the state scrambling to comply with the compact. The only weapon that New Mexico's Interstate Stream Commission and state engineer have to assure compliance is a bludgeon called a "priority call." This procedure would shut down all water use by enough junior water-right holders that the state of New Mexico can

meet its obligations to the state of Texas.

Uncomfortably, the estimate is that water users like the city of Roswell and many of the irrigating farmers in the Roswell Artesian Basin would have to stop using water before the flow of the river at the state line could be sufficiently enhanced. The citizen committee quite recently reached a tough set of agreements that experts think will work both now and in the next decade to avoid the dreaded priority call. No one is happy with the list of actions, but all agree that these moves are necessary. And they further agree that the effect of NOT being able to devise such a list would be economically many, many times more costly.

Note that none of these three examples is directly required by regulation or law, yet each has been successful in balanced preservation of the land. The people seem in fact to have been driven by conscience — the characteristic that Hardin dismisses as inevitably self defeating.

But look deeper. All, fundamentally, are operating out of self-interest to save their own land, and to keep the control of the future of that land within their own community. Implicit in this is that the cost of failure to hang on to such control would be costly in the extreme in values important to that particular community.

So, they are in fact dealing with a their own version of a commons. And to avoid their own ultimate hellish circumstance, they agree to search until a solution to each issue is found, one that every one of them can accept. This obviously leads to solutions with which no one is entirely happy. It can be said, in fact, that every solution so found is likely to be agreed to by each party while their teeth are clenched. So be it.

I admit to a sense of gratification that these recent examples are all from the American West, that they are initiatives of self-reliant people who love their land, and that they fly in the face of any suggestion that reliance on conscience will be self defeating. What will be truly self defeating will be failure to involve stakeholders, that is, the local people, in the process. That, and being less than forthright in providing, openly and in balanced manner, all of the information that is available. Give the people that, then stand back and prepare to be amazed and pleased.

Decision makers, it is our intention on this trip to give you information, insight, and ideas about the San Juan Basin "commons." We aren't optimistic about making your decisions any easier. We hope though that you feel your participation will make them wiser.

#### FOOTNOTE

<sup>1</sup> Science, 162(1968)1243-1248

## Oil and Gas Development in the Context of Multiple Land Use

Steve Henke, *Bureau of Land Management*

**T**he New Mexico portion of the San Juan Basin lies in the northwestern corner of the state and encompasses approximately 2.6 million acres of federal mineral estate. Approximately 80% of the mineral estate in the basin is federally owned and managed by the Bureau of Land Management (BLM). The basin produces an average of 3 billion cubic feet of natural gas daily—about 8% of the national total. This resource generates federal royalties averaging \$280 million annually, half of which, by statute, go directly to the State of New Mexico. Obviously, this is a nationally significant energy resource, and President Bush's national energy plan emphasizes environmentally responsible development of domestic energy from public lands.

Oil and gas leasing and production is one of several resources and uses managed by BLM under the principles of multiple use and sustained yield. On the surface, above this valuable mineral estate, are significant cultural resources, including Chacoan archaeological sites; habitats for a variety of wildlife and plants, including some endangered species; sensitive riparian areas; recreation areas; designated Wilderness areas; a network of ranches; sites that are culturally and religiously important to Native Americans; and public lands where many go to ride, hike, bike, hunt, fish, and seek solitude and refuge from urban pressures.

Under the Mineral Leasing Act of 1920, the federal government leased 97% of the federal mineral estate in the San Juan Basin to private individuals and corporations granting exclusive rights to develop the oil and gas resources. Many of these leases date from the 1940s and 1950s, and most have active production of natural gas from one or more producing formations. Development has proceeded with approximately 19,000 producing wells today and another 10,000 wells projected to be drilled over the next 20 years.

Since the early days of oil and gas leasing in the San Juan Basin by the federal government, Congress has passed a variety of legislation affecting public land management, including: the National Environmental Policy Act; the Endangered Species Act; the Clean Water and Air Acts; the Wilderness Act; the Colorado Salinity Control Act; the National Historic

Preservation Act; and the Federal Land Policy and Management Act, among others. Legislation affecting public land management and establishing public policy typically contains language to the effect that "... Congress finds that it is in the public interest to...develop mineral resources on public lands, provide clean drinking water and air, protect cultural resources, set aside wilderness, comprehensively plan for multiple use..." and so forth. What appear to be obvious conflicts with congressional intent, are, in reality, a challenge to those agencies responsible for multiple use to act in the best interest of the public.

The Executive Branch of the federal government, of which BLM is part, promulgates regulations to implement the acts of Congress. Through various regulations, some in conflict with one another, along with agency policies and bureaucratic processes, we have arrived at a point where we often lose ourselves in the maze of the "hows" and forget the fundamental goal of what is in the public interest. The various laws, regulations, and policies by which BLM manages these public resources allow for proposals, with respect to oil and gas development, which could range from total, unlimited development to no development whatsoever. Surely there is some level of oil and gas development that meets the public interest and is both ecologically sound and socially sustainable. The question becomes how to define that level of oil and gas development in a multiple-use environment.

The Farmington Field Office of BLM is preparing a comprehensive land use plan to guide management of the resources under its care for the next 20 years. Part of the planning process is to define the projected level of oil and gas development on existing leases. The New Mexico Institute of Mining and Technology, in cooperation with the New Mexico Bureau of Geology, prepared an analysis of future development that projects approximately 10,000 additional wells on federally administered lands over the next 20 years (see article by Engler in this volume). The fundamental resource allocation decisions to be made in BLM's land use planning process for oil and gas development in undeveloped areas are: which areas to lease, what special stipulations should be attached to leases, and

what areas should be closed to leasing. Since the federal oil and gas estate in the basin is 97% leased, this question is largely moot. The new challenge becomes defining and effectively analyzing a level of oil and gas development in an Environmental Impact Statement (EIS) that is consistent with the public interest.

Defining the public interest in its broadest sense, is in the author's view analogous to a similar exercise one would undertake in an area where both the surface and mineral resources were privately owned. Assume, if you will, that as a private citizen you owned a square mile of land within the San Juan Basin. Obviously, the value of the mineral resource would have a significant bearing on your decision to allow development. The royalty from development of the oil and gas resource would likely provide significant economic opportunities for your family. You would prudently want to protect your oil and gas resource from drainage by your neighbors. One would want to consider protecting some sensitive surface areas from impact, either totally or seasonally. You would likely work closely with the oil and gas lessee to ensure that development was consistent with your expectations, minimally disrupted your other uses, and that reclamation was completed so as to promote future productivity.

In the land-use planning and Environmental Impact Statement (EIS) process, BLM takes a similar approach to the analysis of proposed levels of development and alternatives. The EIS will define areas that are non-discretionarily (Congressionally) closed to leasing: the Wilderness areas, which comprise about 1% of the area. Some areas have designations or resource values that may require discretionary closure to leasing, or they have restrictions on surface oil and gas use. Areas to be protected through special stipulations will also be identified, such as Areas of Critical Environmental Concern or Special Management Areas. Leasing and development will be controlled through stipulation that would require seasonal closure, such as the big game winter ranges, or special siting stipulations to locate operations away from key recreation areas, endangered species habitats, riparian areas, or cultural sites. Perhaps 20–25% of the surface area would have special restrictions to protect other resource values, restrictions designed to avoid or mitigate impacts from oil and gas development. For the majority of the area, oil and gas development will be permitted under a set of standard terms and conditions that are designed to ensure environmentally responsible development of the oil and gas resource.

The public interest at the local level involves managing development in a socially sustainable manner. Referring back to the private land/mineral owner example: BLM would plan site-specific development, much as any prudent private landowner would, to avoid visual intrusions on the landscape, minimize impacts to other surface uses, protect surface and ground water, and mitigate disruptions from noise, traffic, hazards, or impassable roads.

How would we measure BLM's success in planning for and managing the resources of the San Juan Basin? Indicators of a successful plan and analysis might include: support for the package of proposals and public commitment for implementation; minimal controversy concerning the data and assumptions used for the analysis; a sustainable local community, both socially and economically; orderly development of the oil and gas resource; avoidance and mitigation of impacts to other resources; and completion of reclamation requirements.

As BLM approaches completion of the draft plan/EIS, our goal is that the proposals be balanced and reasonable, and that they reflect what is in the public interest, both nationally and locally.

## Oil and Gas Production In Urban Areas: Conflicts and Solutions

Frank Chavez, *New Mexico Oil Conservation Division*

**I**n the San Juan Basin of New Mexico, the oil and gas industry has dominated the regional economy and local communities for many years. With the first discovery of oil and gas in the early part of the twentieth century, the industry was welcomed for the energy and economic benefit it brought to the area. However, in the last 20 years as communities have grown, the demographics and values of the area have changed. Although the oil and gas industry remains one of the largest single employers in the area and has the largest single impact, the economy of the region has diversified, and the oil and gas industry no longer dominates the regional economy in quite the same way as it once did.

Changes in local values and perceptions may reflect larger-scale changes in our culture. Although the sight of a well with its associated equipment was at one time a symbol of prosperity and human ingenuity, current populations are just as likely to view the same well as a pollution source and a hazard to life. Changes in land ownership have also altered the older, more mutually beneficial relationships between landowner and driller. Most of the original oil and gas leases allowed the landowner to share in the wealth of production through royalty payments; thus, the inconvenience of having a well on one's land was partially offset by the direct financial benefit. Over time, surface rights and mineral rights have been severed for many tracts of land, and landowners today may receive no direct benefit from having a well on their land.

As communities throughout New Mexico continue to grow, we are experiencing more conflicts between the larger communities and the traditional operations of the oil and gas industry. Here are a few examples of problems associated with these conflicts:

- In a period of only a few months, two teenage boys trespassing on well sites were killed. One, in an attempt to "get high," was sniffing vapors from a tank hatch and fell to his death. The other was standing on top of a tank stealing "drip" gas when his partner struck a lighter at the hatch to see how much fluid was in the tank. One boy was propelled over 100 feet in the resulting explosion; the

other boy was badly burned.

- A local school board spent several thousand dollars in construction before they realized that they were building a school closer to an existing well than the fire code allowed.
- A land developer spent time and money designing an upscale subdivision (including a golf course) only to discover that a company, with full legal rights, had commenced drilling a well in the middle of his planned community.
- The New Mexico Oil Conservation Division, locating old "orphan" wells for plugging, found one within 3 feet of a landowner's house.

Historically, most of the local population lived in the cities; rural populations were predominantly farmers and ranchers. Increasingly, more residents are living outside of the cities, seeking the freedom, quiet, solitude, and atmosphere of rural life. Many farms are now being subdivided into home sites. For example, 10 years ago in Farmington the top of Crouch Mesa was home to a small herd of antelope and a few prairie dogs. Today portions of the mesa host over 200 site-built or modular homes, with more planned. The increasing need for housing within the communities of Aztec, Bloomfield, and Farmington is causing those communities to expand into what was once farm and ranch land. There are currently more than 200 gas wells within the city limits of these three communities, and more wells are scattered throughout the outlying areas.

General knowledge of the operations of the oil and gas industry has also declined. New landowners, oblivious to some of the inherent conflicts and concerns, are sometimes placing homes in dangerous proximity to well sites, pipelines, or other facilities. Land values have increased to the degree that a single well site can occupy land that is valued at thousands of dollars. Local real estate agents are not adequately informed about the possible impacts of existing and future oil and gas development when they market land in this area.

At the heart of these conflicts are problems related to old oil and gas leases and regional geology. The oil- and gas-bearing formations of the San Juan Basin

underlie both cities and rural areas. In order to produce these resources, an infrastructure of well sites, roads, and pipelines is needed. Wells must be evenly spaced in order to efficiently drain the oil and gas reservoirs. This creates a problem when the ideal geological locations are occupied by existing homes or other structures. Directional drilling, often suggested as a solution by those not fully familiar with the process, is not an appropriate solution to most well-site problems in the San Juan Basin, due to the depths, abnormally low pressures, and quantities of the reserves involved. Older leases give oil and gas developers almost unlimited access to and use of the land, often to the detriment of the surface owner. The responsible leaseholder has a moral obligation to work cooperatively with the surface landowner and local communities to lessen possible negative effects of such development.

Any leased land has the potential for future well drilling. A completed well requires 1–2 acres of land during the life of the well (for the site, access, and pipelines), in order to be a relatively safe distance from other uses. The well must also be served by pipeline right-of-way. This usage makes those 1–2 acres unavailable for home sites. When a well is finally plugged, a permanent steel marker is placed over the well bore. This land remains undesirable for construction because of the risk of plug failure.

Local governments have been pursuing some solutions. In the early 1980s the communities of Aztec, Bloomfield, and Farmington wrote city ordinances governing oil and gas drilling and production within their jurisdictions. Although there is serious doubt regarding to what degree cities can legally regulate the industry, companies in New Mexico have chosen not to challenge these ordinances. These companies consider themselves part of the community and want to be as cooperative as possible. Existing local ordinances and regulations place stipulations on noise, traffic, location, hours of operation, etc.

San Juan County has chosen not to address these conflicts between the oil and gas industry and other land use and not to implement new regulations. Several years ago landowners filed a lawsuit against a local oil-field waste service company, in response to hydrogen sulfide gas emanating from the waste disposal facility. One of the important questions raised was, “Who was there first?” Regardless of who was first to occupy the neighborhood, the proximity of homes and such facilities creates a serious incompatibility.

The San Juan County fire marshal has implemented

the National Uniform Fire Code standards for oil and gas industry operations. These standards are more stringent than the previous requirements. The setbacks required in the code now limit both the energy industry and other land users as to how close to each other they can conduct their activities.

The issue of community safety is increasingly important. Since the pipeline rupture and fire near Carlsbad in August 2000, we all have a heightened awareness of the potential for problems from oil and gas activities. Some of the wells within city limits are several decades old, with aging downhole and surface equipment. Maintenance and monitoring of these facilities in sensitive areas becomes much more important and increases costs. One high-pressure gas line, on the outskirts of town when it was installed, is now located in a well-populated area of Farmington as a result of the growth of the community.

The oil and gas industry has taken some initiative in finding solutions. Well locations within the cities vary in how they are “finished.” Several in Farmington are attractively fenced, with the surrounding area landscaped into a park. Those locations that are highly visible are maintained with regular painting and clean gravel arranged around the well. In order to reduce truck traffic to the well, some operators are disposing of produced water in the city sewer system at the well site and paying the city for handling and processing of industrial waste. After the tragic deaths that resulted from the Carlsbad fire in August 2000, local companies implemented an educational program that is presented to schools on a regular basis. For wells that require a public hearing before a city council, companies are making thorough educational presentations, describing the processes that will be used.

Conflicts are not limited to well development. The Crouch Mesa situation described above is further complicated by the existence of three oil field waste handling facilities that were permitted by the Oil Conservation Division and constructed before homebuilding began. Two facilities are land farms that, by their nature, generate significant odors. The other facility handles wastewater in a large pit that often generates odors from anaerobic bacteria. Normal well production operations produce odors and noise. The nuisance value of all of these is often very subjective. Several large gas-processing facilities are located in a pipeline corridor just north of Bloomfield, and a nearby residential area is growing quickly. The noise and odors from these facilities may soon become an

issue for residents.

Some possible solutions for lessening the conflict are apparent. Among them:

- Knowing that oil and gas development will continue, communities could designate certain areas for that purpose in cooperation with other governing agencies. This might limit conflicting development.
- Local realtors must be educated about oil and gas development so they can better inform potential sellers and buyers. Standardized explanatory material should be given to all buyers.
- Companies should inform surface land users and local communities about their long-term plans for development or other activities that might disrupt use of the land.
- Land abstracts and deeds should make explicit reference to existing oil and gas leases with appropriate caveats.
- Companies should thoroughly explore the safety and nuisance risks of any equipment, such as compressors and piston lifts, before installation.

There will always be conflicts in how land can and should be used. Better education of landowners and land managers is an important element in lessening this conflict. Including this development in long-term planning for communities and landowners will also help. Finding innovative and cooperative solutions to these common problems is to the mutual benefit of the oil and gas industry, the regional economy, and the residents of the San Juan Basin region.

## Surface and Mineral Rights Ownership in New Mexico

Mark Hiles, *New Mexico Mining Association*

**I**n order to develop a coal reserve into an operating mine, multiple ownership issues (for land and mineral rights) must be resolved. Capital outlay to develop a small surface mine (1 to 4 million tons per year) can easily exceed \$100 million. An economic reserve would very likely exceed 10 sections (6,400 acres), involving multiple landowners. Below is an outline of the types of land and mineral ownership that would probably be encountered, and the estimated costs and benefits of each.

### PRIVATE, FEE SIMPLE, DEEDED

Records for private land are maintained at the office of the county in which the land is located. Private land owners normally negotiate a fee for allowing the disturbance of the surface. Surface and mineral rights are often separate and owned by different entities. The negotiated fee for these rights varies, from outright purchase to paying royalties on tons of coal sold. Such lands initially fell into private ownership through the Homestead Act, or were purchased from the railroad or the federal government.

An example for a mine involving surface rights and subsurface (mineral) rights: A minable section of property would likely produce 20 to 30 million tons of coal. A surface royalty (alone, excluding mineral rights) of 2% of coal sales, at a market price of \$14 per ton, would yield 28 cents per ton. Production of 20 to 30 million tons would yield \$5.6 to \$8.4 million. An owner of the mineral rights would likely negotiate a royalty rate closer to 10–12%, closer to standard state and federal royalty rates. In this example the mineral rights royalty would yield \$28 to \$50.4 million.

### NEW MEXICO STATE LAND

State lands include state trust land (sometimes referred to as school sections property, designated to generate funding for public schools), state parks, and state monuments. Records for state land are held at the New Mexico State Land Office in Santa Fe. Normally if the state owns the surface rights, they own the mineral rights as well. The state land com-

missioner is responsible for management of state trust lands, with the main objective being to maintain state land and generate funding for schools. A standard royalty for state lands has been set at 12.5% for surface and mineral rights and 8% for subsurface or mineral rights.

For example: A minable section of property would likely produce 20 to 30 million tons of coal. A surface and mineral rights royalty of 12.5% of coal sales at a market price of \$14.00 would yield \$1.75 per ton. Twenty to thirty million tons would produce \$35 to \$52 million in royalties for public school funding. A royalty for subsurface or mineral rights at 8% would produce \$22.4 to \$33.6 million in funding for public schools.

State lands are often leased to individuals for grazing on long-term leases. In this case, the surface leaseholder is often paid a royalty or set sum for the loss of their grazing rights. It is common for a leaseholder to be paid a royalty of 1%. At a rate of 1%, 20 to 30 million tons at a market price of \$14.00 per ton would produce \$2.8 to \$4.2 million in royalties.

### UNITED STATES GOVERNMENT (FEDERAL)

Federal land includes U.S. Forest Service land (Department of Agriculture), and land administered by the National Park Service and the Bureau of Land Management (Department of the Interior). U.S. Forest Service and National Park Service lands are generally off limits to coal mining.

Records for federal land open to coal mining are held at the state Bureau of Land Management (BLM) office in Santa Fe. Royalties paid on BLM lands are similar to those paid for state lands. As in the case with state and private lands, the surface and mineral rights are often separate. Federal lands at one time had a straight royalty rate of 17.5 cents per ton, so the market value of coal did not factor into the royalty rate. Currently the royalties are paid based on the price of coal similar to state lands. The Secretary of the Interior must approve the leasing of BLM lands for coal mining. Approval of leases on BLM land requires more extensive comment and notification than leases on state or private land.

### **NATIVE AMERICAN LANDS**

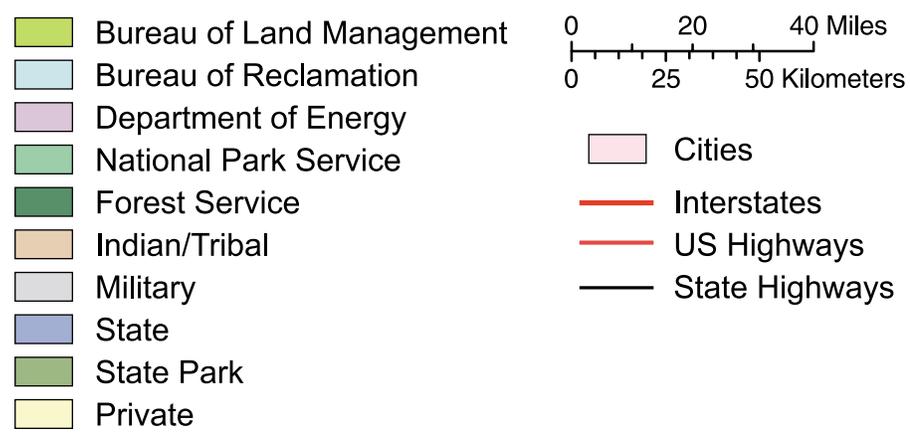
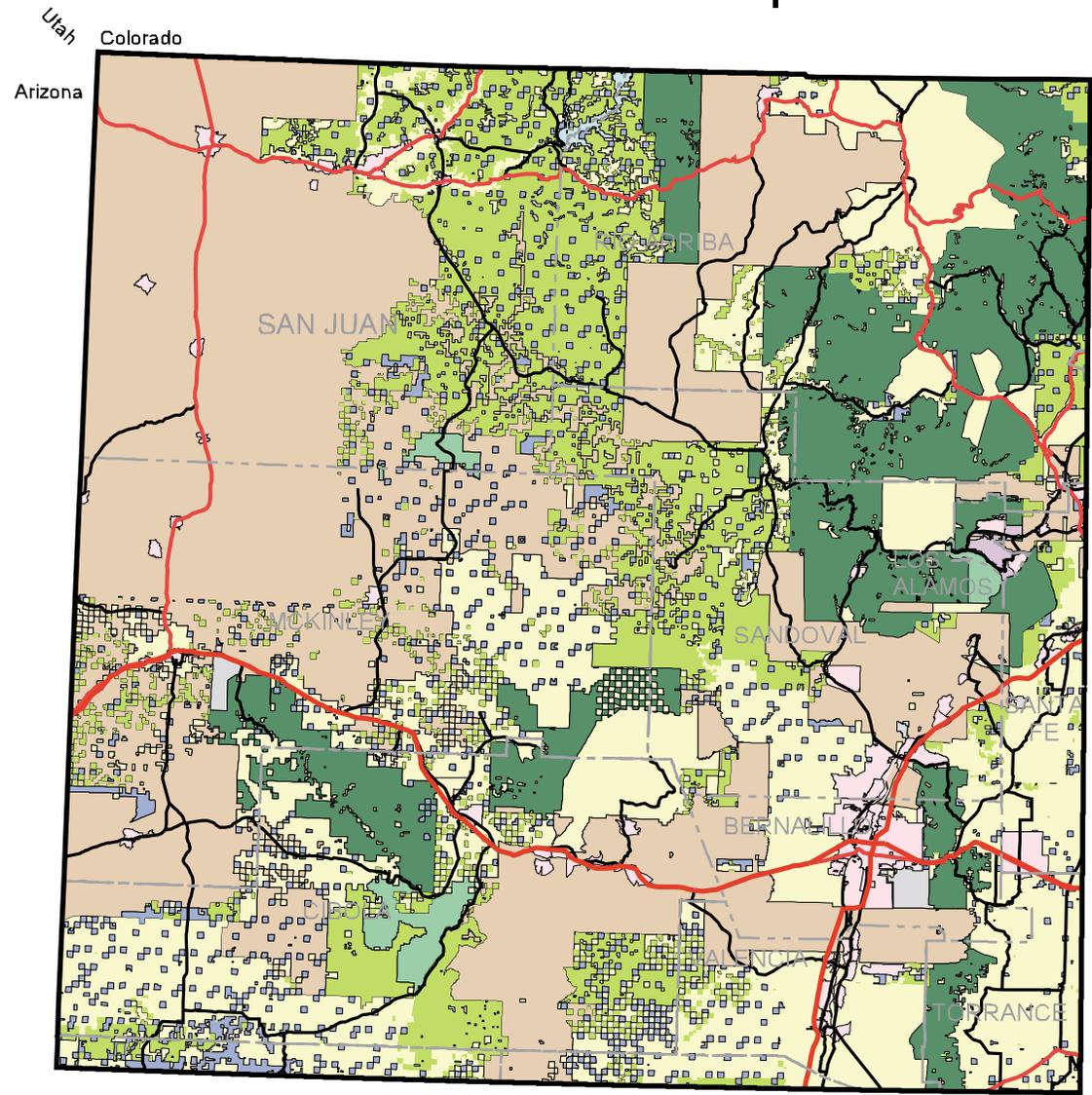
Native American lands include reservation land and allotted land. The Bureau of Indian Affairs maintains records for Native American land. Royalties paid on Native American land are usually similar to those paid on state and federal land. Allotted land is land that was deeded to individual Native Americans through the Homestead Act. Allotted Land is held in trust by the federal government. Allotted land is normally passed on to multiple heirs of the original owner. Approval by all owners is required before permitting for mining. It is often difficult to track down or contact all of the owners to obtain approval.

### **SPANISH LAND GRANT**

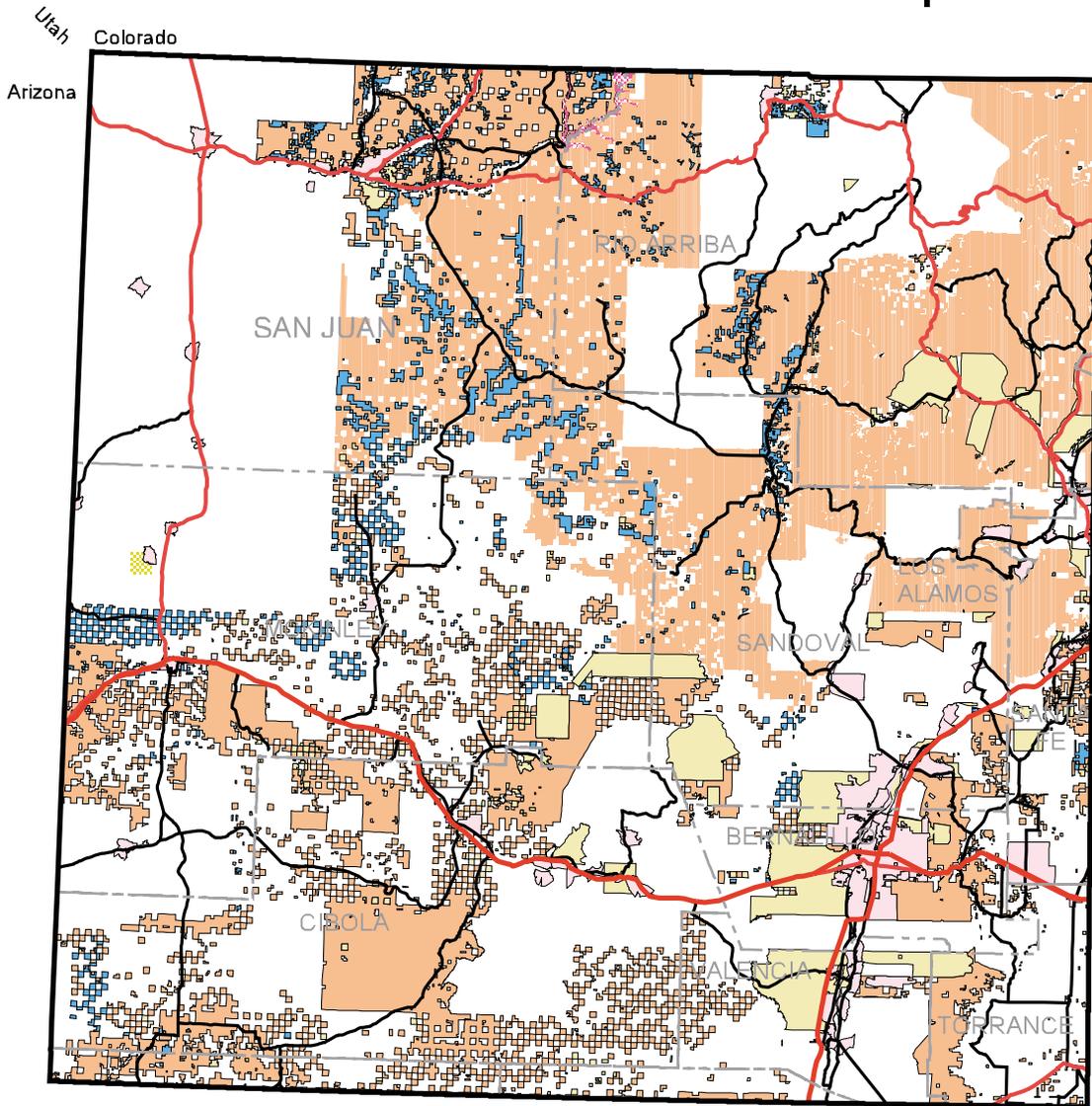
Spanish Land Grant property was granted to the original settlers from Spain when this part of the Southwest was Spanish Territory. Treaties between the United States and Spain maintained original grants after United States jurisdictional control of the territory. Ownership may vary from a community or shareholder corporation-type ownership to individual ownership. Ownership and controls are similar to those for private lands.

The checkerboard nature of land ownership in the San Juan Basin is the rule rather than the exception. It can be a major stumbling block to the development of resources, subsurface or otherwise.

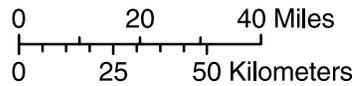
# Land Ownership



# Federal Mineral Ownership



- All minerals
- Coal
- Other
- No minerals



- Cities
- Interstates
- US Highways
- State Highways

## Coal and Coalbed Methane: Conflicting Development in the San Juan Basin

Bill Papich, *Bureau of Land Management*

**T**he Bureau of Land Management's policy of maximizing resource recovery in an area of federal coal and natural gas mineral estates near Farmington has gas drillers and a mining company in a controversy neither anticipated. BHP Billiton, one of the largest mining companies in the world, has operated two open-pit coal mines (the San Juan and La Plata mines) since 1972, supplying fuel to the San Juan Generating Station. Thirty years later, both the San Juan and the La Plata mines are too deep for economical coal extraction. Plans for the future of these mining operations have changed in order to meet the ongoing needs of the San Juan Generating Station.

BHP Billiton initially made three proposals regarding how to meet future coal demands of the San Juan Generating Station. As the San Juan open-pit mine approached the depth of uneconomical coal recovery, BHP Billiton considered two other ways to supply the power plant. One was to transport coal from the company's open-pit Navajo mine on the south side of the San Juan River, which feeds the nearby Four Corners Power Plant. BHP Billiton has a long-term supply contract with Arizona Public Service Company, the operator of the Four Corners plant. The Navajo mine has so much coal available for economical pit mining that it could supply both power plants. The Navajo mine option, however, was scrapped because it included building a haul-road through a semi-residential area, a special management area for an endangered plant, and constructing bridges over the San Juan River and U.S. 64, a major four-lane highway through the area. The second option BHP Billiton considered was extending the La Plata mine northwards into Colorado. This would require a lease from the Southern Ute Tribe. The Utes declined to lease reservation land for coal mining.

The third option was to go underground at the San Juan open pit, and that is the option that was chosen. The San Juan mine is the company's first "longwall" mine in the San Juan Basin. (Longwall mining is a method of underground coal mining in which massive amounts of coal are produced.) "There are a lot of mines that never would have survived if it wasn't due to longwall mining," said Jack Kuzar, a district manager for the Denver office of Coal Mining Safety and

Health, part of the Mine Safety and Health Administration. "It's unreal what you can produce." The mine started last year and is expected to be at full production by late 2002, producing 13,500 tons of coal during every eight-hour shift.

BHP Billiton will go underground to devour and build roads through the coal seam with a machine known as a longwall shearer. A longwall shearer is a rotating drum with carbide teeth, moving back and forth along a coal seam like the carriage of a typewriter. The operators stand protected under a row of roof-supporting thick metal shields supported on 30-ton hydraulic jacks. Riding on skids, the shields are moved forward hydraulically as the machine chews through the coal seam. The roof behind the shield caves in. Longwall shearers grind away at coal seams in swaths hundreds of feet wide. The San Juan mine longwall operation will cut a face of coal 1,000 feet wide and 12 feet thick from top to bottom, for more than a mile into the seam. On this scale BHP Billiton plans to extract coal from approximately 10,000 acres of their mineral leases.

In the 1970s and 1980s the Bureau of Land Management leased the San Juan mine coal seam for both coal mining and natural gas production, a period during which BHP Billiton had not developed a plan for underground mining. During that same period, natural gas production companies had little interest in drilling the area. Methane gas production from coal seams did not take off until 1988–92, when the federal government began offering a tax credit of approximately \$1 per thousand cubic feet of coal seam gas, but only for wells drilled during that period. The tax credit was intended to encourage industry to develop unconventional sources of gas, increasing the nation's natural gas reserves. Before the tax credit, coalbed methane production in the San Juan Basin was a drop in the bucket compared to the basin's total production of natural gas. But since that time, things have changed a great deal. During the first quarter of 2001, coalbed methane production accounted for approximately half of the basin's natural gas production.

The conflict lies in the fact that methods used to extract these two important resources are not neces-

sarily compatible. BHP Billiton is concerned that if the coal seam is drilled for natural gas extraction, it will make underground mining too risky, due to cave-ins and, possibly, spontaneous combustion. Two natural gas production companies, Dugan Production Corporation of Farmington and Richardson Operating Company of Denver, have federal mineral leases that give them the right to produce gas from the coal seam. Richardson currently is drilling coalbed methane wells into the same coal seam to be mined. Dugan Production also has drilled several wells into the coal.

The drilling companies want to produce all the gas possible from their leases. A coalbed methane well can produce gas for 20–30 years. BHP Billiton telling the natural gas producers that drilling operations must be cut short does not sit well with the producers. In some areas of the coal seam, gas production would be possible for only 5–10 years before the underground

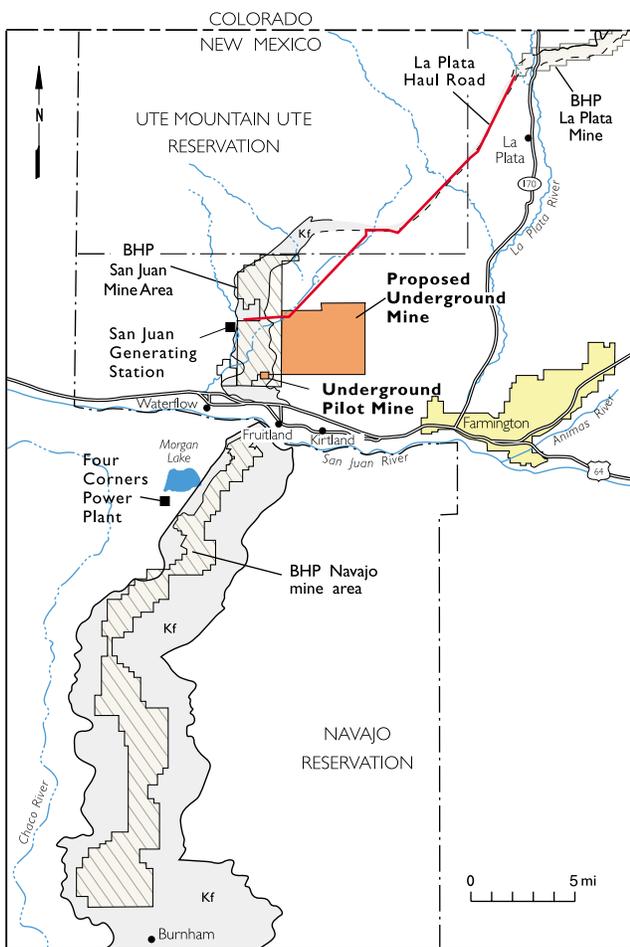
mine reaches the area being drilled for coalbed methane. The natural gas producers have talked about compensation if they are not allowed to produce all the gas possible from the coal seam. Plans for the underground longwall mine cannot be derailed if the power plant is going to continue to operate. The San Juan Generating Station, operated by Public Service Company of New Mexico and one of the largest in the United States, needs the coal, and San Juan County needs the high-paying jobs.

Underground mining began last year from an open-pit mine at a depth of 300 feet, where a 15- to 20-foot-thick coal seam slants downward at an angle of 3 degrees. The mine will stay inside the seam, leaving considerable coal for a sturdy roof and floor. After 17 years—the length of BHP Billiton’s current power plant supply contract with PNM—the mine will be more than 1,000 feet deep.

Gas drillers use various means of cracking coal to increase gas flow through it. BHP Billiton says its technological studies indicate that the integrity of the mine’s roof of several feet of coal will be threatened from fracturing operations of the drilling companies. Mine officials say that dewatering and degassing of the coal ahead of mining would make the mine more susceptible to spontaneous combustion. An additional safety concern the mining company has encountered is the existence of drilling pipe and well casings within the coal seam, which could set off sparks if the underground mining equipment hits them. The natural gas producers have leases to drill through the coal seam to deeper oil and gas producing formations below the coal formation.

The Bureau of Land Management (BLM) is charged with ensuring maximum recovery of natural resources from federal mineral leases on BLM land—and that includes maximum recovery of both gas and coal. The safety of miners, however, overrides energy production. In a meeting last year (2001) between BHP Billiton, gas drillers, and the BLM, Lee Otteni, the BLM Farmington field office manager, said: “I’m not going to risk a miner’s life by trying to maximize production of coal and gas coming out of the same coal seam.”

BHP Billiton’s mining leases do not take precedence over natural gas drilling leases in this instance. If they did, the leases would give custody of the gas to the mining company, which could vent the gas so that it wouldn’t interfere with mining operations. The U.S. Department of Interior Board of Land Appeals, however, has ruled that whoever has the oil and gas lease



**FIGURE 1** San Juan County’s Fruitland Formation coal mines.

has the right to extract the coal seam gas. The BLM has provided technical information on the coal seam to BHP Billiton and the gas producers, to supplement their own information. The BLM has also hosted meetings between companies to encourage settlement negotiations. “The BLM has attempted to get all parties involved to come to some sort of protocol agreement that would lead to a resolution of the conflict,” said Shannon Hoefeler, a mining engineer at the BLM’s Farmington field office. “What BHP wants is a negotiated settlement based on sound technical and economic data.”

## A Rational Approach to Solving Energy-Related Conflicts—Communication by the Jar-full

Dr. John Bartlit, *New Mexico Citizens for Clean Air & Water*

In 1998 the environmental activist-turned-governor of Oregon, Gov. John Kitzhaber, spoke to a gathering in Phoenix of some 350 ranchers, miners, farmers, and a wide mix of officials, industry folks, environmentalists, and western governors. At the end, all of us rose to our feet as one in applause. The talk's stirring finale came from Wallace Stegner's *The Sound of Mountain Water*. Those words hit home with equal force today:

"...One cannot be pessimistic about the West. This is the native home of hope. When it finally learns that cooperation, not rugged individualism, is the quality that most characterizes and preserves it, then it will have achieved itself and outlived its origins. Then it has a chance to create a society to match its scenery."

Yet such words are all too seldom heard in the field of battle. My 33 years of activism have convinced me that the use of information in public issues has more in common with a skyjacker's single-mindedness than with the shedding of light.

How can the game of advocacy be played better in the field? I do not mean played better against some yardstick of idealism; I mean done better to achieve one's goals. As Gov. Kitzhaber and Stegner preach, I, too, believe a fresh approach can help all sides get more of what they really want, and get it faster, than will more of the current methods.

For 31 years my columns have appeared in the Los Alamos Monitor every other Sunday. Many of them work on the puzzle: Can a different approach gain more for your side than the timeworn schemes? If so, how? To reply, this essay builds on my Sunday morning pieces, which are more fun than the usual harangues in public battles (however faint this praise may be). In the Albuquerque Journal, September 2, 2001, I wrote:

The Land of Enchantment harbors immense beds of coal—left by the watery reaches that settled here for some time eons ago. The result is energy companies today cast longing looks in our direction. "Power plant" fills their mind's eye like a youngster's dreams of a shiny new bike. Last

spring's power scramble in California adds hopes of getting the speedy red one with winking lights on the pedals.

How people take to this news is as varied as T-shirt mottoes. Some whoop for joy; some curse the errant waters. No matter which tune you might pick, I suggest a more equable course—one that provides news with enough perspective to yield understanding. This approach is not the usual one seen in public issues. The common way is to show a jar half full of facts—handpicked shards of the whole picture—with no background to judge against, so most of the story is hidden from view.

If I made all the rules—an idea found on no one's agenda—I would add one new rule to the long legal process of building a coal-fired power plant in New Mexico. The rule is simple, runs as swiftly as companies choose to move, and costs near nothing in the process.

My rule would require that the public be informed fairly about the plant before it is all designed. I mean, told a fair sample of the whole story: What the plant does, how it works in plain terms, the air pollutants it emits, the range of choices for their control and how well each works, the cost of each choice, and its effect on consumer bills.

Perspective is a must: A useful means is to compare the emissions, say, with those of a natural gas-fired plant, an advanced-cycle plant, and the current emissions in the area. Then the water needs of a plant can be told and put in a fair perspective. The range of technologies to reduce water use can be explained, together with the cost of each choice and its impact on a monthly electric bill.

We often hear of the local jobs created in the building and running of a power plant. Fairness gives the same praise to the added jobs, and the economic boost, from the hundreds of workers it takes to build and run modern pollution controls.

My rule amounts to no more than a call for truth in advertising. Who would fuss? It is a fair turn: a new link to the classic core of democracy—

an informed citizenry. Don't get me wrong. My idea is not to set a trap. I do not suggest a company has to put itself in the worst possible light. I am talking here about the real options available for a new coal plant: the ones known to any chief engineer worth his salt as a plant designer, the ones the engineers would consider anyway when planning a plant. The energy companies can send this knowledge to the public with the greatest of ease.

The information is already there and, in the course of things, many ads no doubt are planned. All that is needed is to put the knowledge in the ads. Ads also can send people to a company's web site that can tell more details. I see no good reason this thought should feel as unnatural as it does. The move can only build the public's trust in a power company's skill and candor—a trust modern companies prize highly and seek to gain. What is more, I suggest the move would get a company further ahead quicker than a host of the usual means used to pursue trust....

Elsewhere I go further into the failings of public communications in matters of debate. One such piece was a column done with coal people—or, as one might say, in strange company. The credits read: "This and subsequent columns express the combined views of the American Lung Association of Arizona and New Mexico, Arizona Public Service Company at the Four Corners Power Plant, Land and Water Fund of the Rockies, New Mexico Citizens for Clean Air & Water, and Public Service Company of New Mexico at the San Juan Generating Station." The piece focused on coal, but the principles go to any energy-related conflict, and even beyond. In the *Los Alamos Monitor*, July 22, 2001, I wrote:

We (who sponsor this column) all are concerned with issues about coal and its use for power production. The vital public debate about coal issues may strike you the same way it does us—awfully lumpy.

Here is the scene: Half a story comes from the "coal" side and another half from the "green" side. The two halves sound so different that we all figure somebody must be lying. So we pick our favorite team to believe—either coal or green—and trash everything the other one says. The result: Almost nobody can piece together enough of the whole story to make up his own mind.

In our great nation, too many issues seem to

go this way. Yet, far more times than not, what both sides say is true. The two sides just tell different parts of the whole story and say things so people will think the other guy is a liar or a crook, or both. This custom is in part human nature and in part the "American Way."

The problem is made worse by another part of human nature. By nature, news about lies, crooks, and conflicts rouses heightened interest. Or as Mark Twain once said: "A lie can travel half way around the world while the truth is putting on its shoes."

We, the five sponsors of this column, think a clearer story can be told—a story clear enough for the issues to be understood by all and decided by all who are concerned. Beginning with this column, and with others to follow, we set ourselves on this path: We will agree most of the time. At times, we may agree up to a point and then disagree on some aspect. We may disagree because we have different values, or because we draw different conclusions from the shared information, or because too little is known. When we disagree, we will say why we do, so you can judge things your own way....

The story of conflict has other sides, with other angles: Human instinct always shouts to tell us we will get the most of what we want by fighting the other guys about everything. The instinct may be right, but only if time doesn't matter. Fighting takes time. And much more than the time for the fight. There is also the time, cost, and paperwork to work through the enormously elaborate systems society puts in place to keep the battle civil.

Time matters to both sides. Environmentalists want dirty plants cleaned up and even better new kinds of plants. Yet it typically takes decades to get done what could be done in years. Industry wants permits so it can operate. Yet it can take years, or many months, to accomplish what could be done in months or days. The result of fighting about everything is ever the same: the price of distrust is bureaucracy.

The same message comes through again in permitting: Industry wants faster permitting, whereas environmentalists want better compliance with the air and water rules. The two needs affect each other.

Any New Mexico project that might emit air pollutants must get permits from the Air Quality Bureau before being built or operated. Within the limits of the law, the permits set down detailed project requirements, such as the maximum emission rates by pollutant type, kinds of emission controls, operating times,

monitors to be used, reports to be filed, and on and on. A typical construction permit is 16 pages long and takes about three months to get.

If a permit is granted, the project goes ahead. The operating plant then is inspected by the bureau, at some interval, to check that all permit conditions are being met. If they are not met, enforcement actions may follow. The bureau's present staff can make perhaps 250 inspections per year and check on 100 performance tests. There are 2,000 permitted projects in New Mexico, ranging in complexity from a heating unit to an oil refinery, and new and revised permits come at a rate of about 300 per year. You begin to see the challenge of ensuring compliance.

More bureau resources could go either into preparing permits, with their detailed conditions, into inspecting the projects, or into enforcing the permits in case of violations, but not all three. The resources are fixed; what goes one place cannot go to the others. Yet each one takes time, skill, and people (that is, money) to do it right.

The interests of industry and clean-air backers are not all as different as you may think. To be sure, no company likes to have rules enforced against it. But neither does any good-guy company like a bad-guy competitor to escape the rules the good guys meet; that's not fair play. For reasons as different as hats, a wide range of interests gains something from more uniform compliance.

Likewise, all sides gain from rules that are simpler in form (but not laxer), so they are better understood and enforced uniformly. In sum, the prize for everyone is to get swifter and truer permitting and compliance, thus cutting emissions through fewer violations and cleaner equipment or both, all for the same bureau dollars. Not a bad thought.

In the grand scheme of things, regulation won't work well for your side if it doesn't work well all around. The same holds true for public communication. The old use of the jar half full of facts—the handpicked shards of the whole picture—will not gain the most of what you want in the shortest amount of time. It will but leave easy targets for the opposition and soak up time and money in the fight.

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Ron Broadhead worked for the former Cities Service Company in Oklahoma and has been with the New Mexico Bureau of Geology and Mineral Resources since 1981 where he is presently principal petroleum geologist and associate director as well as adjunct faculty. He has recently worked on oil and gas resource assessments of the Tucumcari Basin, McKinley County, and De Baca and Roosevelt Counties and is part of a team that is developing a new technology to reduce risk in petroleum exploration. In 2002 Ron received the Monroe G. Cheney Award from the Southwest section of the American Association of Petroleum Geologists. Ron Broadhead received his B.S. in geology from New Mexico Tech and his M.S. in geology from the University of Cincinnati.

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David Coss has been director of the Field Operations Division for two years and has worked for the State Land Office for 4 years. The Field Operations Division works with individuals and entities that lease state trust land, other government agencies, and private entities to protect and enhance the value of surface resources on state trust lands. The division includes professional staff in natural resources management, environmental reclamation, hydrology, archaeology and geographic information systems. Before coming to the State Land Office, Mr. Coss worked for the city of Santa Fe as Public Works Department director and city manager. He has also worked for the New Mexico Environment Department in the Surface Water Quality Bureau and as director of the Environmental Protection Division. He is a graduate of both New Mexico State University and Southern Illinois University at Carbondale, with bachelor's and master's degrees in wildlife science.

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Sandra Ely is the bureau chief for the Air Quality Bureau of the New Mexico Environment Department. She has a B.S. in nursing from Creighton University, a B.S. in conservation and resource science from the University of California at Berkeley, and an M.S. in environmental studies from the University of Oregon.

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Thomas Engler currently holds the position of chairman/assistant professor of petroleum engineering at New Mexico Tech. Previously he was senior instructor/assistant professor at the University of Tulsa and production engineer for Marathon Oil. Engler's current research interests are petrophysical interpretation and unconventional gas recovery. He is a registered professional engineer and is an active member of the Society of Petroleum Engineers, American Association of Petroleum Geologists, and SPWLA. Engler received B.S. degrees in geology and petroleum engineering from New Mexico Tech in 1980 and 1982, an M.S. in petroleum engineering from New Mexico Tech in 1992, and a Ph.D. in petroleum engineering from the University of Oklahoma in 1995.

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As president of the New Mexico Oil and Gas Association (NMOGA) Robert M. Gallagher is the chief executive of an association made up of 250 member companies, ranging from the largest major in the world to the smallest independent in New Mexico. The association promotes the welfare of the oil and gas industry and the conservation and orderly development of the oil and gas resources within the state of New Mexico. In 1998 Gallagher was appointed by President Clinton to serve as a principal advisor for oil and gas to U.S. Secretary of Energy Bill Richardson. Mr. Gallagher is a leader on the national level for the oil and gas industry, providing input to the Bush administration's task force concerning the development of a national energy policy. Mr. Gallagher graduated from New Mexico State University with a bachelor's degree in criminal justice. He holds a degree with honors from New Mexico Military Institute.

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Norman Gaume has served as director of the New Mexico Interstate Stream Commission, New Mexico's water planning and development agency, since 1997. The Commission's responsibilities include investigation, development, conservation, and protection of New Mexico's water resources and stream systems; interstate stream compacts administration; resolution of interstate and federal water resources issues affecting state water resources; and management of New Mexico's regional water planning program. Previously, Mr. Gaume managed the city of Albuquerque's Water Resources Division from its creation in 1990 until 1997. Mr. Gaume is a New Mexico native and a registered professional engineer. He has a B.S. in electrical engineering and an M.S. in civil engineering from New Mexico State University.

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Pat Goodman has spent most of his career working in power plants; he has served more than 29 years at Public Service Company of New Mexico (PNM). As vice president of generation, construction, and operations, Goodman is responsible for the operation of all of PNM's power plants and also oversees the construction of its new facilities. As a part of these duties, he also directs the work of PNM's environmental services group. Pat graduated from the University of New Mexico with a degree in electrical engineering.

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Laird Graeser is currently a Fulbright scholar lecturing on tax policy and public administration at Urals State Technical University, Ekaterinburg, Russian Federation and other universities in the Urals area of Russia. From December 1986 to September 2001, he was chief economist for the New Mexico Taxation and Revenue Department, specializing in revenue estimating and tax policy development and analysis.

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Grant Hammer has worked at the Lybrook facility since 1995. He and his staff are responsible for the up-keep, accuracy, and efficiency of all process controls, rotating equipment, and emergency systems. They also operate the facility, load trucks, and do administrative paper work, and they are required to be in strict compliance with all regulatory agencies and programs such as O.S.H.A., D.O.T., and the Williams System Integrity Plan.

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Jim Hannan currently serves as the chair of the Rio Grande Chapter, Sierra Club. The chapter represents the entire state of New Mexico and El Paso, Texas. In New Mexico the club is an active participant in legislative and regulatory issues affecting the environment, including mining, energy, and water. Jim, a CPA, works at the Santa Fe Community Housing Trust, a nonprofit affordable housing provider. He has been active in the Santa Fe Area Homebuilders Association Green Building Committee, working on issues of energy efficiency, indoor air quality, and water conservation.

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Steve Henke has worked for the Bureau of Land Management (BLM) since 1976 as a range conservationist, branch chief, assistant district manager, and field office manager. From 1998 to 2001 Henke was executive director and BLM's regional coordinator for Southwest strategy in Arizona and New Mexico. He is the author of the Rio Puerco Watershed Act. Henke has a B.S. in range science from New Mexico State University.

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Mark Hiles has worked as an environmental professional in the uranium industry (for 14 years) and in the coal industry (for 10 years). He served for 8 years as environmental systems manager for Lee Ranch Coal Company, and 7 years as coal subcommittee chairman for the New Mexico Mining Association. Mark has a B.S. in agriculture from New Mexico State University.

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Gretchen Hoffman has been a coal geologist at the New Mexico Bureau of Geology and Mineral Resources for 21 years. Her work experience includes field mapping in west-central New Mexico, running a drilling program for a 3-year coal quality evaluation study in the San Juan Basin, and many coal resource evaluation studies, primarily in the San Juan Basin. Gretchen is the New Mexico Bureau of Geology's representative on the Coal Surface Mining Commission. Her other research interests include industrial minerals associated with coal, such as humates, clinker, and fly ash. She received her B.A. from Adams State College and M.S. from the University of Arizona.

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Russell Huffman is plant manager of the 1,800 megawatt San Juan Generating Station near Waterflow, New Mexico. The station is an ISO-14001 certified facility and is a charter member of the federal Environmental Protection Agency's Environmental Performance Track Program. Russell has been with PNM since 1979 and has held a variety of positions at San Juan, which is the seventh-largest coal-fired generating station in the western United States. He is a member of the Generation Council and the Target Advisors Group of the Electric Power Research Institute.

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Bob Jenks has worked for the State Land Office since 1993 when he was appointed assistant commissioner. In that capacity he has the opportunity to advance natural and cultural resource conservation on state trust land through policy development and program implementation. His responsibilities include working with the exceptional professional staff at the State Land Office to further its natural resource management, environmental reclamation, archaeological, and technology development programs in pursuit of the agency's mandate of providing financial support for education in New Mexico. He also administers its agricultural leasing, rights-of-way, and records management programs. Before joining the State Land Office, Mr. Jenks worked for the Department of Game and Fish as a conservation officer, biologist, project manager, and assistant chief for their Habitat Environment and Lands. He is a graduate of New Mexico State University with bachelor's and master's degrees in wildlife science.

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Robert Lee is director of the Petroleum Recovery Research Center (PRRC) and part-time associate professor in the petroleum and chemical engineering department where he was a full-time professor before his appointment to the PRRC and department chair from September 1994 through 1997. Since 1999 he has served as New Mexico Oil Conservation Commissioner and was last year's recipient of the New Mexico Oil and Gas Association's Pete Porter Award. Dr. Lee's specialty lies in the study of natural gas, and his research interests center on studying problems associated with water coning, produced water purification, hydrates, stress-dependent permeability, and high-velocity gas flow. He is co-author of the book *Natural Gas Engineering: Production and Storage*. He is program chair for the Roswell section of the Society of Petroleum Engineers and is a member of AIChE. Lee earned M.S. and Ph.D. degrees in chemical engineering from Oregon State University and the University of Michigan, respectively.

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Dave has been an environmental geologist at the New Mexico Bureau of Geology and Mineral Resources since 1980. His work has focused on a great variety of topics, including: impacts of surface and subsurface mining; shrinking, swelling, collapsing, and corrosive soils; behavior of arroyos; geology of archaeological sites; movement of contaminants in the shallow subsurface; faulting, earthquakes, and earthquake education. He has been involved in geology outreach for teachers and students, has worked as a geologist for Southwest Institute, as a sabbatical replacement at Washington State University (1976-1978), and as a seasonal interpreter for the National Park Service. Dave holds a B.S. from Beloit College (anthropology and geology), and an M.S. and a Ph.D. in geology from the University of New Mexico.

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Lynda M. Lovejoy was elected to a four-year term as commissioner of the newly created New Mexico Public Regulation Commission in 1999 and served as chairwoman of the commission from January to December 1999. Her previous work experience includes: 1) serving as (acting) executive director of the Navajo Skill Center located in Crownpoint, which is now known as Crownpoint Institute of Technology and is the first vocational-technical training institute of the Navajo Nation; and 2) serving as executive staff assistant to the Navajo Nation president with responsibility for coordinating issues and projects with federal, state, and local entities. Lynda is an enrolled member of the Navajo Nation. Lynda has a bachelor's degree in public administration from Northern Arizona University and an associate of arts degree in elementary education from the University of New Mexico branch campus.

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Amory Lovins, a MacArthur fellow and consultant physicist, has advised the energy and other industries for nearly three decades as well as the Departments of Energy and Defense. Lovins has published in 27 books and hundreds of papers; his work, often with co-CEO L. Hunter Lovins, has been recognized by the "Alternative Nobel"; Onassis, Nissan, Shingo, and Mitchell Prizes; the Happend Medal; and the Heinz, Lindbergh, Hero for the Planet, and World Technology Awards. The Lovinses founded and lead Rocky Mountain Institute ([www.rmi.org](http://www.rmi.org)), an independent, market-oriented, nonprofit applied research center, which spun off E SOURCE ([www.esource.com](http://www.esource.com)) in 1992 and in 1999 Hypercar, Inc. ([www.hypercar.com](http://www.hypercar.com)), which Amory Lovins chairs.

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Benjamin P. Luce is a physicist with Los Alamos National Laboratory and president of the New Mexico Solar Energy Association, an educational nonprofit organization. He is co-chair of the Coalition for Clean Affordable Energy, a policy-oriented nonprofit organization. Subsequent to completing a postdoctoral appointment at Los Alamos National Laboratory Luce remained in the Theoretical Division (T-7). His work at Los Alamos has been in the dynamics of nonlinear partial differential equations, with applications to nonlinear fiber optical pulse propagation, ocean circulation, microwave heating, and bioremediation. Since 1997 he has also conducted research on renewable energy, carbon sequestration, and alternative fuel synthesis. Luce received his Ph.D. in physics from Clarkson University in 1993.

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Jim Luther is currently the environmental manager for BHP Billiton, San Juan Coal Company, which includes La Plata and San Juan mines. He has been employed with BHP Billiton for 6 years. His previous employment includes 13 years as an environmental consultant for the mining industry and 5 years with the Wyoming Department of Environmental Quality (DEQ), Land Quality Division. Jim ultimately became the program manager at DEQ and was in charge of all coal and large non-coal mine permitting. Jim has 24 years experience in the mining environmental field. Jim graduated from the University of Wyoming with a bachelor of science in range management in 1978.

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Louise Martinez currently serves as bureau chief of the Energy Efficiency Programs Bureau in the Energy Conservation and Management Division of the New Mexico Energy, Minerals and Natural Resources Department. Ms. Martinez has served as program manager for transportation programs, including infrastructure development and alternative transportation, state coordinator for Clean Cities projects, the Institutional Conservation Program, and Small Schools Program and served as the department contract officer for several years. Ms. Martinez's work experience includes over twenty years in state government mainly in governmental accounting, contracts, and project management. Her areas of expertise include procurement, project monitoring, and state and federal regulations.

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Ginger is a senior economic geologist with the New Mexico Bureau of Geology and Mineral Resources. She began work with the bureau in 1980 as a minerals geologist specializing in uranium deposits. She has published over 150 articles on the metallic mineral resources of New Mexico, including best-selling maps of the gold and silver deposits of New Mexico. Her descriptions of the geology of New Mexico's state parks have become a regular feature in *New Mexico Geology*. Ginger is an energetic researcher in the field of alkaline magmatism, carbonatites, anorthosites, and A-type granites. Recently she was elected as an editor for the American Institute of Professional Geologists. She also was elected chairman of the steering committee for the Acid Drainage Technology Initiative group, which conducts research and disseminates technologies on acid drainage. She holds B.S. and M.S. degrees in geology from New Mexico Tech and received her Ph.D. in geoscience from the University of Texas at El Paso in 1993.

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On May 1, 2001, Rory McMinn was appointed to fill a vacancy on the Public Regulation Commission representing District 2. New Mexico's voters mandated the creation of the Public Regulation Commission by merging the former Public Utility Commission and the State Corporation Commission. Commissioner McMinn is the first commissioner who was not a member of either of the two preceding agencies. District 2 includes approximately the eastern third of the state. McMinn served two consecutive terms on the Chaves County Board of Commissioners. He has been very active in community and business affairs within Roswell and New Mexico since returning to the state in 1986. He has spent most of his career in oil and gas exploration; oil, gas, and refined product transportation infrastructure construction; telecommunications infrastructure build-out; and specialty metal fabrication and manufacturing. Commissioner McMinn was educated in the Roswell, New Mexico, and Midland, Texas, public school systems and graduated from West Texas State University (now West Texas A & M) with a B.B.A.

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Dave Melton is president of Diversified Systems Manufacturing (DSM), a renewable and distributive energy consulting firm, located in Albuquerque, and he is co-owner of Sacred Power Corporation, a renewable energy manufacturing and installation firm. DSM was created in 1997 to assist the Pueblo of Laguna in its pursuit of diversification of business ventures into the renewable and energy efficiency industry. Mr. Melton was elected vice-chair of the newly created Rebuild Central New Mexico, the local energy efficiency support organization sponsored by the U.S. Department of Energy. Mr. Melton has also been appointed to the Pueblo of Laguna Utility Authority Board representing his home village of Paguete. In addition, Mr. Melton is a member of the New Mexico Solar Industry Association, the New Mexico Solar Energy Association, and the Interagency Advanced Power Group. Mr. Melton is an enrolled member of the Pueblo of Laguna. He received his B.A. in economics from the University of New Mexico and has over 30 hours of graduate study from UNM's School of Public Administration.

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Jim has lived in New Mexico since 1981. Before state service he worked in cultural resource management and conducted archaeological investigations throughout New Mexico. Between 1985 and 1994 he worked for the Historic Preservation Division, Office of Cultural Affairs on archaeological and historic preservation issues statewide. In 1994 Jim moved to the Mining and Minerals Division, Coal Reclamation Program, and he has been program manager since 1998. Jim has an M.A. in anthropology from the University of New Mexico.

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William C. Olson is a hydrologist with the New Mexico Oil Conservation Division in Santa Fe, where he is responsible for the investigation and remediation of oil field related ground-water contamination. He received his B.S. in geology and M.S. in hydrology from the New Mexico Institute of Mining and Technology.

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Bill Papich is a former newspaper reporter, television reporter, and freelance writer who last year began working as the community relations specialist for the Farmington Field Office of the Bureau of Land Management.

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John moved to New Mexico in 1981 and has worked for a number of private and government organizations whose focus is the management and protection of natural resources. John presently is a program manager for the Mining and Minerals Division and is responsible for the development of several publications relating to New Mexico's extractive minerals industry. He attended the University of Wisconsin in Madison and graduated with degrees in geology and history.

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Greer currently directs the publications program at the bureau. His experience includes seven years as a geologist working in the oil patch, ten years with the National Park Service, and four years as managing editor at Grand Canyon Association. His career has involved teaching, writing, and field work throughout North America. He is a member of the Geological Society of America and serves on the board of directors of the Publishers Association of the West. He holds a B.A. and an M.A. in geology from Washington University in St. Louis.

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James Ray has worked for Public Service Company of New Mexico (PNM) for 20 years. His work experience includes many years in human resources and labor relations. In the last 7 years, James has managed the administrative support departments for the generating facilities within PNM. These departments include safety, employee training, human resources, procurement, warehousing, accounting, and business IS systems. James received his B.B.A. in management from New Mexico State University.

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Paul Saavedra joined the Water Rights Division of the Office of the State Engineer (OSE) in 1988. He reviews and processes water-rights applications and supervises the administration of water rights throughout the state, and he acts as an expert witness in water-rights administrative and court hearings. Between 1978 and 1988 Paul worked in OSE's Design and Construction Section reviewing the plans and construction of dams and ditches, inspecting dams throughout the state, coordinating the rehabilitation of ditches, and assessing flood damage to water facilities. Paul received a bachelor of science in civil engineering in 1978 from the University of New Mexico.

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Mr. Sardella co-founded the Southwest Energy Institute in 1998 to research and promote policies that encourage investment and growth in micropower technologies. As a director of the institute, he has advised governmental and private organizations on energy policy matters, including the New Mexico Legislature, Public Regulation Commission, and State Energy Office, as well as the Santa Fe Board of County Commissioners and city council, and the New Mexico Solar Energy Industries Association. Mr. Sardella maintains an engineering practice in Santa Fe. Working under a joint program of the New Mexico Energy Office and the U.S. Department of Energy, he presently advises local businesses on energy conservation,

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Patrick Scharff has been with Public Service Company of New Mexico (PNM) since 1996 where, in addition to managing PNM's distribution planning department, he has been responsible for all customer generation programs including net metering. He had PNM's lead technical responsibility for participating in the crafting of New Mexico's net metering rule. Before joining PNM Patrick was with Tucson Electric Power (TEP) where he managed the system operations and distribution services departments and created and managed TEP's energy conservation and load management department. Scharff received a B.S. and an M.S. in electrical engineering (1973) and an electrical engineering electric utility management degree (1974) from New Mexico State University.

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Peter Scholle has had a rich and diverse career in geology: 9 years with the U.S. Geological Survey, 4 years directly employed by oil companies (plus many additional years of petroleum consulting), 17 years of teaching at two universities, and now a career in state government at the New Mexico Bureau of Geology and Mineral Resources. His main areas of specialization are carbonate sedimentology and diagenesis as well as exploration for hydrocarbons in carbonate rocks throughout the world. He has worked on projects in nearly 20 countries, with major recent efforts in Greenland, New Zealand, Greece, Qatar, and the Danish and Norwegian areas of the North Sea. A major focus of his studies dealt with understanding the problems of deposition and diagenesis of chalks, a unique group of carbonate rocks that took on great interest after giant oil and gas discoveries in the North Sea. His career has also concentrated on synthesis of sedimentologic knowledge with the publication of several books on carbonate and clastic depositional models and petrographic fabrics. His wife and he have published many CD-ROMs for geology, oceanography, and environmental science instructors, and they currently are developing computer-based instructional modules and expert systems in carbonate petrography. Peter Scholle received a B.S. in geology in 1965 from Yale University. He continued his studies at the University of Munich on Fulbright/DAAD Fellowships and at the University of Texas at Austin. Scholle received M.S. and Ph.D. degrees in geology in 1969 and 1970 from Princeton University.

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Dipen Sinha has worked at Los Alamos National Laboratory since 1980. Sinha is presently leader of the ultrasonics applications team. His current interests are in the following areas: 1) ultrasonic-resonance-based material (fluid) characterization; 2) nondestructive characterization and evaluation of materials; 3) ultrasonics based sensors for a variety of applications; 4) biomedical instrumentation, sensors, and techniques; and 5) novel ultrasonic imaging technique for biomedical and geological applications. Sinha has been granted 12 patents and has six pending. He has over 60 publications in refereed journals on low-temperature physics, nondestructive testing, solid state physics, and instrumentation, and he is senior editor of *Handbook of Elastic Properties of Solids, Liquids, and Gases*, Volume IV, Academic Press (2001). Dipen Sinha received a B.Sc. degree in physics in 1970 from St. Xavier's College, Ranchi, India. He earned an M.Sc. degree in physics and a post-graduate diploma in industrial physics from the Indian Institute of Technology, Kharagpur, India, in 1972 and 1973. Sinha received a Ph.D. in physics from Portland State University, Oregon, in 1980.

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Wendy Soll's technical focus is in ground-water hydrology. Dr. Soll is involved in program development for energy and sustainable systems at the laboratory. Wendy is active in community outreach and education, and she is an associate editor of *Water Resources Research*. Wendy Soll has a B.S.E. degree in mechanical engineering from Princeton University and an M.S.M.E. in mechanical engineering and a Sc.D. in civil engineering from the Massachusetts Institute of Technology. She also received an M.B.A. from the University of New Mexico.

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Bill Standley came to Farmington in 1989 by way of Santa Barbara, California. In his 12 years of living in Farmington Bill has been actively involved in the community. Having retired after 31 years with Sears Roebuck & Company, Bill accepted the position of advertising director with the Farmington Daily Times. Bill was then hired as the general manager for Construction Supply Company, remaining there until he decided to run for public office. He was elected to the office of mayor in March 1998. He currently serves as Treasurer on the New Mexico Municipal League Board. He has also been appointed to the Community and Economic Development Steering Committee and the Information Technology and Communications Policy Committee for the National League of Cities. Bill was named the "Man of the Year" in 2000 at the Four Corners Conference for Professional Development in Farmington, and more recently he received the "Citizen of the Year" Award for 2001 from the Farmington Chamber of Commerce. Bill is a graduate from Stockton College.

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William J. Stone has 30 years of academic, industrial, and government-agency experience in various aspects of hydrology. This has included positions with the New Mexico Bureau of Mines and Mineral Resources, Newmont Gold Company, and the New Mexico Environment Department. He is currently hydrology task leader for the regional well program at Los Alamos National Laboratory. His research interests include geologic controls of hydrologic phenomena and the hydrologic cycle in arid lands. Dr. Stone is the author of many professional papers and the book *Hydrogeology in Practice—A Guide to Characterizing Ground-Water Systems*. William Stone holds B.S., M.S., and Ph.D. degrees in geology.

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In 1956 Frank hired on as a "ground-water geologist" with the U.S. Geological Survey in Albuquerque—he was fresh out of graduate school, Steve Reynolds was the new state engineer, and the '50's drought was in full swing. Since then he has taught hydrogeology and geology at New Mexico Tech; managed Environmental Impact Statement projects across the U.S. and Canada; been manager of hydrology on DOE's Uranium Mill Tailings Remedial Action Project; provided expert testimony on a half dozen Superfund hazardous-waste cases; been science advisor to State Engineer Tom Turney; been an instigator of, and active in, the Middle Rio Grande Water Assembly; and is now a senior outreach geologist/hydrologist with the New Mexico Bureau of Geology and Mineral Resources. He wants New Mexico to grow, but to keep looking like New Mexico—and

he is convinced that he's smarter about that now than when he first got here. Frank holds a Ph.D. in geology from the University of New Mexico.

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Harold Trujillo currently serves as bureau chief of the Energy Technology Bureau in the Energy Conservation and Management Division of the New Mexico Energy, Minerals and Natural Resources Department. Mr. Trujillo and his engineering staff are responsible for implementing the state government Energy Management Program, Public Facilities Energy Efficiency and Water Conservation Act, public school efficiency design standard, and U.S. Department of Energy grants on wind, solar, and building energy efficiency, and they were instrumental in getting the 1983, 1986, 1989, and 1992 Model Energy Codes adopted in New Mexico. The New Mexico chapter and Western USA region of the Association of Energy Engineers recognized him as "Energy Executive of the Year" for 2000. He holds a B.S. in mechanical engineering from New Mexico State University.

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