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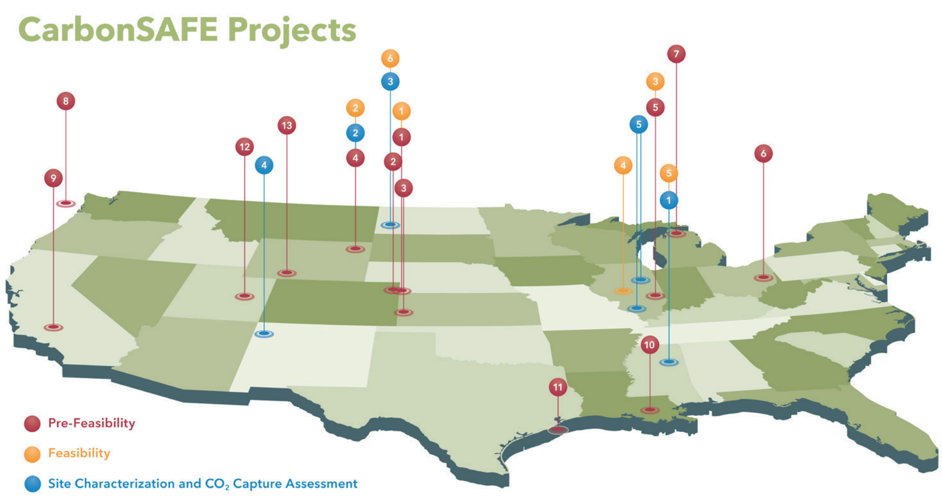
Carbon Sequestration and Hydrogen in New Mexico: Subsurface Resources for a Low-Carbon Economy

The United States is on the verge of a major paradigm shift in energy production, adding climate mitigation efforts and low-carbon alternatives to traditional carbon-based fossil fuels. New Mexico has the potential to be on the cutting edge of the new low-carbon economy because of our solar and wind energy, geothermal resources, natural gas reserves, underground storage potential, other infrastructure, and an experienced workforce. The state can take advantage of these resources in order to sequester greenhouse gases deep underground to prevent their emission into the atmosphere. Our natural gas resources and solar and wind energy farms position us to take advantage of the coming surge in hydrogen-based energy, which will power the electrical grid, heavy-duty motor vehicles, and fuel cells. These cleaner technologies will be vital to both reducing the nation's greenhouse gas emissions and providing sustainable revenue streams to power the state's economy.

New Mexico is rich in geologic resources and has a long history of extracting those resources from the subsurface. From mining to petroleum production, these materials have provided jobs and fueled the state's economy. Mining processes solid rocks to yield metals or other materials, whereas liquid and gas resources, such as oil and natural gas, are pumped from porous rocks deep underground.

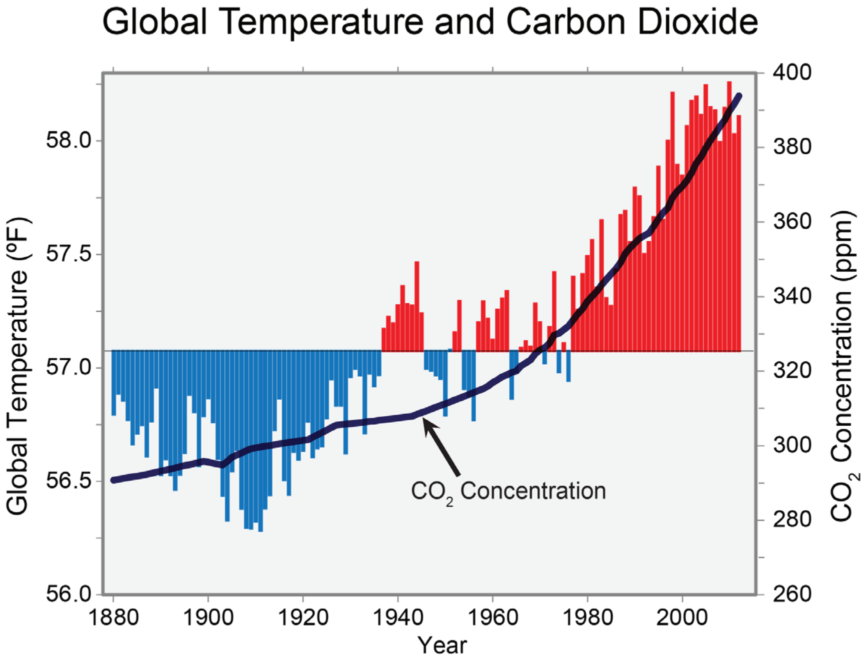
In response to the climate change crisis, there are now environmental and financial incentives to use New Mexico's subsurface resources in new applications beyond the traditional extractive techniques. Depleted oil and gas reservoirs and saline aquifers can be used to provide storage for greenhouse gases, through a processes called sequestration, to prevent their emission into the atmosphere. Hydrogen is poised to become a major source of clean energy for long-duration energy storage, grid reliability, and heavy-duty transportation. New Mexico is well situated to become a regional hub for the production and distribution of hydrogen due to our subsurface natural resources, access to alternative energy (solar, wind, geothermal), and existing infrastructure. The transition to a low-carbon and sustainable economy will require both short-term subsurface storage for hydrogen and long-term sequestration of carbon dioxide (CO_2). New Mexico can use its subsurface natural resources and existing infrastructure to contribute to our nation's transition to a low-carbon economy.



Carbon sequestration project areas. Source: U.S. Department of Energy National Energy Technology Laboratory, https://netl.doe.gov/carbon-management/carbon-storage/carbonsafe

Overview of Greenhouse Gas Emissions

Earth's surface temperature depends on the amount of solar energy that is absorbed relative to the amount reflected back into space. Greenhouse gases, both natural and introduced by human activities, absorb solar radiation absorbed by Earth's surface and prevent it from reflecting back into space. The result of this energy trapped in our atmosphere is a warming Earth. An increase in greenhouse gas emissions produces climate change that can be observed in



Increase in CO_2 concentration and temperature change over the past 140 years. Source: U.S. Global Change Research Program, www.globalchange.gov/browse/multimedia/global-temperature-and-carbon-dioxide

global temperature rise that manifests as increased regional aridification and more intense droughts. The three most significant greenhouse gases are CO_2, methane, and nitrous oxide.

Carbon dioxide created by combustion of fossil fuels (oil, gas, coal) is by far the most common greenhouse gas emitted from human activities. In the United States, 79% of greenhouse gas emissions are CO_2 from transportation, industrial activities such as cement and steel manufacturing, and fossil fuel-based (coal and natural gas) electrical power generation.

Reducing global greenhouse gas emissions and minimizing the effects of climate change will require a multi-fold approach that includes reducing the level and mitigating the impact of CO_2 emissions to the atmosphere. Mitigation through decarbonization alters activities so that CO_2 emissions are lessened, for example, by shifting from coal to solar power generation. Carbon capture and storage (CCS) of greenhouse gas emissions, a type of decarbonization, involves altering infrastructure so that greenhouse gases are directly captured before entering the atmosphere. Installing scrubbers on industrial and power-plant sources to remove CO_2 and other greenhouse gases from the waste stream and injecting those gases into the subsurface (i.e., carbon sequestration) is one form of CO_2 mitigation. Both reduction and mitigation are important for reducing carbon emissions.

Carbon Sequestration

Fossil fuel-powered vehicles and fossil fuel-powered electrical power generation are major sources of atmospheric CO_2. Although capturing gases from individual vehicles is impractical, gases from power plants and other industrial sources, such as cement manufacturing, can effectively be captured and permanently sequestered deep underground in geologic formations. The captured CO_2 is liquefied and pumped underground using injection wells that can be located onshore or offshore.

Carbon sequestration related to oil and gas activities has been common practice in New Mexico for decades. Since the early 1970s, oil companies have been using a form of sequestration called enhanced oil recovery (EOR). In an EOR operation, CO_2 is injected into oil reservoirs to push oil out of the pore spaces in mature oil fields. The oil is pumped to the surface, and the CO_2 is permanently sequestered underground. This technique is commonly used in the Permian Basin region of southeastern New Mexico and in other basins around the world.

Much of the natural gas produced in New Mexico must be cleaned of impurities before being sold to consumers. The impurities include toxic chemicals such as hydrogen sulfide (H_2S) and CO_2. These are removed from the gas stream and injected back into deep reservoirs via acid gas injection (AGI) wells. Such wells have been utilized in New Mexico since 2002. Currently, the only active AGI wells are in the Permian Basin.

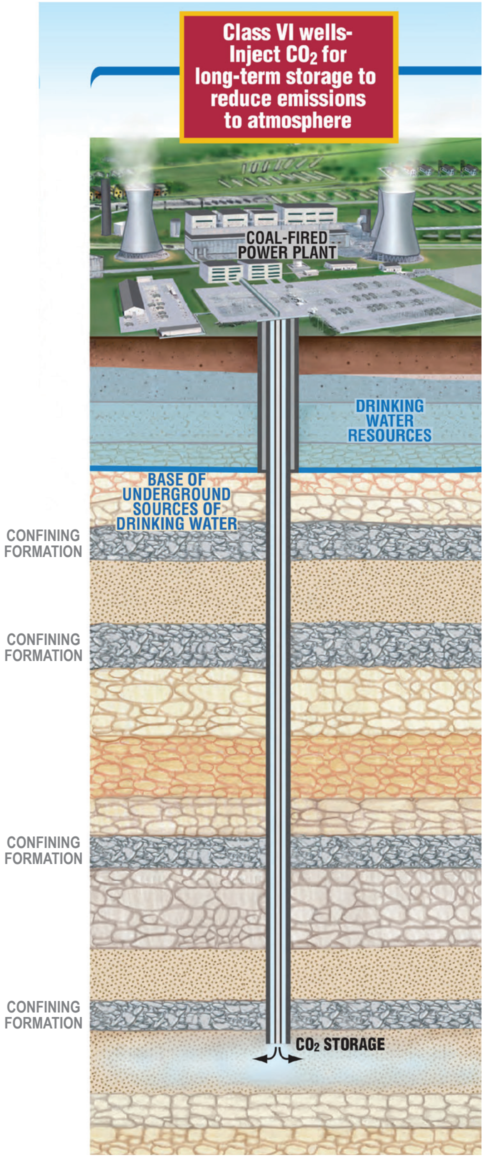
Sequestration wells are regulated at both the state and federal level. Currently, the Environmental Protection Agency (EPA) classifies wells used for geologic sequestration of CO_2 as Class II or Class VI. Class II wells are those that inject CO_2 and other gases, such as H_2S, as part of oil and gas activities. Class VI wells are those that inject CO_2 from large-scale operations, such as electrical power generation plants, where the goal is to permanently remove greenhouse gases from the atmosphere to help mitigate climate change. Class VI injection projects are permitted by the EPA except for in North Dakota and Wyoming, where permitting is controlled at the state level. The EPA process of permitting Class VI wells considers environmental and societal factors as well as technical components of the sequestration system for the life of the project.

The technical components of site evaluation for storage include evaluation of reservoir characteristics, seal capacity of overlying and underlying rock, reservoir water salinity, regional and local faulting and seismicity, and preexisting wells. In addition to the site evaluation, the project construction, operation, testing, monitoring, and site closure are all regulated for the life of the project. For a reservoir to be considered a good candidate for CO_2 storage, it has to have adequate capacity to store the needed volume of gas as well as competent sealing rock units above and below the injection zone.

A storage reservoir can be defined by the physical properties of porosity and permeability, which, along with reservoir thickness and areal extent, ultimately determine how much CO_2 may be sequestered.

Carbon Sequestration in Basalt Studied

The New Mexico Bureau of Geology and Mineral Resources is one of three collaborators on a $1.2 million Department of Energy grant to study a novel CO_2 sequestration technique that could permanently store carbon in basalts. When CO_2 is pumped into certain high-Ca and high-Mg rocks, such as basalt, the carbon may react with the Ca and Mg to form carbonate minerals, a process known as carbon mineralization. Unlike traditional sequestration techniques, the mineralized carbon does not leak out of the rock. Researchers will look at the chemistry and mineralogy of New Mexican basalts, and perform small-scale tests using this new sequestration technique.



Schematic diagram of carbon dioxide sequestration. Source: U.S. Environmental Protection Agency, https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide

Porosity is the amount of void space in a volume of rock. Permeability is the ability of a fluid or gas to move through a rock, and is largely controlled by the connectedness of the pores. The higher the porosity and permeability of a potential reservoir rock, the more CO_2 can be stored in it. In addition to these factors, the sealing capacity of the rocks surrounding the reservoir determines how well the CO_2 will be trapped in the reservoir and prevented from leaking into nearby rocks. The rocks providing the seal must have very low porosity and permeability and should not be fractured or faulted in any way that would allow CO_2 to escape into other overlying rocks. Thus, geologic faults in the area of the site must be fully characterized because faults provide a potential leakage pathway out of the reservoir. To protect usable water, regulations prevent CO_2 from being injected into reservoirs that have the potential to be used for drinking water or agriculture in the future. All active water and petroleum wells must be isolated from the potential sequestration reservoir, and abandoned wells must be properly plugged so they do not provide a pathway for leakage.

Economic Drivers Behind Carbon Dioxide Sequestration

The United States Income Tax Regulation section 45Q specifies the tax credits that can be claimed by companies for carbon sequestration. The 45Q was first created by the Energy Improvement and Extension Act of 2008 and has been modified several times. Under the new Inflation Reduction Act of 2022, tax incentives to capture CO_2 increased for storage in geologic formations to $85/ton, with other incentives for other utilization and storage options. Under the 2022 changes to the tax code, a company can operate a carbon sequestration project and sell its 45Q credits to another entity. The Inflation Reduction Act also stipulates that permitting must be finalized in the next decade, with work on projects beginning by 2033. The 45Q updates in 2022 are driving the business of carbon sequestration. Many oil and gas companies with expertise in subsurface geology have assembled teams to evaluate carbon sequestration projects.

Beyond 45Q tax incentives, the federal government has encouraged carbon mitigation efforts by funding research at universities and national laboratories that partner with private companies for large- and small-scale sequestration projects. One such effort, the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative, was started in 2016 through the U.S. Department of Energy (DOE) and the U.S. National Energy Technology Laboratory (NETL). CarbonSAFE projects study and assist partners in the design and building of large-scale carbon sequestration projects in a four-phase process. Phases 1 and 2 study feasibility, Phase 3 characterizes site suitability, and Phase 4 funds construction of the storage facility. Through CarbonSAFE projects, New Mexico Tech (NMT), the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), the Petroleum Recovery Research Center (PRRC), and Sandia and Los Alamos National Laboratories have partnered with private companies to study the San Juan Basin's carbon sequestration potential.

New Mexico universities, research institutions, and national laboratories have also collaborated in the DOE-funded Carbon Utilization and Storage Partnership for the Western United States (CUSP). The CUSP program is a large-scale, multi-state initiative to address technical challenges in data collection, regional infrastructure, and technology transfer. The goal of the CUSP program is to accelerate onshore deployment of carbon sequestration technologies in the western United States.

Carbon Storage Projects in New Mexico

Efforts have recently been underway to reduce CO_2 emissions from power generation by closing fossil fuel-powered electrical generation plants. In New Mexico, the Escalante Generating Station in McKinley County closed in 2020, the San Juan Generating Station in San Juan County closed in 2022, and the Four Corners Power Plant near Fruitland, within the Navajo Nation, is slated to close in 2031. However, government grants and tax options are incentivizing the utilization of these plants by retrofitting them for carbon sequestration or by switching to cleaner energy sources such as hydrogen. Thus, these economically important power plants may continue to operate with the option of sequestering pollutants into underground storage.

The San Juan Basin of northern New Mexico and southern Colorado is a prolific oil and gas producing area, with nearly 100 years of exploration and production history. Its tens of thousands of wells provide a wealth of information about basin geology. The basin contains over 12,000 feet of layered limestone, sandstone, and shale formations below the surface. Most of the oil and gas production is from rocks that are less than 8,000 feet deep, and groundwater aquifers are typically shallow. Below the depth of oil and gas production and groundwater are several porous layers of sedimentary rock that could store significant amounts of CO_2. A $21 million project funded through the DOE CarbonSAFE program and private matching funds is currently studying the carbon sequestration potential of the basin.

The Four Corners area also contains large coal deposits with active mines. If carbon sequestration is viable in the San Juan Basin, there is potential for existing and recently closed power plants and adjacent coal mines to remain active while sequestering their emissions safely underground. This is particularly important for the region because the Four Corners area will benefit economically by keeping these power plants and mines open. In addition, oil and gas industry workers in the area provide a skilled workforce that is trained with many of the skills required for carbon sequestration operations, such as maintaining and monitoring sequestration/injection well fields.

Hydrogen—
A Clean Fuel of the Future

Hydrogen (H_2) is a colorless, odorless, non-toxic, highly combustible gas, and it is abundant, occurring in water, the atmosphere, and in organic compounds. To produce H_2, the bonds between the hydrogen atom and another element or compound must be broken. For example, breaking apart the hydrogen and oxygen in water (H_2O) creates H_2 and O. But the atomic bonds are strong, and splitting them requires energy. The production of H_2 is commonly described using a color spectrum based on the production pathway.

The cleanest method of H_2 production is by electrolysis powered by zero-carbon electricity, where an electric current splits apart water molecules. Green hydrogen is the cleanest electrolysis method and uses power derived from renewable energy sources, such as solar, wind, or geothermal, creating almost no greenhouse gases. However, if electrolysis is powered by fossil fuel-derived power, it can be responsible for more greenhouse gases than the steam methane reforming methods described below.

Natural gas reforming, also known as steam methane reforming, produces hydrogen from natural gas by using high-temperature steam to break the hydrogen bonds. This is a relatively old technology, and it currently produces about 95% of the hydrogen used today. Incorporating carbon sequestration would reduce the emissions, and this is referred to as blue hydrogen. If generated without carbon sequestration, hydrogen production through steam reforming is called grey hydrogen.

Gasification of coal or other types of biomass, known as brown and black hydrogen, has a larger greenhouse gas footprint than steam methane reformation. Hydrogen is produced by applying heat and pressure in the presence of air, oxygen, or steam to the coal, lignite, or other biomass. This produces a low-quality H_2 gas that must undergo another step of steam purification. Using carbon sequestration technologies to capture CO_2 from the various waste streams can decrease their greenhouse gas impact on the atmosphere.

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Greenhouse gas emissions for various types of hydrogen production. GHG = greenhouse gas, CCUS = carbon capture, utilization, and storage. Source: Global Energy Infrastructure, https://globalenergyinfrastructure.com/articles/2021/03-march/hydrogen-data-telling-a-story/

Is Hydrogen the Fuel of the Future?

As currently used in vehicles, hydrogen fuel cells produce no greenhouse gases because they are powered by an electrochemical reaction rather than by combustion. The only tailpipe emission is water—a valuable resource in New Mexico—although emissions from hydrogen production must be accounted for. With the exception of long-range, heavy-duty trucks, most vehicles can be electrified by existing EV technology more efficiently and cost-effectively compared to using hydrogen. Scaling up fuel cell technologies from motor vehicles to planes, ships, and large-scale power generation will require an enormous expansion of H_2 production, development of new fuel cells, and extremely expensive infrastructure improvements. At present, our resources for reducing light vehicle emissions are best used to continue building out a nationwide charging network for EVs.

Another direction for H_2 power generation is the construction of power plants that use a mixture of H_2 and natural gas. The Long Ridge Energy Terminal in Ohio recently became the first power plant in the nation to take such a fuel mix. Its turbine can be powered by up to 20% H_2. However, this only reduces emissions partially due to the fact that hydrogen has approximately one-third the volumetric energy density of natural gas, so more blended gas has to be burned to achieve the same power output. In the future, the plant could continue to lower its carbon footprint by using carbon sequestration technologies to capture the CO_2.

One of the critical barriers to widespread usage of H_2 is storage. With surface storage containers, using H_2 as an alternative fuel helps manage the intermittent nature of renewable energy sources like wind and solar power, but these surface containers usually store a limited amount of H_2. Therefore, to meet the goals of the new H_2 energy economy, another storage option has to be found.

Like CO_2 sequestration, H_2 would benefit from large-volume subsurface storage systems. As hydrogen hubs spread across the United States, it will become critically important to store excess hydrogen safely and securely, with no explosivity risk or leakage potential. Hydrogen has different physical and chemical properties than CO_2, so it reacts with subsurface materials differently, and these differences are a topic of ongoing research. Also, underground H_2 storage will require rapid access to stored, off-peak-produced hydrogen during periods of peak demand, and the reservoirs and seals will have to be structurally sound to allow cyclic injection and withdrawal of the H_2 gas.

Carbon sequestration and hydrogen production and storage are technologies that could contribute to a sustainable economy in New Mexico. The impacts on local communities and the environment are major factors that must be considered as low-carbon alternatives are added to the existing carbon-based fossil fuel economy. With thoughtful application, New Mexico has the potential to be a leading state in the transition to a low-carbon economy by building upon its strong history of natural resources use.

Luke Martin and Dana Ulmer-Scholle

Luke Martin is a senior petroleum geologist at NMBGMR. Dana Ulmer-Scholle is a research scientist at the Petroleum Recovery Research Center at New Mexico Tech and adjunct geologist at NMBGMR.

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Bureau News

Mark Mansell (1961–2023)

Mark Mansell
Photo by Dana Ulmer-Scholle

Our longtime GIS analyst Mark Mansell passed away unexpectedly in April. Mark was hired as a full-time employee in 1996. He had previously worked for the Bureau of Geology as a student while pursuing a Bachelor of General Studies, which he completed in 1995, followed by a Bachelor of Basic Sciences in 2001. His GIS work at the bureau focused on creating maps and analyzing spatial data, and he was a pioneer in the development of digital geologic maps in New Mexico. Although Mark's job was office based, he loved field work, and enthusiastically participated in field projects and New Mexico Geological Society field conferences. Mark's dogged determination to get things done is well summed up in this quote by Thomas Edison from his email signature: "I have not failed. I've just found 10,000 ways that won't work."

Earth Science Achievement Awards

Dennis McQuillan
Photo by Katie Bauer

The annual New Mexico Earth Science Achievement Awards honor two recipients, one for "outstanding contributions advancing the role of earth science in areas of public service and public policy" and the other for "outstanding contributions in advancing earth science research and education." Nominations are always welcome and should be forwarded to the director of the NMBGMR.

The service/policy award went to retired New Mexico Environment Department (NMED) scientist Dennis McQuillan during a ceremony in the state capitol. McQuillan graduated from the University of New Mexico in 1978 with a BS in geology and minors in chemistry, mathematics, and physics. At NMED, he worked to establish new water regulatory frameworks and programs advancing health and safety through citizen engagement and education. His background in geology served him well as he became deeply involved in public health, civil and sanitary engineering, microbiology, and public relations. After retiring in 2020, he continued to serve as an expert witness for the state. Regrettably, Dennis McQuillan passed away on April 11, 2023.

Kent Condie

The research/education award went to Professor Kent Condie in recognition of his 44-year academic career in the Earth and Environmental Science Department at New Mexico Tech. Dr. Condie is an expert in the geologic evolution of Earth, and is the top-ranked scholar at New Mexico Tech based on h-index and citations. In 2018, he received the Geological Society of America's highest research honor, the Penrose Medal. Dr. Condie has taught and mentored many students, some of whom have spent their subsequent professional careers in New Mexico. After retiring in 2004, his geologic research has continued.

Water Data Workshop Hosted by Bureau

The annual New Mexico Water Data Initiative Workshop was convened by NMBGMR staff at New Mexico Tech in May. The workshop connects scientists and government professionals involved in the effort to better quantify the state's water resources, as mandated by the Water Data Act of 2019. The various state agencies are tasked with developing a user-friendly data portal to guide water-resource decision making. Participants discussed how their organizations are collecting, sharing, storing, and reporting information on groundwater levels, water wells, streams, rivers, weather, water quality, and historical data. Improved access to such data will aid water planning, especially as climate change decreases the availability of surface water and groundwater.

Consortium Receives National Science Foundation Engines Award

New Mexico Tech is a partner in a project awarded $1 million from the NSF Engines program. Focusing on sustainable energy resources and workforce development, the consortium—known as the Permian Energy Development Laboratory—will attempt to help diversify the Permian Basin's long-term economic sustainability. Dr. Nelia Dunbar, NMBGMR director and state geologist, noted that the project will be great for New Mexico because the research will focus on supporting communities through the ongoing energy transition by encouraging public-private partnerships in energy research and the evolution of workforce capabilities.

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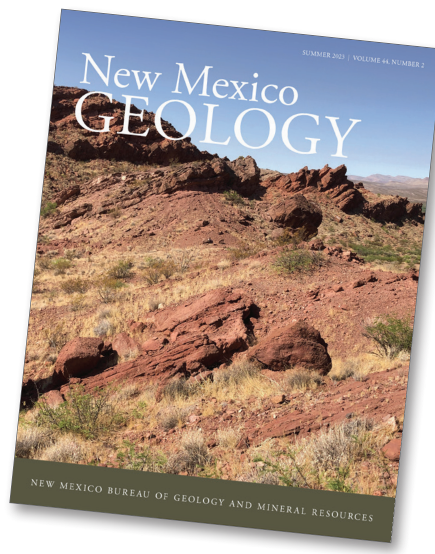
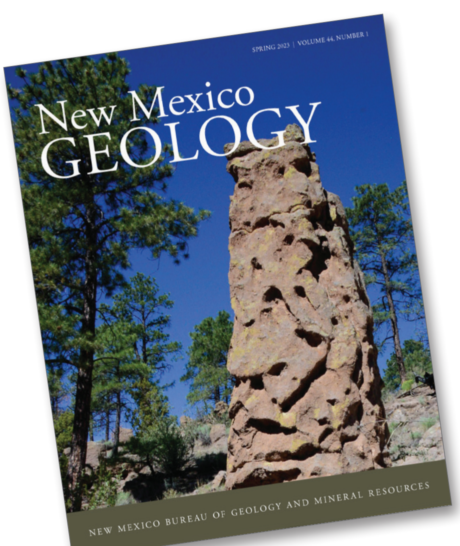
New Publications



New Mexico Geology, Volume 44, Number 2
San Diego Mountain: A "Rosetta Stone" for Interpreting the Cenozoic Tectonic Evolution of South-Central New Mexico

For more than 65 years, geologists working in southern New Mexico have recognized that unconformities, volcanic and sedimentary rocks, and structures exposed at San Diego Mountain and in the Tonuco uplift of northern Doña Ana County are keys to understanding the Cenozoic geologic history of the region. Combined with outcrops from neighboring mountain ranges, these outcrops provide a seemingly continuous stratigraphic record of Cenozoic events. Also revealed by these extraordinary outcrops is the nearly 30-Myr-long, surprisingly complex evolution of the Rio Grande rift in south-central New Mexico. Available for free download: **https://geoinfo.nmt.edu/publications/periodicals/nmg/backissues/home.cfml?Volume=44&Number=2**



New Mexico Geology, Volume 44, Number 1
The Goblin Colony: Spectacular Monoliths and Walls of Altered Bandelier Tuff South of the Valles Caldera, New Mexico

The authors of the featured article investigated the origin of eroded spires, fins, columns, steam pipes, and tabular ledges that developed in the 1.23 Ma Bandelier Tuff in a place known as Goblin Colony in the southern Jemez Mountains. Goblin Colony, so named because the eroded features look like goblin faces on moonlit nights, is a popular hiking destination. Using geologic mapping, an aerial drone survey, and petrologic and geochemical results, the authors determined that these features formed when relatively cool and gas-depleted Bandelier Tuff encountered surface water (springs, a pond, or a marsh) in the bottom of a wet paleocanyon. Available for free download: **https://geoinfo.nmt.edu/publications/periodicals/nmg/backissues/home.cfml?Volume=44&Number=1**