



*45th US Rock Mechanics / Geomechanics Symposium*  
 June 26 – June 29, 2011  
 The Westin San Francisco Market Street, San Francisco, CA



Volume 1, Issue 3 Spring 2011

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**45<sup>TH</sup> U.S. ROCK MECHANICS / GEOMECHANICS SYMPOSIUM**

Over 300 papers have been accepted for presentation at the 45<sup>th</sup> U.S. Rock Mechanics / Geomechanics Symposium to be held **26-29 June 2011** in San Francisco, California. In addition, four keynote addresses are planned as well as 12 opening presentations to kick off the 44 technical sessions.

Two technical tours are available. The first will explore the geological engineering aspects of the San Francisco Bay area. A later tour will visit the US Geological Survey facility in Menlo Park as well as stops along the San Andreas Fault.

Special events include a tour of the California Wine Country, a boat visit to Alcatraz Island, a bus tour of the highlights of San Francisco, a walking tour of the Golden Gate Bridge, dinner on the Waterfront's Pier 39, a walk through the Muir Woods National Monument and Sausalito, lunch in Chinatown, coffee on a North Beach Java Walk, and a special Dinner-Dance Cruise on San Francisco Bay.

The symposium will host an exhibition for companies and organizations to display and network with participants.

A block of hotel rooms has been reserved for symposium attendees at the Westin San Francisco Market Street. The Westin is located in the lively South of Market district, close to Union Square and the Financial District. Guests can walk to cable cars and trolleys that go to China-

town, Fisherman's Wharf, and the Alcatraz ferry. The San Francisco Museum of Modern Art is also nearby. The San Francisco and Oakland Airports are easily accessible from the hotel by train. The Westin has made rooms available to symposium delegates at a very favorable rate.

Further information on the symposium can be found at [www.armsymposium.org](http://www.armsymposium.org).



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**TECHNICAL SESSIONS**

- Topics include:
- Advancements in Laboratory Testing
  - Applied Deep Coal Mining Mechanics
  - Bridges and Underground Laboratories
  - CO<sub>2</sub> Sequestration
  - Compaction, Depletion and Sand Production
  - Discontinuous Deformation Analysis
  - DUSEL Rock Mechanics
  - Enhanced Geothermal Systems
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  - Injection Geomechanics
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  - Integrated Reservoir Characterization
  - Lab to Basin Scale Geomechanics
  - Mine Seismicity
  - New Frontiers in Rock Mechanics
  - Numerical Modeling for Excavation Design
  - Reservoir Characterization
  - Rock Mechanics for Mine Stability
  - Rock Mechanics in Cave Mining
  - Rock Mechanics in Underground Mining
  - Rock Mechanics Issues in Afghanistan
  - Rock Physics for Reservoir Characterization
  - Similarities & Differences in Shale Reservoirs & Seal Shales
  - Site Characterization
  - Stability of Rock Slopes

See **YOU** in **San Francisco**  
**Register TODAY!**



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## TECH Notes POLICY Issues

### Geologic Sequestration of Carbon Dioxide: A Condensed Survey of Assessments, Research and Demonstration Programs

By Wolfgang R. Wawersik, ARMA Fellow

#### Recognition of Problem

After lengthy discussion within the United Nations, excessive, worldwide emission of CO<sub>2</sub> was formally recognized with the publication of the Kyoto Protocol in 1997. By 2010 the Kyoto Protocol had been signed and ratified by 191 countries. It entails a commitment to reduce greenhouse gas emissions, capture anthropogenic CO<sub>2</sub> and transport it to places where it can be put to industrial use, fixed through mineralization, safely stored in geologic formations, or injected into the oceans. Given what appears to be abundant storage volume and geologic precedent, CO<sub>2</sub> storage in geologic formations is universally favored, partially helped by experience gained in the industrial use of CO<sub>2</sub> for enhanced oil recovery (EOR).

Long-term geologic storage of CO<sub>2</sub> has been advocated and evaluated by at least three major international organizations; (1) the Intergovernmental Panel on Climate Change (IPCC), which was endorsed by the UN General Assembly and became co-winner of the 2007 Nobel Peace Prize; (2) the [International Energy Agency \(IEA\)](#), IEA Greenhouse Gas R&D Program; and (3) the ministerial level [Carbon Sequestration Leadership Forum \(CSLF\)](#), established in 2004 and representing 24 countries and the European Commission.

Starting with recommendations by IPCC, IEA, and CSLF, many countries developed separate national or state/province-level programs for CO<sub>2</sub> sequestration executed by governmental organizations, collaborations between government, industry, and universities; and also by private organizations. Major US activities are planned, funded, and directed by the [National Energy Technology Laboratories of the Department of Energy \(NETL\)](#) and supported by National Laboratories and fundamental research in the DOE Office of Basic Energy Sciences. In turn, CO<sub>2</sub> storage programs in Canada appear to be led by the Alberta Energy and Utility Board and the Alberta Geological Survey, while the [Cooperative Research Center for Greenhouse Gas Technologies \(CO2CRC\)](#) is prominent in Australia and New Zealand. CO2CRC is described as a joint venture between industry, universities and other research bodies from "Australia and New Zealand, Australian Commonwealth, State and international government agencies."

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Questions or comments? Email us at [newsletter@armarocks.org](mailto:newsletter@armarocks.org)



## ANNOUNCEMENTS

### ARMA Board Elects New Officers

At its recent meeting in March, the ARMA Board of Directors elected Mark Zoback from Stanford University to succeed Azra Tutuncu as president of ARMA. Antonio Bobet, professor at Purdue, was elected vice president; Tony Iannacchione from the University of Pittsburgh will serve as secretary; and Bill Dershowitz from Golder Associates was reelected as treasurer. Zoback has served as ARMA vice president and helped organize the 2008 Rock Mechanics Symposium in San Francisco.

### Mark Zoback Elected to NAE

ARMA member Dr. Mark Zoback was recently elected to the National Academy of Engineering, a recognition that is one of the highest professional honors accorded the engineering profession. Zoback was cited for his work in advancing the application of geomechanics to oil and gas production, geothermal stimulation, and carbon dioxide sequestration. He joins other ARMA members in NAE: Bernard Amadei, Charles Fairhurst, Dick Goodman and Sid Green.

### ASTM International Recognizes Hamid Nazeri

ARMA member, Hamid Nazeri, of Advanced Terra Testing, Lakewood, Colorado, will receive the Richard S. Ladd Standards Development Award at a meeting of the Committee on Soil and Rock, ASTM, in Anaheim, California, on 13 June 2011. This award is presented in recognition of Nazeri's extensive effort in preparing the ASTM standard "Test Method for Laboratory Determination of Abrasiveness of Rock Using the CERCHAR Method."

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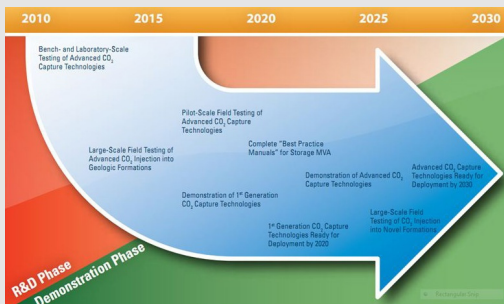
**TECH  
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University initiatives are headquartered, for example, at Stanford University ([Global Climate & Energy Project](#)) and MIT ([MIT Energy Initiative](#)). [RECS \(Renewable Energy Certificate System\)](#) might be the smallest entity- an alliance of experts involved in teaching and training of staff involved in CO<sub>2</sub> storage developments. A new journal at [carboncapturejournal.com](#) is dedicated specifically to carbon capture and storage issues. Taken together, the number of bodies and activities involved represents massive intellectual and financial efforts devoted to research, technological developments, and demonstrations. Most recent activities in the larger organizations appear to emphasize field demonstrations. Two of the older and best known field demonstrations are the CO<sub>2</sub> injections into a saline aquifer above the Sleipner oil field, Norway and the combined application of EOR and CO<sub>2</sub> storage in the Weyburn-Midale oil reservoir in Saskatchewan, Canada.

**Issues, Program Plans and Implementations**

A broad overview of scientific, technical, economic, legal, and regulatory issues plus public acceptance is available as a PowerPoint presentation by Stefan Bachu at a [2006 Yale University Forum on Carbon Sequestration](#). Greater details concerning the status of international carbon storage activities and plans into the 2020s are described in two excellent documents: the 2010 updates of [Technology Roadmaps of the Carbon Storage Leadership Forum \(CSLF\)](#) and the [National Energy Technology Lab of the US Department of Energy \(CCS-NETL\)](#).

A U.S. Department-of-Energy summary of goals and schedules and a time table is presented in Figure 1.



Left: Figure 1. CCS-NETL Research Development and Deployment Overview.

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**ANNOUNCEMENTS**

**ARMA Student Chapter Formation**

An inaugural ARMA student chapter has been established at Colorado School of Mines (CSM) in 2011, with 68 students joining. Former ARMA President and Professor at CSM, Azra Tutuncu organized the chapter with the support of Geomechanics Engineering and Research. **Congratulations, CSM!**

Other student chapters are under consideration. Discussions are currently underway with faculty at King Fahd University in Saudi Arabia.



ARMA CSM Student Chapter (above) at "Unconventional Geomechanics Lunch and Learn" hosted by Dan Moos and Baker Hughes.

**Distinguished ARMA Member Named 2011 Michel Award Winner**

ARMA's first president and current ARMA Fellow, Priscilla Nelson has been named the recipient of the American Society of Civil Engineering's Henry L. Michel Award for Industry Advancement of Research for 2011. This award recognizes and acknowledges leaders in the design and construction industry whose dedication and vision have provided cornerstones for improving the quality of people's lives around the world through research in design and construction. Nelson received her award at a gala event in April in Washington D.C.



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The scope of worldwide carbon storage programs is indicated by 32 past and present CSFL-recognized carbon capture and storage projects including a Coalbed Methane Technology/ CO<sub>2</sub> Sequestration Project in China, a Geologic Storage Assurance project in Salah, Algeria and Regional Carbon Sequestration Partnerships. U.S. commitment is suggested by NETL's use of \$100 million just to characterize a minimum of 10 geologic formations throughout the United States. Additionally, DOE is funding field tests under its Regional Carbon Sequestration Partnership Program, which involves injecting at least 1 million metric tons of CO<sub>2</sub> into geologic formations at each of several large-volume test sites.

At this stage, probably the most important focus areas in the CSFL and CCS-NETL Roadmaps are: (1) the characterization of geologic formations in terms of storage capacity and long-term CO<sub>2</sub> containment potential, which applies equally to the dominant hosts for CO<sub>2</sub> storage: depleted oil and gas reservoirs, saline aquifers, salt caverns and unmineable, deep coal beds; (2) the integrity of traps and seals following CO<sub>2</sub> injection especially in depleted hydrocarbon reservoirs that have undergone multiple production and stimulation cycles; (3) trapping mechanisms, flow patterns, geochemical and mechanical interactions with formation rocks including fracturing; (4) verification of numerical methods to understand, interpret, and predict the long-term behavior and migration of CO<sub>2</sub> as a function of coupled

geologic, thermal, hydrologic, geochemical, and geomechanical conditions; (5) the establishment of credible data bases in order to conduct analyses to support #2 and required under #4; (6) instrumentation and algorithms to characterize and monitor the fate of CO<sub>2</sub> and its hosts; and (7) knowledge and technologies to monitor and potentially counteract CO<sub>2</sub> leaks with failures of boreholes or natural (geologic) seals.

Experts, roadmaps, and related studies (for example, [Bachu, S. and Stewart, S. Suitability Analysis; BES Assessment of Research Needs](#); Wawersik, W.R., et al., *Advances in Geophysics*, Vol. 43, 97-177, Academic Press, 2001) emphasize that the suitability of geologic formations and the fate of injected CO<sub>2</sub> are profoundly influenced by the properties of CO<sub>2</sub>. Below the critical point at 31.1°C and 7.38 MPa, carbon dioxide behaves either like a gas or a liquid. Above the critical point, CO<sub>2</sub> will be in a supercritical state having some of the properties of a liquid (e.g., density) and a gas (e.g., viscosity) and is not miscible with water. Other relevant properties of CO<sub>2</sub> are its solubility in saline water, affinity to coal, and its ability to act as a solvent for some hydrocarbons. It follows that depending on local or regional geothermal gradients, the transition of CO<sub>2</sub> from gaseous to supercritical state will impact injection parameters and the storage capacity of candidate formations. At depths greater than about 800 m, the properties of the supercritical CO<sub>2</sub>, including density, viscosity, miscibil-

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## ANNOUNCEMENTS

### Richard Gray Recognized for Alumni Achievement

ARMA member Richard E. Gray received a 2010 Alumni Achievement Award from Carnegie Mellon University for his accomplishments and devotion to the practice of geotechnics, geotechnical engineering and engineering geology.

Gray's exceptional work has made him one of the world's foremost experts in land subsidence caused by mining operations, disposal of expansive shale and slag, and mine reclamation. A registered geologist in 14 states, he has worked extensively throughout the country, in addition to consulting on mine subsidence in Alberta, Vancouver Island, and in New Zealand; on steel-mill foundations in Iran; and on mine fires in India.

Over the years, Gray has held the chairmanship or presidency in all three of the United States' engineering geology organizations, and has selflessly given his time to the benefit of local, state, and national levels of such organizations as the American Society of Civil Engineers.

For his longstanding service, he received the Award of Merit from the American Society for Testing and Materials, among a host of other high honors. Gray co-founded DiGioia Gray & Associates in 2005, continues to contribute to the field, and helps to educate the next generation of engineering geologists.



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ity, etc., will affect gravity separation between CO<sub>2</sub> and water in aquifers and in oil and gas reservoirs containing water as well as other fluids. The low viscosity of supercritical CO<sub>2</sub> also tends to enhance flow channeling in heterogeneous and fractured formations, and it may alter the sealing capacities of wellbore seals and faults.

An expanded discussion in the CCS-NETL Roadmap states that the development of data bases for storage analyses is critical. Improved data bases will be built on carefully designed and executed field demonstration tests. However, the Roadmap also points to successful replacements of older, conventional dual porosity, dual permeability, and equivalent permeability approaches, etc., by multiphysics codes capable of simulating fully coupled processes including “flow through faults and fractures and contaminant rock deformation induced by fluid pressure.” It appears that these codes are sufficiently advanced to estimate “the possibility of leakage through an existing fault, as well as forecast the potential risk of CO<sub>2</sub> injection causing new faults or fractures to form.” The Roadmap does not mention the origin of these codes and whether they have been applied to and tested in history matches using hydrological, oil, and gas reservoir data.

### Dissemination and Synthesis of Results

The worldwide scope concerning geologic carbon storage offer enormous possibilities for research, technology developments, and field testing towards safe site

selections and openings. However, to accomplish this efficiently and effectively requires an unprecedented degree of coordination, communication, and synthesis. To start with, there is a need for a clearinghouse for information ranging from planning documents and assessments, such as roadmaps, down to the publications by individual investigators. Cognizant of the problem, DOE/NETL has created a large web-based repository holding documents and an excellent monthly newsletter. To the same end, in June 2009 the Australian Government established the [Global CCS Institute](#) with guaranteed funding for four years at 100 million \$au per year for the expressed purpose of sharing, i.e., disseminating knowledge, fact-based advocacy, and assisting projects. Such repositories should facilitate access to project information such as the 2002 injection of 290 metric tons of CO<sub>2</sub> into a depleted, well-characterized oil reservoir in southern New Mexico (Pawar, R.J., et al., *Environm. Geosci.*, Vol. 13, No. 3, 163-180, 2006). As of 2006, this comprehensive project (backed by lab tests, geophysical measurements, and numerical analyses) had produced significant, unexpected results that may merit reanalysis using the latest codes separately or connected to the planning of new demonstration tests elsewhere. ■



### IN MEMORIAM

**Jose Filomeno Teixeira Agapito**



1937–2009

Joe Agapito passed away unexpectedly on 25 November 2009 in Grand Junction, Colorado, at age 72. In the technical community, he is well known as the founder of Agapito Associates, Inc. (AAI). Joe was also an avid and generous supporter of

ARMA. He served on ARMA's first Board of Directors.

From humble beginnings in Fundao, Portugal, Joe attended Camborne School of Mines (U.K., '63), met his Scottish wife Veronica, and eventually moved his wife and daughter to the United States. Joe earned his M.S. degree in Mining Engineering from the University of Missouri, Rolla ('64), then his Ph.D. in Rock Mechanics and Mining Engineering from the Colorado School of Mines (Golden, Colorado '72). Joe worked with White Pine Copper Co. ('64-'68), Atlantic Richfield Company (ARCO Colony Oil-Shale Mine, '72-'74), then Golder Associates, ('76-'78).

His wealth of education, training and experience, coupled with a keen understanding of underground rock mechanics, prompted Joe to start AAI in 1978. The company is headquartered in Grand Junction, Colorado, with a satellite office in the Chicago area as well as a facility in Golden, Colorado. The company's reach is worldwide, providing a broad range of geomechanics services to the mineral and energy industries. The company holds a solid, highly regarded stature in the mining, petroleum and civil industry.

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## TECH Notes POLICY Issues

### The Future of DUSEL

By Derek Elsworth, ARMA Fellow and Member of the Executive Committee of DuRA

Since our last update at the ARMA 2010 symposium in Salt Lake City, much has happened with DUSEL (Deep Underground Science and Engineering Laboratory). In June of 2010 we were looking forward to the completion of the Preliminary Design Report (PDR) that would be then submitted to the National Science Foundation (NSF) by Spring 2011. But there have been a number of twists in the road since then – some surprising.

September 2010 saw the inaugural meeting of the DUSEL Users' Research Association (DuRA) – the new umbrella for the entire science community interested in performing experiments at DUSEL. This first meeting was at FermiLab (IL) and focused on the rollout of the first preliminary design of the laboratory. Given the positive reaction of the community, it was then engines full-ahead to meet the planned deadline for completion of the PDR by the end of 2010.

Concurrent with the final stages of the preliminary design, a National Research Council (NRC) committee was established to examine the merits of the science planned for DUSEL. This committee was first convened in December 2010 with presentations on the science questions to be addressed by DUSEL – including those most relevant for our community: biology, geoscience, and engineering (BGE). Those committee participants are James Tiedje (Biology), Steve Laubach, (Geoscience) and Charles Fairhurst (Engineering).

However, the independent evaluation to be provided by this group was clouded by prior reports from a subcommittee of NSF's National Science Board (NSB). That group was rumored to be withholding bridge funding that would allow the completion of the PDR and its ultimate submission to the NSB. It ultimately transpired that NSB was worried that the stewardship of such a major user facility by NSF was unprecedented and necessitated clarification of the role that DOE would play in its management. In essence this was a suggestion that DOE might better fill the role of principal steward of the project – one in which DOE was already vested in a number of planned experiments.

At the same time as the NRC review, the design of the facility was being completed. It was expected that both the PDR and the NRC reviews were still the principal components that would guide a decision of the National Science Board in either recommending or not recommending the project to Congress. However, this was not to be. The President's budget in February 2011 switched planned future funding for the completion of the DUSEL design from NSF to DOE to continue exploring the viability of DUSEL (Subsequently, a portion of this NSF funding was reinstated). This changed the situation little but did place the burden on DOE to assume stewardship of the project.

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**IN MEMORIAM** (continued)

**Jose Filomeno Teixeira Agapito**

Joe was a Fellow in the Institute of Mining and Metallurgy, England, and a member of AIME, SME, ISRM, and ARMA. The Society for Mining, Metallurgy, and Exploration (SME) recognized Joe for his distinguished service in 1993. His publications (over 40 in total), volunteer-spirit in professional organizations, and the success, longevity, and integrity of AAI's staff, all attest to Joe's visionary and entrepreneurial acumen. Joe's seminal innovations in the safety of huge 60'x 60' room-and-pillar mines, advances in applied *in-situ* stress measurements, and thoroughness in geotechnical studies made significant geomechanics contributions to the industry and government.

He is survived by his wife, mother, two children, and a granddaughter.

Joe was a true, compassionate gentleman and a very successful engineer-founder-executive, yet remained very modest. ARMA, his family and colleagues, and the geomechanics community will miss him.

<http://www.agapito.com>





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**ARMA  
News**

## 35,000 Reasons to Cheer

By Ahmed Abou-Sayed, ARMA Fellow and ARMA and SPE Board Member

ARMA members have 35,000 reasons to cheer. This is the number of ARMA papers downloaded from OnePetro, the SPE digital library, during 2010. ARMA currently has about 3500 papers included in OnePetro, out of the more than 106,000 total documents. ARMA members receive a discounted price for ARMA documents by providing their ARMA login information. ISRM joined OnePetro last year, expanding the collection of materials likely to be of greatest interest to ARMA members. For your information, OnePetro currently includes documents from 12 participating organizations, and an additional one – the Pipeline Simulation Interest Group – will be added in May. OnePetro will continue to grow both through the addition of more documents from existing societies, and as new societies are added. Many of the documents included in OnePetro were not previously available in digital format or online. In June, SPE will be modifying the search technology used in OnePetro. Expect to see a few changes in the search screens, as well as an improvement in the search results received. OnePetro will continue to evolve to become a more useful research tool for the E&P industry.

During 2010, more than 3 million papers were downloaded from OnePetro. Now, let us discuss how you would access OnePetro (see the ARMA link to OnePetro [http://www.armorocks.org/digital\\_library.html](http://www.armorocks.org/digital_library.html)). OnePetro offers a wide range of options for accessing the papers in the collection – pay as you go, which is great if you just need to buy a couple of documents. Individual subscriptions to OnePetro are available. They offer a discounted price by pre-paying for 25, 50, 100, or 200 documents (although they must be used within 12 months). Limited corporate subscriptions allow companies to pre-pay for a certain number of documents (from 300 to 10,000) that can be accessed by all employees (using corporate IP validation or other means). Finally, unlimited corporate subscriptions give all employees of a company unlimited access to materials from OnePetro. OnePetro also offers unlimited university subscriptions which are discounted 90% or more from corporate pricing, in order to support the education of professionals entering our industry. Corporate subscriptions are especially beneficial in countries where paying through the internet with a credit card is not an option – companies can set up a subscription and make one payment that will then provide validated access for their employees throughout the year.

Happy reading everybody and OnePetro to all of you. Cheers!



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Questions or comments? Email us at [newsletter@armorocks.org](mailto:newsletter@armorocks.org)



## The Future of DUSEL (continued)

So where is DUSEL now? The final version of the PDR was internally reviewed in March 2011 with a very complimentary outcome. The NRC science review is being completed. It is expected that both the design report and the NRC science review will be sent to NSF and passed directly through to DOE. Concurrently, DOE is examining the best pathway for its underground science program. This review is examining what facilities (Homestake, Soudan, SNOLab, or others) may best host the anticipated physics experiments.

So where does that leave our community? We are currently in a holding pattern. The BGE experiments planned for DUSEL are certainly as relevant today as they were a year ago. A recent review by NSF's GEO program has confirmed the relevance of the exploratory program to develop the design of some seven potential BGE experiments. However, to move ahead, we need to first know where such experiments could be completed, and this in turn, depends on the output from DOE's review of the siting of the various physics experiments – this should be complete in a few months. NSF continues to be an expected participant in supporting experiments at DUSEL, wherever that may be. The various proponents of potential experiments at DUSEL continue to work on experimental designs, convening regularly at professional meetings to share results and discuss synergies. This ongoing engagement contributes to our ability to make the case for the importance of BGE activities at DUSEL in contributing to the nation's well being in terms of energy security, sustainability and advances in sub-surface science and engineering.

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