

In this issue

President's Letter

Student Chapters

- 3 Overview
- 4 Design Contest
- 6 Research Competition
- 7 Photo Contest
- 10 Mentor-Student Event

Technical Committees

- 10 Overview
- 12 Underground Storage
- 26 Induced Seismicity
- 26 Hydraulic Fracturing
- 27 Tunneling
- 28 Drilling

ARMA LETTERS

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President's Greeting: How Can ARMA Better Serve You?

Gang Han, ARMA President 2021 - 2023

Dear ARMA Members,

The recent ARMA Board of Directors election resulted in four new members for 2021 – 2027: Richard Schultz, Tryana Garza-Cruz, Shawn Maxwell, and Gabriel Walton. In addition, the Board has appointed new officers for

2021 – 2023: Haiying Huang as Secretary, Doug Blankenship as Treasurer, Andrew Bunker as Vice President, and me as President. Congratulations to the new leadership.



A big round of applause is due for the distinguished service from the retiring Board members and officers: Laura Pyrak-Nolte, Loren Lorig, Maria-Katerina Nikolinakou, and Joe Labuz. ARMA is fortunate to have had such dedicated and professional leadership.

I deeply appreciate the trust and opportunity from the Board and ARMA members to further serve the organization. The encouragement from so many mentors, leaders, fellow members, and staff have helped me grow over the past two decades at ARMA. With your support and contributions, we will continue advancing our mission: to advocate for all aspects of rock mechanics and geo-engineering.

We are living in an extraordinary time with unprecedented challenges and opportunities. Similar to many other professional societies, ARMA has been affected significantly by the Covid pandemic and recent industry downturn. Our membership registrations fell by 40% from the pre-pandemic level while our in-person annual symposium had to be canceled for health and safety reasons.

Meanwhile, we are seeing tremendous interest in ARMA conferences, technical communities, student chapters, emerging

fields, and society activities — confirming the important role of rock mechanics and geomechanics in the energy industry, civil, mining, and other industries around the world.

Let me highlight a few of these accomplishments:

- In June, the first-ever virtual ARMA Annual Symposium had full-blown success technically, logistically, and financially, thanks to the relentless and tireless organizing committee. Over 600 participants from 40 countries shared their knowledge in 75 technical sessions, including a new focus on geothermal. In addition, the first panel of “Women in Rock Mechanics” highlighted the ongoing Board efforts to improve Diversity, Equity, and Inclusion (DEI) at ARMA. Meanwhile, attendees enjoyed virtual events and activities such as student competitions, committee receptions, music gala, culture night, rock photos, award ceremonies, and others.

- Over 160 registrants from 16 countries attended the 2020 International Geomechanics Symposium (formerly the ARMA Middle East Workshop). The 2021 series has attracted record-breaking abstracts from 47 international organizations in 20 countries. Over 100 authors will exchange their knowledge along with the three dedicated ARMA Fellows who will teach and train students and professionals.

- ARMA technical communities recently have experienced phenomenal growth. The Hydraulic Fracturing Community has grown to over 1000 members thanks to its biweekly online seminars; the Induced Seismicity Community membership doubled after kicking off regular webinars; the Drilling Mechanics and Engineering Community has grown significantly as well; Tunneling has attained new depth; and the Underground Storage and Utilization Community, our newest, has established strongholds in low-carbon arenas such as Carbon Capture and Sequestration (CCS). And the Board approved the formation

of a Discrete Fracture Network (DFN) Technical Committee in September, 2021.

- The number of ARMA student chapters has tripled since 2020, growing to 14 student chapters including four international universities. At the first ARMA Student Design Competition, over 40 teams from 29 schools worldwide participated with winning teams from Peru, Canada, and India.

Note: Detailed reports on Student Chapters and Technical Committees are the focus of this issue.

More initiatives and exciting developments are underway. ARMA needs your help to address ongoing challenges, identify improvement opportunities, and grow into a more technological, innovative, diverse, and transparent society contributing to this low-carbon climate-conscious era.

We want to hear from you. How can ARMA better serve you? I will host a regular virtual chatroom titled “*President’s Coffee*”. The discussion will be held biweekly, focus on specific topics important for ARMA, and solicit member suggestions. More details will be available shortly.

Lastly, for those I have not yet had the pleasure of meeting, allow me to briefly introduce myself. I am a first-generation immigrant from China, studied in Canada, worked in the UK, and now live in United States with my beautiful family. I am a long-distance runner, a mountain biker, and a devoted cheerleader for my young pianists, swimmers, and dancers. I look forward to meeting members, either in-person or online, and learning more about you. Together we will face challenges and opportunities head on and continue to heighten the global profile of rock mechanics.

Along the way, let’s have fun.

Sincerely,
Gang Han, PhD
President, American Rock Mechanics
Association
www.armorocks.org

Student Chapters

Chapter Overview

Submitted by Andrew Bunker, Departments of Civil/Environmental Engineering and Chemical /Petroleum Engineering, University of Pittsburgh and ARMA Board of Directors; and James S. Roberts, ARMA Staff.

ARMA is committed to building the technical and scientific knowledge base in rock mechanics and geomechanics and to ensuring wide acceptance among current and future researchers and practitioners. Strong student membership ensures continuity of ARMA's mission. Student Chapters on campuses of educational institutions empower students to participate in activities that address issues, challenges, and opportunities related to ARMA's mission.

In recent years, there has been remarkable growth in the number and geographic reach of Student Chapters. There are currently 14 in number, listed below. They represent five countries. These organizations are fully approved by their host universities, have faculty advisors, and maintain an active set of programs and events. They are governed by their officers, and make an annual effort to recruit current students as members, enrolling them in activities planned by the chapter.

Colorado School of Mines	University of North Dakota
University of Houston	Texas A&M
University of Kentucky	Texas Tech
Indian Institute of Technology (School of Mines)	The University of Texas/Austin
Missouri Institute of Science and Technology	University of Texas/Permian Basin
Monash University (Australia)	University of Toronto
Universidad Nacional de Colombia (Medellin)	Virginia Tech

Some of the types of activities chapters have sponsored include:

Guest speakers (particularly featuring senior AMRA members, including Fellows; these are often done as Zoom calls); Corporate partnerships; Field trips; Job search and professional development; Contests and competition; Support for annual ARMA symposia (including volunteering to serve during the event); Social events; Civic and community events

Chapter members are encouraged to communicate with other chapters, to share ideas and participate in programs. An active roster of officers and members is maintained and support from ARMA Board, members and staff is provided.

One of the exciting things in the current year is student-initiated contests and competitions. Members came up with the ideas, sought participation by ARMA members, and conducted the events. Key features and outcomes of these events are summarized in the following sections.

For further information

If you would like additional information on student chapters, please see three links on the ARMA website (www.amarock.org, under Student Chapters). Those three are How to Form a Chapter, Maintaining a Chapter, and Sample Bylaws.

2021 Student Design Competition

*Submitted by Juan J. Monsalve, Virginia Tech and
Cristian D. Cardenas, University of Kentucky*

The first ARMA Student Design Competition was proposed and jointly organized by the University of Kentucky and Virginia Tech ARMA student chapters, with the support of the ARMA Board of Directors. Dr. Loren Lorig (Itasca Group, Inc., ARMA Board of Directors) agreed to serve as the competition's mentor.

The design competition offered undergraduate and graduate students enrolled in rock engineering-related programs the opportunity to test their knowledge, creativity, team-work, and problem-solving skills by exposing them to a real-life rock engineering-related case-study problem. The ARMA Student Design Competition was sponsored by Itasca Consulting Group; Itasca provided the data for the case-study problem, made its software available, and committed funding for the prizes. The College of Engineering of the University of Kentucky also provided funding for the competition prizes, totaling \$2,500 for the winners of the competition.

This competition was initially announced on 15 March, with the registration period open until 16 April; during that time, 40 teams from 29 universities in 17 countries registered. As a way to promote the competition and involve the students interested in participating, an

introductory webinar was organized on 9 April, when Itasca's Loren Lorig outlined the competition and introduced Itasca's FLAC/Slope open-source software as a tool to solve slope stability engineering problems. The introductory webinar was attended by 167 participants, and the recording was posted on Itasca's YouTube Channel. The recording has had over 1,200 views.

The design problem was released on 9 April. The objective was to determine the maximum mining depth such that the total income equals the production cost under a series of conditions. The participants were also asked to discuss the effect of variability on their results and to assess and address all potential risks that could arise in their designs. The teams had four weeks to work on their solution. At the end of this stage, 21 teams submitted their entries.

The reports were reviewed by a judging panel made up of Dr. Emmanuel Detournay (University of Minnesota), Dr. Paul Young (University of Toronto), Dr. Mark Diederichs (Queen's University), and Dr. Antonio Bobet (Purdue University). After a thorough review process the judges selected the best six reports, which were then defended in an on-line presentation that narrowed the field to the top three teams. Table 1 presents the list of finalist teams selected by the judges, the university and country each team represents, and the list of members for each team.

Table 1. Teams Selected for the On-line Final Presentations Session

Team Name	University	Country	Team Members
GEPA: Geotechnical Engineering Peruvian Advisory UNI	Universidad Nacional de Ingenieria	Peru	Carlos Vera Jiménez, Edwin Araujo Barahona, Luis Minaya Abanto, Rubén Romero Mayma and Manuel Torres Hidalgo
LMR Consulting	Laval University	Canada	Antonie Caron and Christopher Durham
Stabilizers	IIT (ISM), DHANSBAD	India	Madhav Singhal, Amara Venkata Sai Srujan, Battula Sreeshma, Anjali Atreyi and Nimmagadda Sravani
Manic Miners	University of Belgrade	Serbia	Durdevic Rade and Milijanovic Aleksanda
Veteran Endeavor	UPN "Veteran" Yogyakarta	Indonesia	Ifa Aulia Chusna, Renaldo Pratama, Nur Rohmanuddin, Heru Suharyadi and Vega Vergiagara
UND Crazy Hawks	University of North Dakota	North Dakota, United States	Ahmed Merzoung, Habib Ouadi, Dawn saepia and Xueling Song

Final presentations were scheduled on 14 June, through the Go-To-Meeting platform. Each finalist team had 10 minutes to defend their reports and justify their designs and 5 minutes to answer questions from the judges. This event had 52 attendees. The recording of the event was posted on the Itasca's YouTube Channel, and has had over 300 views. Figure 1 shows a snapshot during the presentation of the Geotechnical Engineering Peruvian Advisory UNI team.

After the presentations, the judging panel decided to award two first places, and one third place. The Geotechnical Engineering Peruvian Advisory from the Universidad Nacional de Ingeniería de Perú, and LMR Consulting from Laval University were awarded first place. Team Stabilizers from the Indian Institute of Technology (Dhanbad) was awarded third place. Results of the competition were announced during the online ARMA Symposium 22 June. Figure 2 shows the moment

the winners of the competition were announced by Dr. Lorig.

The ARMA Student Design competition proved to be a successful initiative to encourage the interest of students in rock engineering. This event was a complete success, not only as a challenge to participating students but also by promoting the formation of even more ARMA student chapters in multiple countries around the world.

The organizers are grateful to the ARMA board of directors, and more specifically Peter Smeallie, Loren Lorig, and Andrew Bunger for all their support and mentorship provided throughout the conception, planning, and development of this program. We hope this event becomes a regular event with growing interest during future ARMA symposia.

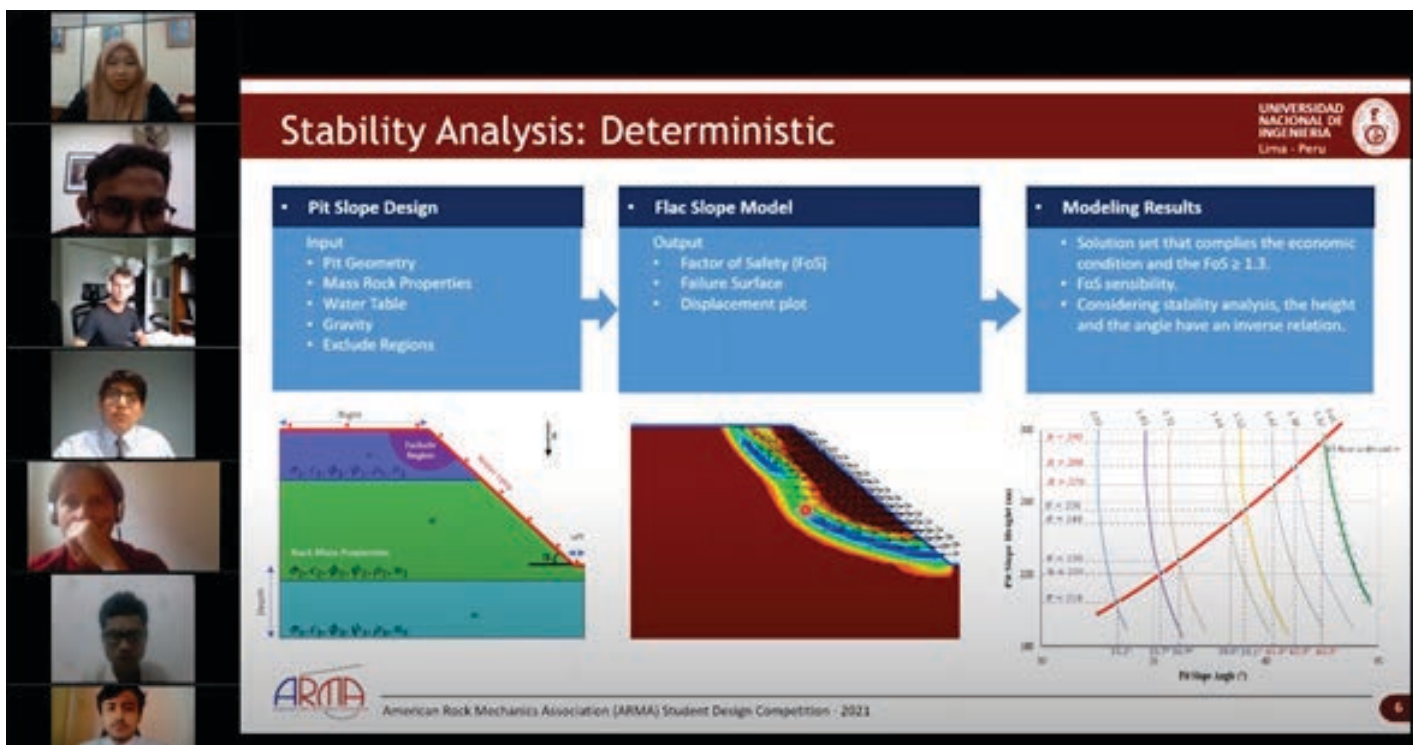


Figure 1. Snapshot of the Final Presentations Event during the GEPA's team presentation.

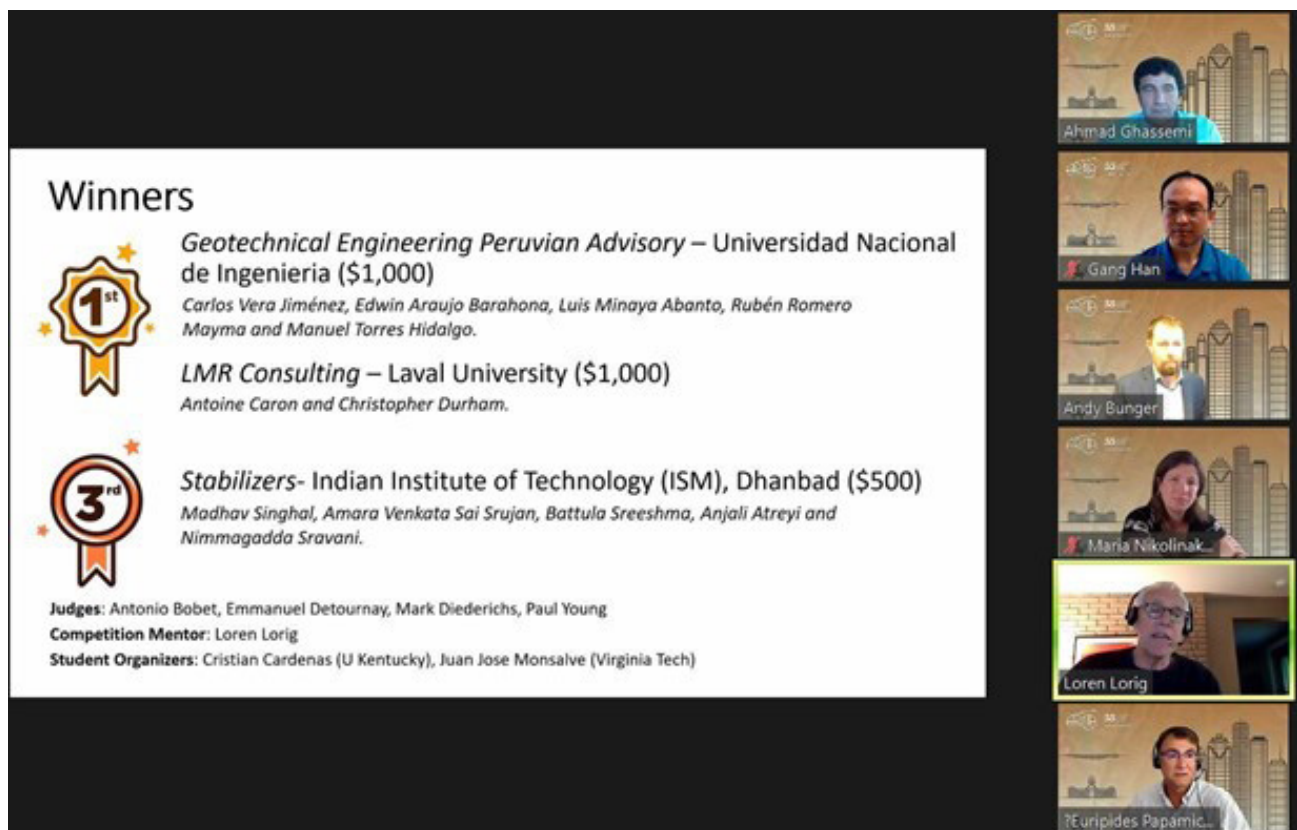


Figure 2. Competition Winners Announcement During the ARMA Symposium.

2021 Research Competition

Submitted by Xuejia Du (University of Houston) and Doyin Kolawole (Texas Tech)

The initial ARMA Student Research Competition was held in conjunction with the 2021 Symposium. This contest was organized by students from the Texas Tech and University of Houston chapters. Their intent was to promote research by student members of ARMA. All students were invited to submit an entry, but it was oriented to M.S. and Ph.D students. Participants were asked to submit a research paper to a select panel of judges, then make a presentation with followup questions. The judges were the following ARMA members: Emmanuel Detournay (University of Minnesota), Wolfgang Wawersik (Sandia National Laboratories, retired), Ruiting Wu (Chevron), Herbert Wang (University of Wisconsin-Madison), and Varun Varun (Itasca Consulting Group).

There were six entries in the competition, representing six different universities. The participating students were: Zhaoyang Ma (Monash University), Xueling Song (University

of North Dakota), Ibrahim Eltaleb (University of Houston), Juan J. Monsalve (Virginia Tech), Anastasia Xenaki (University of Kentucky), and Yongzan Liu (Texas A&M University).

The winning paper was announced at the ARMA annual symposium, along with a cash prize of \$200.

The award went to Yongzan Liu (Texas A&M University) for his paper titled “Quantitative Hydraulic Fracturing Geometry Characterization Using Low-Frequency Distributed Acoustic Sensing Measurements.”



2021 Photo Contest

Submitted by Babak Khadivi, President, Monash Student Chapter

The American Rock Mechanics Association Photo Contest was organized by the Student Chapter at Monash University, Australia. In sponsoring this project, the originators framed their intent:

Similar to words, photography is a language to document and to publicize different aspects of a researcher's career that sometimes surpasses the words. Photography enables us to share meaningful experiences with others and inspire them through various perspectives in the form of static moments.

The first ARMA Photo Contest was held in June 2021 in two groups - student and professional - without a limit to the number of participants. The contest was open to anyone interested in the field of rock mechanics/geo-mechanics. The expectation was that it would display the excitement of this field through visual means.

In the student category, participants were invited to submit photos that were partially or totally related to their research. In the professional category, students, academics and industry professionals were invited to submit original photos on any rock mechanics subject. Over 60 photos were submitted by different scholars and practitioners from United States, Australia, Canada, Italy, Germany, Spain, Greece and Colombia. A panel of ARMA judges, from U.S.,

U.K., UAE and Australia selected the best six photos. The winners were announced at 55th US Rock Mechanics/ Geomechanics Symposium on 22 June, 2021; winners received cash prizes and letters of commendation.

The contest was an amazing experience for organizers. It also created an enjoyable moment for the participants and the symposium attendees. Encouraging feedback was received from symposium attendees who called the contest a "great initiative" and expressed their compliments to the invested efforts and impressive photos leading to the contest; there were calls for continuation of the contest as part of future symposia.

Organizers are thankful to all the participants who took advantage of the great opportunity to genuinely explore the world of rock mechanics through their valuable contributions. They offer special thanks to Monash committee members (Rachel Peng, Maxwell Hendrianto, Tanghan Jiang, Yuqi Song, Manoj Samarakoon and Babak Khadivi); faculty advisors (Prof. Jian Zhao and Dr Hossein Masoumi); judging panel (Tryana Garza-Cruz (ITASCA, US), Alexandra Tsopela (Rockfield, UK), Hamda Ahmed Alshehhi (ADNOC, UAE), Hossein Masoumi (Monash University, Australia) and Babak Khadivi (Monash University, Australia)), and ARMA board (Joseph P. Morris, Gang Han, Andrew Bunker, Peter Smeallie, Maria-Katerina Nikolinakou and Jim Roberts) for their support in making this contest a success.

The winning photos are posted below, with the names of those submitting entries.



First Place: Tunnel "spikes" - Depth pins prior to the secondary shotcrete lining. Photo by Tom Roper, Australia.



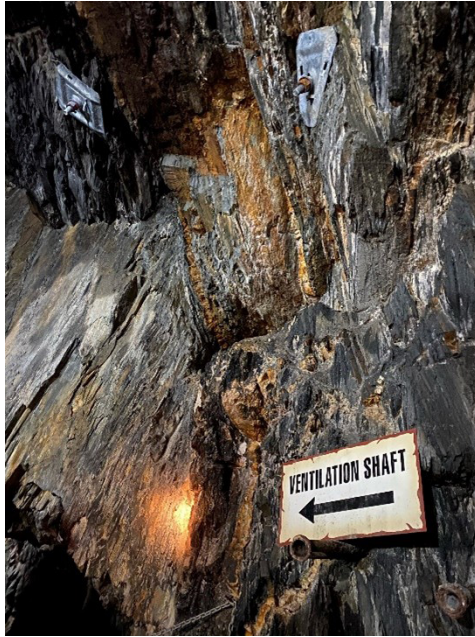
Second Place: *A site engineer inspects a tunnel in the calm before the next shift, Sydney, Australia. Photo by Eva Grasso, Australia.*



Third Place: *The Grasberg open cut mine with a rare equatorial glacier in the background, Freeport, Papua. Photo by Amelia Kennedy, Australia.*



First Place: *Vertical coal seams, a view from the open pit of La Margarita Coal Mine, Colombia. Photo by Ferney Londoño, National University of Colombia.*



Second Place: An old and closed underground gold mine, Valhalla, Victoria, Australia. Photo by Fatemeh Amirpoorsaeed, Monash University.



Third Place: Haul truck with a load of copper and gold, Grasberg Mine, Freeport, Papua. Photo by Amelia Kennedy, Monash University.

2021 Mentor-Student Event

Submitted by Oladoyin Kolawole (on behalf of the Organizers of Mentor-Student event)

The 55th U.S Rock Mechanics/Geomechanics Symposium featured an event to connect student members with experienced mentors. This “Mentor-Student” event was held virtually on 18 June. The event attracted over 90 participants, which included 19 mentors (made up of ARMA fellows, ARMA future leaders, and other experts from academia, industry, government institutions; most are listed below). Over 70 students (BS, MS, and PhD) from all over the world participated in the event. Student from 13 countries attended the virtual event, including: Australia, UK, China, Canada, Malaysia, Saudi Arabia, United Arab Emirates, Indonesia, Vietnam, Colombia, France, Turkey, and the United States.

The event lasted for 7 hours, starting from 10:00 am ET to 5:00 pm ET. During the event, Zoom breakout rooms were created with one, two, or more mentors in each room to speak to students who visited the rooms.

The students asked questions from the mentors on a variety of topics such as:

- Low job opportunities after graduation in the wake of a global pandemic.
- Post-graduation career choice: industry vs. academia.
- Career and skills transition to other research areas.
- How to grow professional networks.
- Graduate school opportunities and funding.

At the end of the event, students and mentors were able to exchange thoughts and ideas, and the organizers received good feedback from all participants.

Organizers look forward to hosting (in-person) another Mentor-Student event during the 2022 ARMA Symposium in Santa Fe, New Mexico.



Technical Committees

Overview

One of the distinguishing features of ARMA is its interdisciplinary nature. There are many different academic disciplines that are represented, a wide range of corporate memberships, and varying individual approaches to rock mechanics and geomechanics. This in turn, encourages research and development, innovation, and exploration at the cutting edges in science and technology.

Because of this emphasis, the ARMA Board of Directors created ARMA Technical Committees. The mission of the ARMA Technical Committees is to support and conduct activities that contribute to the development and dissemination of knowledge in rock mechanics and geomechanics, to engage current and prospective ARMA members in technical activities, and to support the vision of ARMA.

The purposes of the technical committees include, but are not limited to:

- Create a Technical Community of both current and prospective ARMA members that provides a common platform for inquiry in selected sectors of rock mechanics and geomechanics
- Plan and organize technical sessions,

specialty conferences, workshops, and short courses as means of promoting those common areas of inquiry;

- Solicit, prepare and/or review and edit papers, reports, manuals, and guidelines of practice; and
- Seek ways to disseminate and exchange relevant scientific and technical knowledge.

There have been five Technical Committees authorized by the Board of Directors. Technical committees on Hydraulic Fracturing and Induced Seismicity have been active since they were authorized by ARMA in 2017. 2018 saw the establishment of Drilling Mechanics and Engineering, followed by Tunneling in 2019, and more recently by Underground Storage and Utilization in 2020.

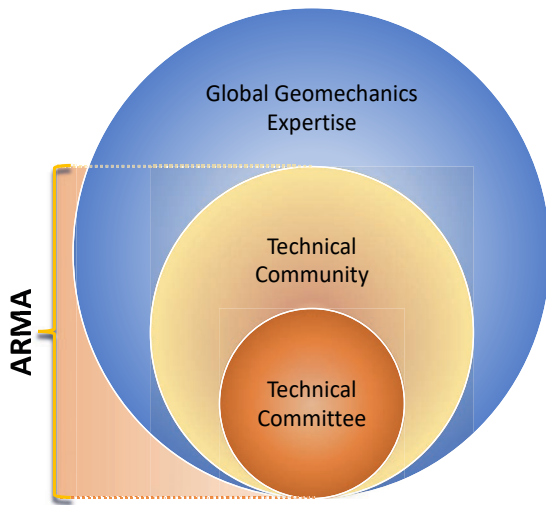


Figure 1. Relationship between an ARMA Technical Committee, its associated Technical Community, and the larger geomechanics global expertise and interest base.

Organizational Structure

The committees are all organized in the same way, with its Chair nominated by members and appointed by the ARMA Board of Directors. Other officers are appointed by the Chair. All officers and two-thirds of the committee members must be members of ARMA. In addition, there may be an unlimited number of non-ARMA members, designed as part of a Technical Community. This structure is graphically presented in Figure 1.

The Technical Committees and Technical Communities support ARMA's goal of serving the international geomechanics expertise and

interest base through a variety of pathways. These may include formal or informal contacts between ARMA and other organizations, such as the International Society for Rock Mechanics (ISRM), European Geosciences Union (EGU), the Society of Exploration Geophysicists (SEG), the American Geophysical Union (AGU), the Society of Professional Engineers (SPE), and the American Association of Petroleum Geologists (AAPG), university research teams; governmental entities such as the national laboratories; and companies. But involvement in the Technical Community is open to any interested parties regardless of membership in ARMA (e.g., via webinars or professional meetings). These non-voting members can contribute to the operation and direction of the Technical Committee functions as they see fit. This structure has been designed to be inclusive and to encourage participation by those that choose to affiliate due to common interests in a particular branch of rock mechanics and geo- mechanics.

Communications and Social Media

The nature of the Technical Committees requires considerable attention to communication. This is important for the work of the Committee, creating opportunities for sharing knowledge and seeking integrated approaches to rock mechanics. This holds true for Technical Communities as well.

To accomplish this, Technical Committees have made special use of common social media: LinkedIn and YouTube, as well as participation through such means such as Zoom, GoTo Meeting and other collaborative sites. Some of these approaches have been developed to serve the general membership of ARMA, while others have been uniquely designed for a specific Committee's purposes.

Technical Committee Descriptions

In the following sections, each of the Technical Committees is described, along with contacts for the committee Chair for those seeking further information or to join in the committee. The first report, Underground Storage and Utilization, is featured, providing a detailed model of how a specific technical area could be conceived, organized and then serve ARMA, the members of the Technical Committee, and the Technical Communities. Summaries of the other Committees follow.

Underground Storage and Utilization

Submitted by Richard A. Schultz, Committee Chair, Orion Geomechanics LLC (Cypress, Texas) and the USUTC Team¹

*Contact: Email: oriongeo@gmail.com.
Telephone: (281).415.3875*

Summary

A new Technical Committee was established by ARMA in 2021 for Underground Storage and Utilization (USUTC). Its role is to focus on the geomechanics of underground storage of all types of energy-related products in ways that ensure safe storage and utilization operations. Its efforts also align with national and international priorities, such as security of energy supply, reduction of greenhouse gases, and the ongoing energy transition toward a net-zero economy.

USUTC is currently active in four cross-cutting technical themes and five energy-related product areas, with each of the technical themes being required for underground storage of any product to be safe and effective:

Technical Theme	Stored Energy-Related Product
Characterization of the Storage Container	Hydrocarbons
Monitoring and Risking	Hydrogen
Coupled Processes and Modeling	Carbon Dioxide
New Technologies	Thermal and Nuclear
	Compressed Air Energy Storage

These energy-related products can be stored underground using either: porous-rock storage, which includes both depleted oil-and-gas fields and saline aquifers; or engineered containers, which are built largely as solution-mined salt caverns and, less frequently, mined hard-rock caverns. Storage of product in any type of subsurface container requires use of all four of the technical theme areas noted above and described in this article.

This article provides an extended look at the types of situations where underground storage may be useful, then describes the origins, organization, and the program strategy of the Technical Committee. Accomplishments of the USUTC to-date, and the benefits for members of the Technical Committee, its associated Technical Community, and ARMA are also summarized.

Introduction

The American Rock Mechanics Association (ARMA)'s Technical Committee on Underground Storage and Utilization (USUTC) focuses on the geomechanics of underground storage of all types of energy-related products, with emphasis on safe storage and utilization operations. The overarching goal of the Technical Committee (TC) is to raise the level of understanding and appreciation of the criticality of subsurface energy storage and utilization at-scale for the global energy transition toward a net-zero economy, and to define and promote required technical breakthroughs to achieve this.

The intended audience of the TC includes (a) researchers and practitioners in university, industrial, and research laboratories; (b) industry regulators at all levels; and (c) related technical communities. With ARMA already recognized

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in the field of earth materials, this TC's goal promotes ARMA's participation in the broader subsurface applications such as those associated with the energy transition.

Energy-related product storage and utilization is integral to achieving the desires of low-carbon and sustainable energy that are actively being pursued by the nation and worldwide. Because the expected scale needed for energy storage is too large to use only the surface (such as steel tanks) for many applications, the subsurface fills an essential role in energy storage, security of supply, and resilient deliverability.

The approach of the USUTC is to reach across disciplinary boundaries to connect scientists, engineers, professors, students, postdocs, storage operators, consultants, and others from around the world who are interested in the fundamentals, development, and potential of underground storage and utilization. It also sponsors coordinated sessions at ARMA symposia, technical workshops, and other forums as a service to our members and their colleagues.

This Technical Committee aligns with ARMA's strategic focus on serving its members and their colleagues with key information, networking opportunities and knowledge exchange, and identification of promising technical work and collaborations. Part of its role is to proactively "look around the corner" for opportunities in which ARMA could take a leading role in promoting technical areas covered by this TC along with other emerging, forward-looking topics.

Surveying the Landscape

To appreciate the subject-matter scope of the Technical Committee, a summary of the varieties of applications and uses of underground storage is presented.

Underground storage and utilization (USU) of various gases, liquids, and solids is ubiquitous around the world, with a long history in numerous countries (e.g., Peila and Pelizza, 1995; Bensen and Cook, 2005; Perry, 2005; Anonymous, 2009; Evans, 2009; Matos et al., 2019; Koohi-Fayegh and Rosen, 2020; World Nuclear Association, 2020; Bérest, 2021). Of these, the commodities related to energy production, such as crude oil, natural

gas, radioactive material, and compressed air, have been stored since the early 20th century.

The storage of thermal energy, carbon dioxide, and hydrogen in various concentrations and blends has drawn the attention of governments, regulators, oil-and-gas companies, investors both large and small, public utilities, and other energy operators worldwide for the value they can add to the interested parties' business development and longer-term climate mitigation activities. Underground energy-related product storage has possible uses in multiple economic sectors such as utilities, transportation, economics, venture capital, and evolving technologies such as liquefied natural gas (LNG) and hydrogen. These varied products are growing into import/export commodities that can contribute to nationally important priorities such as greenhouse-gas reduction, reduced carbon footprints, and sustainable energy. USU also plays a role in the "security of supply," given that maintaining resilient energy capacity and deliverability is considered to be a strategic national necessity.

The underground storage and utilization industry encompasses a diverse array of energy-related products, geological storage types and locations, and cross-cutting technical themes. The geologic settings of many types of stored products are illustrated in Figure 1 along with some common above-ground storage (AGS) technologies.

Energy-related products can be stored either at the ground surface or in the geologic subsurface. Certain products, however, such as liquefied natural gas (LNG), are best stored in surface tanks. The low temperatures required for underground storage would be difficult to produce and sustain within a subsurface geologic container. Other types of energy-related products are better suited to geologic storage. For example, crude oil is commonly stored in solution-mined caverns built within salt domes as are found in the U.S. Strategic Petroleum Reserve along the U.S. Gulf Coast; another example is nuclear material stored in mined caverns such as the Waste Isolation Pilot Plant in Carlsbad, New Mexico, USA. On the other hand, natural gas and carbon dioxide are generally stored in porous rocks, in either depleted oil-and-gas fields or deep saline aquifers.

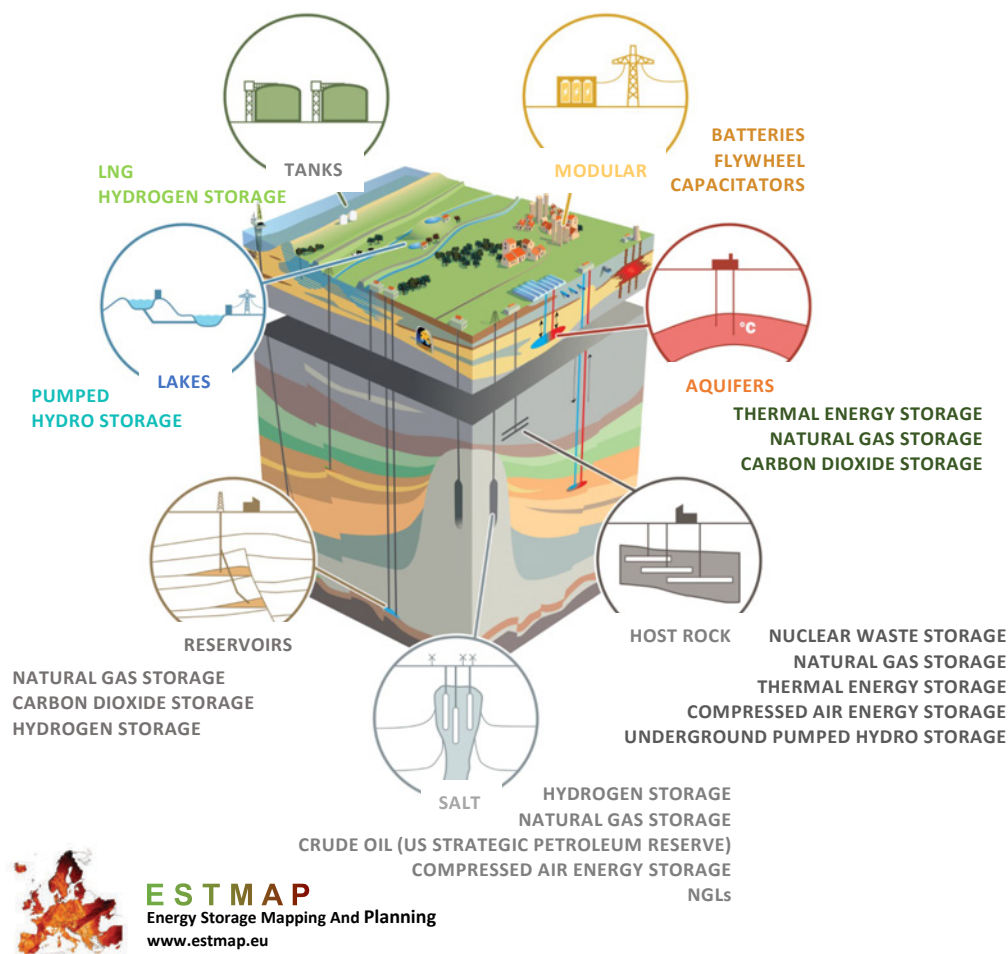


Figure 1. Geologic locations where various energy-related products can be stored, (after Estmap (2016), used by permission). Products can be stored and accessed for utilization in various underground containers in addition to above-ground storage.

Given that there are limits on the surface area that can be made available for above-ground storage (AGS) technologies, use of the geologic subsurface expands underground storage and utilization opportunities into a vast three-dimensional volume. The shallow burial of natural gas pipelines, subway systems, and public utilities such as water and power distribution conduits demonstrate the efficacy and cost-effectiveness of this approach for those purposes. Energy-related products such as carbon dioxide, hydrogen, natural gas, nuclear material, and thermal energy can be stored in several different subsurface geologic containers depending on factors such as cost, suitability, regulations, and policies.

The term “container” in this article refers to

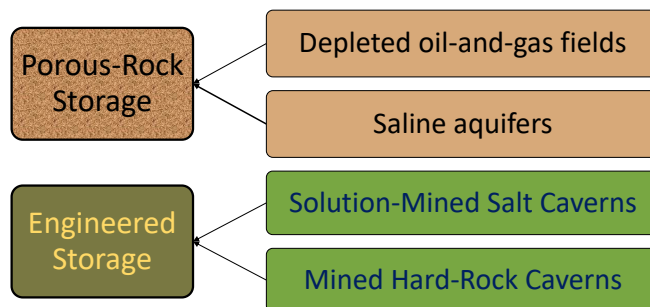


Figure 2. Types of underground storage containers.

either the natural geologic structural traps used for porous-rock storage, or to engineered cavities such as solution-mined salt caverns and mined galleries in hard rock that are used to store energy-related products. A rich variety of subsurface storage containers is available, each

with its own specific set of geologic, engineering, and operational characteristics. The most common types of storage containers are shown in Figure 2.

Of these, “porous-rock” storage takes advantage of the geology, whereas “engineered storage” containers are designed and built to store particular energy-related products in large underground volumes enclosed by a low-permeability medium, such as salt, tuff, or granite. Depleted fields are the most common type of porous-rock storage, followed by saline aquifers. The most common type of engineered container is solution-mined salt caverns; the other type consisting of caverns, drifts, and galleries produced by hard-rock mining methods is less commonly used but may be more appropriate for particular situations. Geologic considerations thus are of primary concern in siting any type of underground storage facility.

Porous-rock storage offers large working-gas volumes but with deliverability rates (i.e.,

injection and withdrawal) that are limited by the petrophysical characteristics of the storage reservoir. Engineered containers such as salt caverns, in contrast, offer much higher delivery rates but from generally smaller working-gas volumes. The choice of which container type to develop hinges on (a) finding a suitable geologic location, and (b) evaluating the degree of connectivity of the proposed storage container to existing infrastructure, such as wells, pipelines, sources of product (e.g., CO₂ captured from local industrial plants, H₂ produced from renewable energy sources), and the needs of the end-user (i.e., local population centers, industry, transportation centers, energy hubs, economics, and risk/reward evaluation). Once a suitable geologic location has been chosen, such as a geologic trap, salt dome, or bedded salt layer, the containers are designed and constructed within the geologic confining medium (rock or salt) to house a wide range of energy-related products (Figure 3).

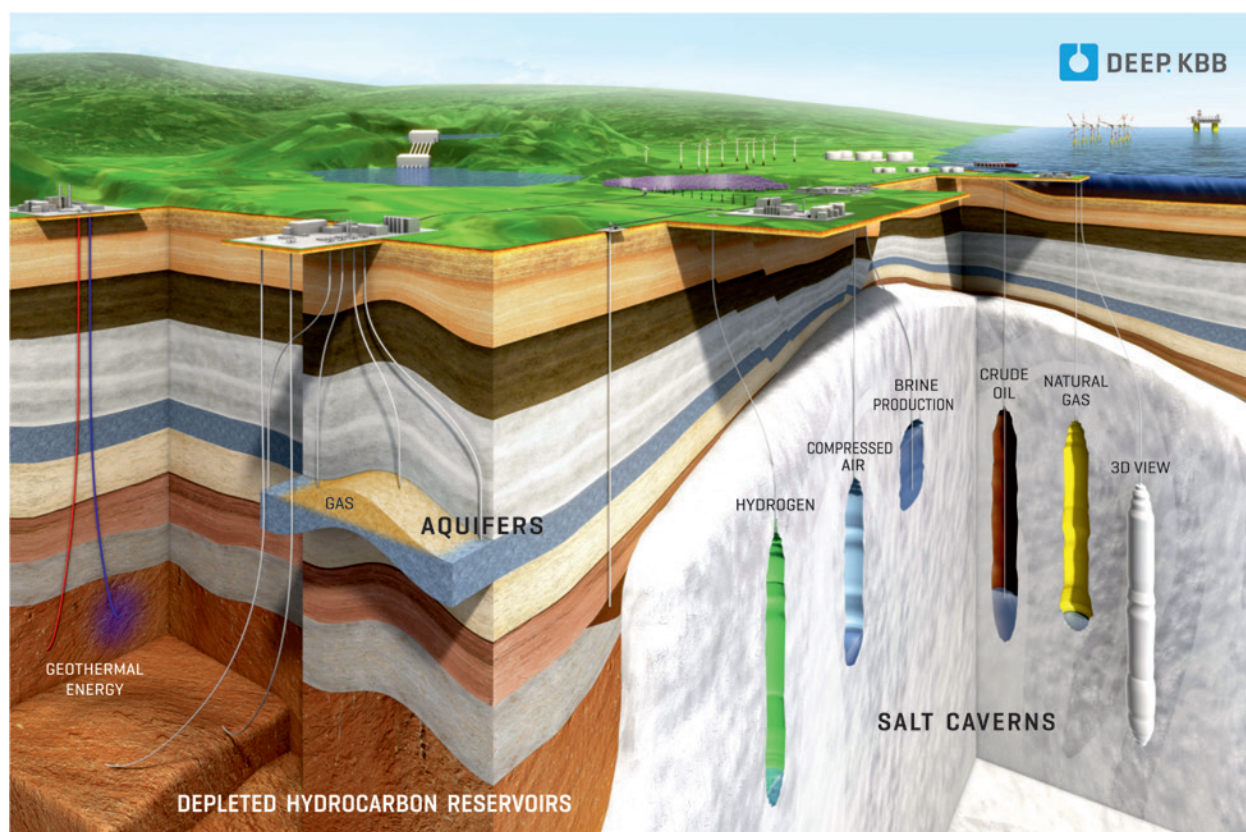


Figure 3. Types of subsurface containers and energy-related products. Porous-rock storage containers are shown on the left; engineered containers with various energy-related products that can be housed in them, on the right. (Figure © KBB.DEEP, used by permission).

In the U.S., some 90% of the nearly 400 underground natural-gas storage facilities are in porous rock (i.e., depleted fields and saline aquifers) with the remaining 10% being in solution-mined salt caverns (e.g., Evans, 2009; Evans and Schultz, 2017). A comparable number with similar percentages is found in Europe and Russia.

Energy-related products such as crude oil, hydrogen, and natural gas liquids (NGLs) are currently stored in either salt or hard-rock caverns. Given their versatility as engineered containers, a growing number of caverns is rapidly being built to store energy-related products in areas such as Europe, Russia, Turkey, and China.

Carbon dioxide is generally treated in two fashions: (1) As a material, or undesirable greenhouse gas, to be stored and sequestered underground for long-term isolation from the geologic and atmospheric environments, and/or (2) as a resource that can be used to enhance oil recovery (EOR; e.g., NETL, 2010) or, when combined with hydrogen obtained from photovoltaic or other methods, to produce methane, termed synthetic natural gas (SNG), which would be a renewable resource. These and other applications are collectively referred to as Carbon Capture, Utilization, and Storage (or Sequestration), or CCUS.

Disposal of high-level radioactive material from civil and military nuclear reactors currently is treated as an undesirable waste product to be sequestered over the long term (World Nuclear Association, 2020), similar to CO₂ sequestration. However, these nuclear materials could potentially be identified as a resource for utilization, similar to carbon dioxide today.

Geothermal energy encompasses both deep and shallow geothermal energy resources. Thermal energy storage in the context of this article refers to shallow geothermal energy exploitation, utilizing reservoirs/tanks at shallow depths (10–15 m below the ground surface) to store and extract water primarily for heating and cooling purposes. In contrast, deep geothermal energy systems harness heat energy from the deep subsurface (usually several kilometers beneath the Earth's surface) for either direct heating or power generation using steam and turbines (Zhang and Zhao, 2020). The latter, and hazardous chemical

materials disposal, are not considered in this article. Similarly, although designing for and maintaining well and pipeline integrity is critical to any subsurface facility, this TC focuses on the rock mechanical and geomechanical components of underground energy-related product storage and utilization.

The USU industry is an essential component of the overall energy infrastructure, which may be considered as having three general and overlapping parts: (1) acquisition or generation of the energy source, such as wind energy, solar energy, nuclear, thermal, hydrocarbons, and hydrogen among others; (2) processing, storage, and transport of the energy-related products; and (3) utilization of the energy-related products by customers, such as operating companies, utilities, and the domestic and export markets.

Energy infrastructure generally focuses on the above-ground energy infrastructure, such as powerlines, pipelines, power plants, refineries, transportation systems, and the like. However, the below-ground component of the total energy infrastructure — underground energy storage — is a critically important component, despite its smaller degree of recognition by U.S. governments, funding agencies, public utilities, or research universities. Nevertheless, underground energy-related product storage and utilization is synergistic with its above-ground infrastructure.

As an example, the U.S. energy infrastructure for hydrocarbon storage and transport is particularly well developed. Part of the midstream market sector (See figure 4, part 2), it connects upstream (i.e., exploration and production, E&P, part 1), which supplies hydrocarbons, with downstream (part 3), that provides hydrocarbon products such as gasoline, jet fuel, fertilizers, and plastics to customers.

An extensive network of shallowly-buried pipelines transport hydrocarbons from their underground storage facilities to various markets (Figures 5a through 5d). The current pipeline network that connects sources of CO₂ with injection sites for Enhanced Oil Recovery (EOR; NETL, 2010) is also shown in Figure 5e. The locations of the three hydrogen-filled solution-mined salt caverns constructed in salt domes along the U.S. Gulf Coast near Houston (Clemens, Moss

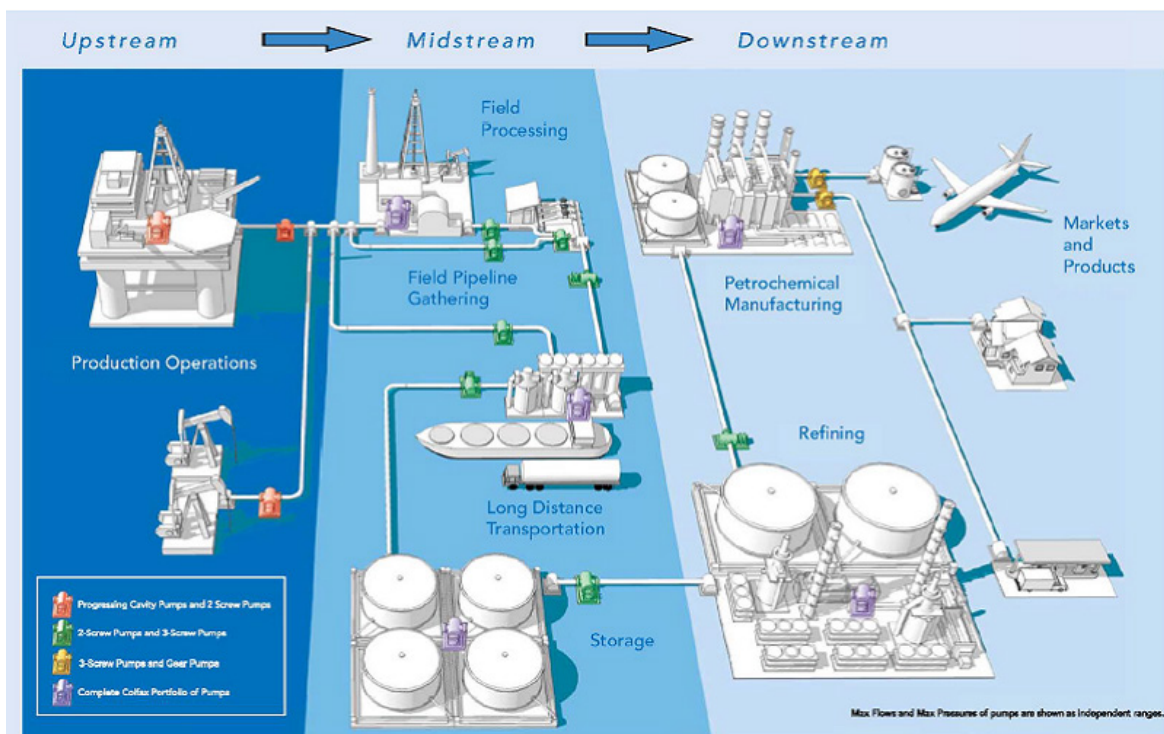


Figure 4. Illustration of the above-ground energy infrastructure for hydrocarbons (Image source: <https://codovia.com/oil-gas/oilfield-services-providers/>.)

Bluff, Spindletop; not shown in the figure) feed refineries and petrochemicals plants. Another large-scale hydrogen storage project in salt is

being constructed in central Utah that would hold the equivalent of 1,000 MW of power (refer to [Advanced Clean Energy Storage Project](#)).

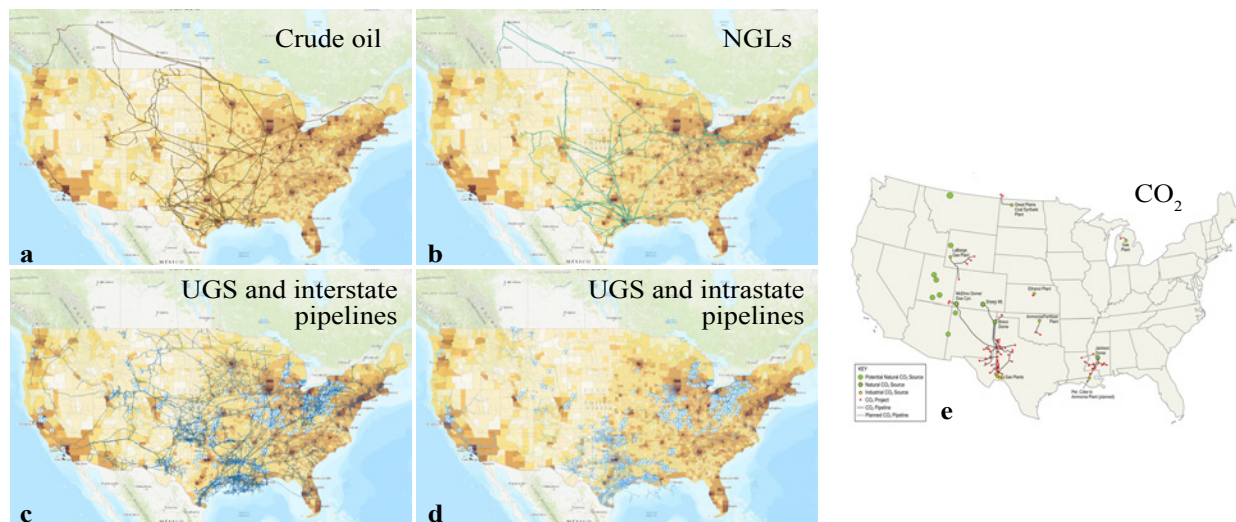


Figure 5. Infrastructure maps for energy-related products, lower 48 U.S. states and southern Canada; data from U.S. Energy Information Agency (EIA) [Energy Mapping System](#). (a) Crude oil; (b) NGLs (referred to as HGL used in EIA); (c) Underground natural gas storage facilities with interstate pipelines; (d) Underground natural gas storage with intrastate pipelines; (e) Location of current CO₂ EOR projects and pipeline infrastructure, from NETL (2010). Shaded areas in a–d indicate U.S. population density per county.

Once fossil fuels and CO₂ have been produced, they are transported by various means such as gathering lines, trucks, railway, barge, or ship to a point where they are stored, whether in above-ground storage (AGS) such as tanks or in underground storage (UGS) within the geologic subsurface. These underground storage facilities provide the above-ground energy infrastructure with an additional amount of volume, deliverability, resilience, and security.

Setting the Committee's Agenda

Given the overview of underground storage, it next is necessary to review how ARMA commissioned the USUTC to respond by defining a research agenda and operational activities. Initially started as an informal, ad hoc technical community in Summer 2020, formal approval to operate as a Technical Committee was granted in May 2021.

The Committee started out as an experiment to explore whether a broad umbrella-like structure might bring together, promote synergies between, and energize several traditionally separate areas at ARMA symposia. These included CCUS, high-level nuclear material storage, hydrocarbon storage

(e.g., in the U.S. Strategic Petroleum Reserve), compressed-air energy storage (CAES), and others that benefit from geomechanics input and expertise. The Committee was started as a bottom-up, member-driven initiative in response to recognized challenge areas.

In establishing the TC, organizers wanted to broadly consider an array of stored energy-related products and associated technical activities, not only in the U.S. but globally. This conception laid out several technical themes that are commonly carried out to predict and maintain safe and secure underground storage of the various energy-related products.

An email was sent out in June 2020 to all ARMA members to assess their interest in underground storage and utilization topics. Responses from 83 members were compiled in July and updated through Winter 2020–2021. Respondents were asked to choose three areas of interest to them — and several identified more. Members were also asked about their desired degree of involvement (e.g., planning or chairing sessions on their topics at ARMA symposia) and interest in a webinar series. Their responses are displayed in Figure 6.

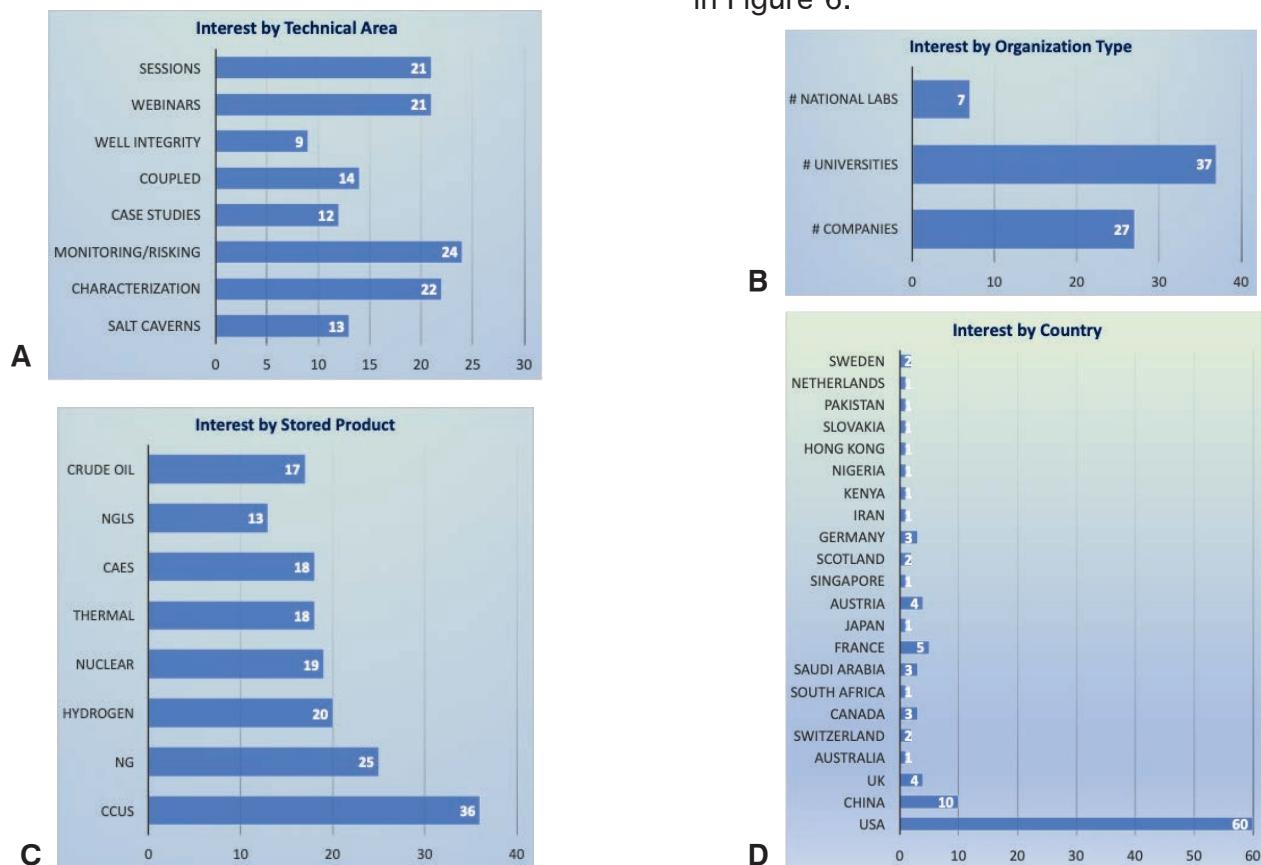


Figure 6. Results of ARMA members surveyed for interest in USU, plus additional non-members who had expressed interest in becoming involved once the TC began its online activities.

As can be seen in Figure 6, the responses revealed considerable depth among ARMA members and their international colleagues. Broad interest was expressed across all technical interest areas and stored energy-related products (Figures 6a and 6c), as described further below. The organizations and countries represented by ARMA respondents, and others who had expressed interest as a result of the Summer and Fall 2020 webinars, are shown in Figures 6b and 6d, respectively. The most interest was expressed by those affiliated with universities (n = 37: faculty, postdocs, students, members of university-based research centers), followed by practitioners in industry (n = 27). Also interested were members of government institutions, including domestic and international research labs, and policy centers (n = 7). The largest number of respondents were U.S.-based (n = 20), with some 20 additional countries also being represented (Figure 6d), suggesting that underground storage and utilization topics transcend national boundaries and reinforcing the global recognition of storage-related geomechanics.

The responses covered two topical groups: Technical Themes and Stored Product Type. Some of the main findings are described next.

- Intriguingly, of the six main technical themes identified, the most interest was expressed in monitoring and risking (or risk analysis) of underground storage facilities. Monitoring here includes, for example, microseismic, geodetic/InSAR, downhole surveillance (temperature, pressure, fluid chemistry, gas anomalies), and observation wells. Risking includes identification and mitigation of subsurface hazards that could be addressed via geomechanics. This theme is an important one in that it addresses the safety and environmental concerns of any type of subsurface facility, over various time scales, which may inform decision makers based on geomechanics input.
- Characterization was the next technical theme of wide interest to the survey respondents. In brief, characterization involves experimental, theoretical, and laboratory assessments of the host rock (e.g., porous reservoir or salt), caprock/top-seal sequences, and the surrounding rock volume as they pertain to underground product storage. The extent and characterization

of pore volume available in a storage reservoir, for example, is typically assessed vertically and laterally by seismic, coring, downhole, and other methods including the evaluation of dynamic changes in the reservoir and seals with time during field operations. The extensive research and understanding of shales as unconventional reservoirs (e.g., Zoback and Kohli, 2019) can be applied to assess the performance and integrity of top and side seals, as can their response to drilling and hydraulic fracturing.

- Along with container characterization, coupled processes and modeling were noted as an important technical theme for the design and safe operation of any underground storage facility. The transport of heat and fluids in soils and rocks can be affected by coupling between thermal, hydrological, mechanical, and chemical (THMC) processes (<https://eesa.lbl.gov/capabilities/coupled-processes>). Like characterization, the field of coupled processes and modeling is well represented in ARMA's membership.
- Salt caverns have long been used to store hydrocarbons (i.e., crude oil, natural gas) and compressed-air worldwide, but are increasingly being considered and built for storage of a wider range of energy-related products such as hydrogen and NGLs.
- Considerable interest and excitement were expressed to gain access to and evaluate case studies of underground storage and utilization projects to gain more insight into what worked well, and what could be improved. Experiences from both public and private facilities, along with large consortium-level projects, have a role to play in this regard. This theme also included new and emerging technologies, about which much interest was demonstrated. For example, members wanted to know more about which technologies were currently being used in underground storage projects, what are the key learnings or common key performance indicators (KPIs), and what new techniques or technologies might need to be developed that could further ensure safe and effective storage.
- More than 20% of the initial respondents mentioned an interest in contributing to or chairing sessions at ARMA symposia on storage-

related topics. A comparable number expressed interest in formally joining the TC as a result of the webinars that were held and posted on YouTube.

- The stored energy-related product of greatest interest was CO₂ (n = 36, or 90%) followed by hydrocarbons (natural gas, crude oil, and natural-gas liquids (NGLs)). CAES and storage of radioactive nuclear material, thermal energy, and hydrogen attracted the attention of several respondents.

Given the enthusiastic response of ARMA members to the survey, an ad hoc Technical Community was organized to evaluate its potential as a formalized Technical Committee.

Launching the Committee

The first challenge was to set priorities among the multiple technical themes and types of energy-related products being stored underground that

were indicated by the survey respondents. About a dozen ARMA members who had expressed an interest in actively participating provided feedback to the initial spreadsheet categories. The resulting consolidation into four technical themes and five energy-related product types, along with the main container types, is shown in Figure 7.

Succinctly, three fundamental components of underground energy-related product storage and utilization were recognized: (1) product type, (2) container type, and (3) technical theme. The technical themes illustrated in Figure 7 identify fundamental physical processes; measurement, modeling, and monitoring approaches; and current or promising technologies such as improved wellbore integrity or seismic imaging that are considered to be necessary for safe and secure underground storage and utilization of any type of energy-related product in any type of container.

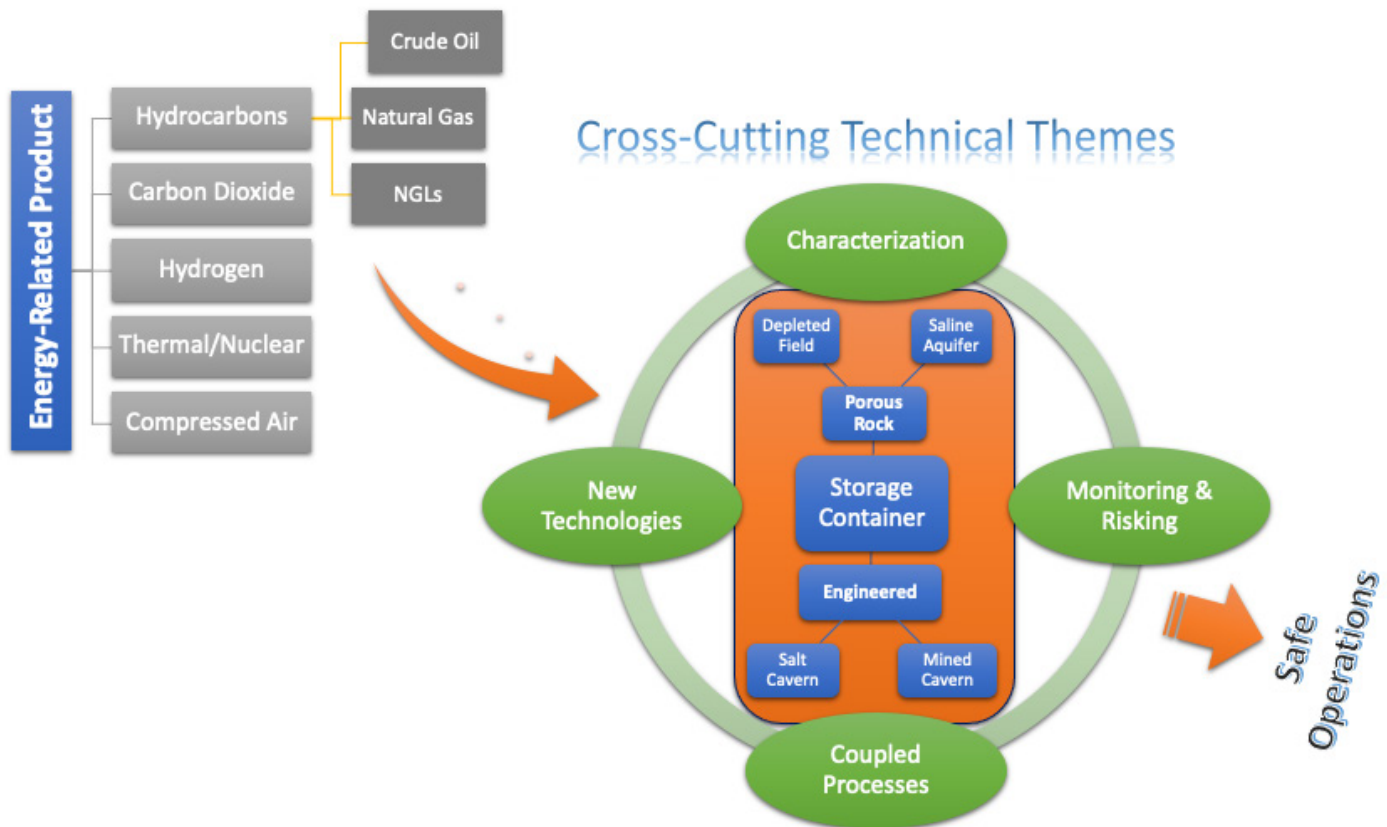


Figure 7. Conceptual workflow between type of energy-related product, storage container, and technical themes in underground energy-related storage and utilization.

The second challenge was to design and implement an organizational structure for the TC that would represent these fundamental components and populate them with interested and experienced technical volunteers. This structure (Figure 8) flowed into existence easily once the technical framework (Figure 7) was settled upon.

Because the TC was envisioned from the start as an ‘umbrella’ group connecting multiple technical and energy-related product areas and container

types, the organizational structure may appear to be somewhat more elaborate than that of other ARMA TCs. However, several aspects of this TC’s structure give it the flexibility to adapt rapidly to changes in the underground storage and utilization landscape in the future (Figure 8). For example, technical themes or energy-related product areas may be added, removed, or modified within the ‘umbrella’ structure in parallel with changes in emphasis within the storage and utilization industry.

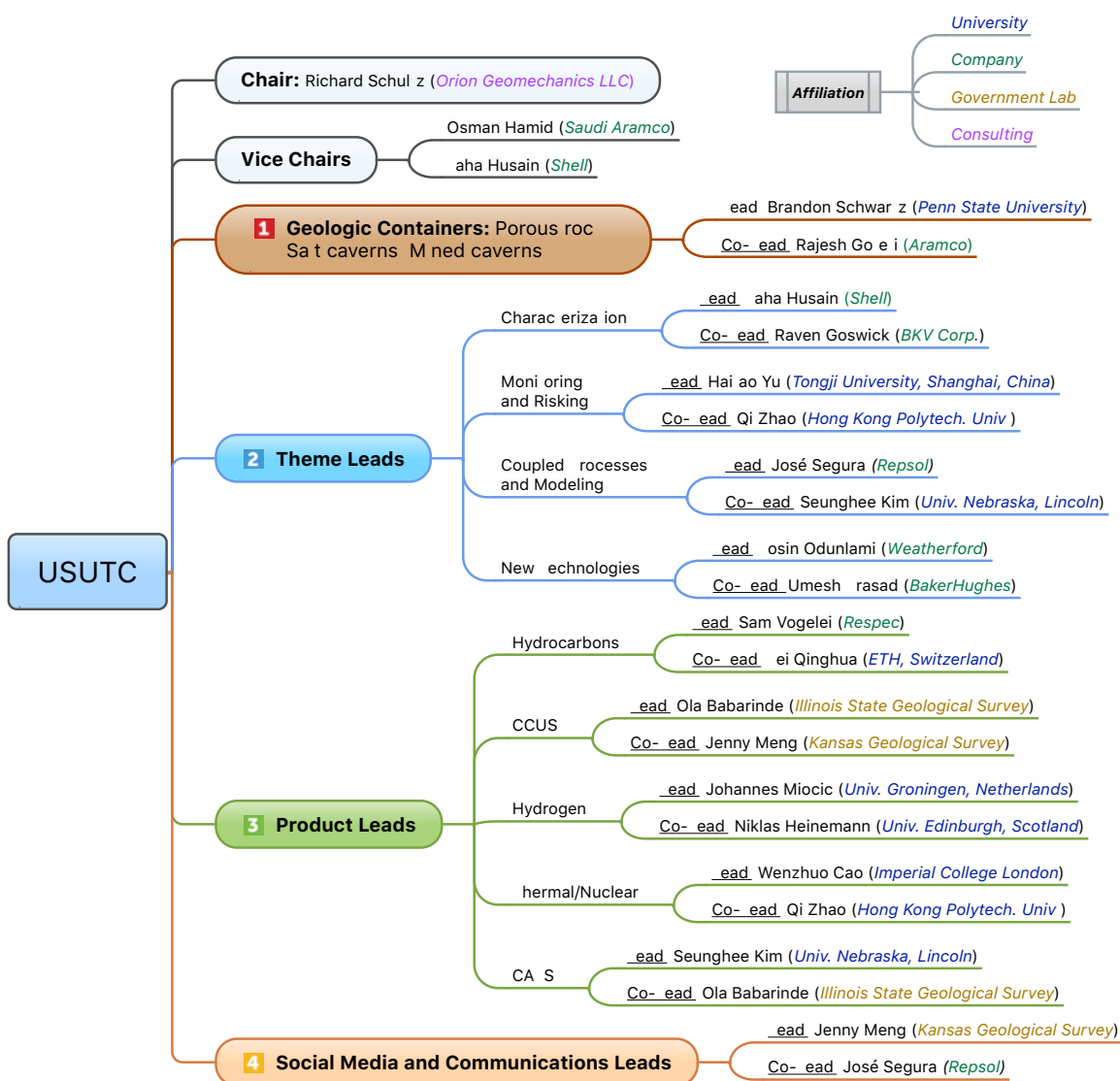


Figure 8. Organizational structure of the USUTC showing its founding members.

In consultation with the TC leadership team, a charter (e.g., Herman and Siegelau, 2009) was drawn up that specifies the overall goals and strategy of the TC, technical drivers (aka the “business case”), benefits, key milestones, and risk assessment and mitigation. Principal stakeholders were identified along with written specification and consensus of team member roles and responsibilities (Table 1).

focus areas as the need arises.

Making Use of Social Media

Officers and members recognize the importance of communication within the committee as well as with those in the larger Technical Community. Two techniques are of particular use:

Table 1. Technical Committee Member Responsibilities

TC Chair	The Chair provides overall direction to the TC and ensures that the objectives and milestones are met. The Chair is the principal point-of-contact within ARMA unless this responsibility is delegated to another. The Chair will entertain and implement any changes to the TC team as appropriate.
Vice Chair(s)	The Vice Chair(s) assists the Chair in the performance of his/her duties and will be ready to step into the Chair’s role when called for. The Vice Chair(s) will maintain such records as needed to maintain organizational memory of the TC. The Chair and Vice Chair(s) will work as a team to coordinate the activities of the theme/product teams so that ARMA, its members, and their colleagues worldwide benefit from the TC’s activities. The Vice Chair(s) will work with the Chair to periodically evaluate the staffing and trajectory of each theme/product team and recommend modifications to ensure coverage of the main theme/product areas as they wax or wane over time.
Theme/Product Leads and Co-Leads	The Theme/Product Leads and Co-Leads are responsible for producing benefits from their teams, such as webinars, technical discussions, ARMA symposium sessions or workshops, and collaborative activities with other technical organizations, in consultation with the Chair and Vice Chair(s).
Social Media Lead and Co-Lead(s)	Serve as single-point-of-contact within the TC to engage with social media platforms and post upcoming webinars and related activities. They create and manage the TC email account for team members and social media to use to maintain contact with the TC. They also create and populate a social media presence on platforms such as LinkedIn®, YouTube, Twitter, Facebook®, and Instagram™ to promote TC activities.

Although the overall management and oversight of the USUTC is vested in the Chair/Vice Chair(s), they function primarily as ‘connectors’ for the individual technical and product teams. The TC has a matrix structure, suitable for virtual and/or self-organizing teams. Each team has considerable flexibility to operate, with light oversight from the Chair/Vice Chair(s) who remain available to the leads/co-leads. Each team member is expected and encouraged to “lead upwards” so that their experience and concerns can influence the full TC. Each team member is also asked to proactively communicate laterally to ensure the smooth and timely functioning of their respective teams. Both of these include recommending changes to TC

LinkedIn®

Social media engagement began with the creation of a dedicated LinkedIn® page (<https://www.linkedin.com/in/usutc-arma-508b1a1b6/>). It serves as a single-point-of-contact for professionals on LinkedIn® to communicate with the USUTC and to access some of its resources. For example, webinars hosted by ARMA technical committees require access details to be provided to interested parties on request (such as for Zoom-hosted events); these can be distributed using a generic platform such as LinkedIn®, rather than by less-secure public distribution (e.g., email). Announcement of events such as webinars posted on LinkedIn® that use the USUTC

page can also serve as a means for contacting the TC. The USUTC LinkedIn® page fulfills these functions while promoting other ARMA-sponsored Technical Committees and activities to a broader and more corporate-focused audience than may be represented by a scientific society.

YouTube

In conjunction with the growth of the USUTC, the question of where webinars and other audiovisual materials could be easily accessed arose. The frequency of webinars hosted by several of ARMA's technical committees since Spring 2020 created a dynamic where the website had difficulty in keeping up with the rapidly advancing schedule. Archiving of webinar materials for later viewing also became an issue. The USUTC chose to follow a model of other technical groups by shifting their webinar videos onto YouTube. This cost-free platform has become one of the outlets of choice for outreach to the broader global community, even for highly technical material that had been approved for public release. Other TCs had already begun moving in this direction and the USUTC chose to build on these experiences to utilize the YouTube platform.

A 'branded' channel was built and deployed for ARMA which can serve as a single point of access for the channels created independently by other TCs. Each TC channel can host videos of webinars and other materials as they choose. The USUTC hosted several regular webinars plus two others including an invited virtual seminar to the University of North Dakota's Student Chapter; an additional 30 respondents from the global community joined the TC as a result of the webinars. Providing for multiple access pathways to content is key, since YouTubers can access any video directly without having to navigate down from the ARMA channel. The YouTube channels help to mitigate the website's workload and archiving issues by hosting rapidly changing presentation schedules, videos, and related content there for free worldwide distribution.

Technical Committee Accomplishments

During the June 2020–June 2021 reporting period, the USUTC has:

- Fulfilled its founding mandate to collect and energize certain previously distinct areas within ARMA including carbon dioxide capture, utilization and storage; high-level nuclear materials storage; hydrocarbon storage (e.g., in the Strategic Petroleum Reserve); compressed-air energy storage; and other areas that benefit from geomechanics input and expertise, while keeping geothermal energy as its own area. This effort will continue as awareness of the TC spreads across the ARMA membership.
- Created an informal logo for use with the ARMA logo on the USUTC LinkedIn® page and YouTube channel.
- Organized and hosted nine webinars as part of a new series plus two special webinars through September 2021.
- Increased the visibility and awareness of USU topics; hardly a day goes by without news of CCUS, the New Hydrogen Economy, underground integrity and safety, crumbling infrastructure, and other topics that are gaining in importance worldwide as the nation moves into a broader energy mix.
- Established a LinkedIn® page to serve as a focal point for academic and industry professionals who utilize this social media platform for news on USU topics. It also serves as a "landing pad" for those requesting information or links to USUTC events, such as webinars, without compromising personal or company email accounts.
- Established a dedicated channel on YouTube to facilitate global access and distribution of ARMA-related videos, such as webinars, organized and hosted by the USUTC. New YouTube channels for ARMA Technical Committees and other activities were also organized under an overall, newly established ARMA YouTube channel.
- Created a dedicated team folder on Google One drive to facilitate access to TC materials. This folder archives the foundational and later documents of the TC, including:
 - o Its Charter, including the TC's coverage areas and organizational structure;
 - o The application to ARMA to form a Technical Committee including survey results and tabulated data on ARMA membership and diversity/gender equity data;
 - o Annual reports; and
 - o Working materials and workflows for ongoing projects, workshops, sessions, and publications.

- Prepared and submitted a proposal to ARMA in January, 2021 to establish a formal Technical Committee on USU. The Technical Committee was approved by ARMA in March, 2021.
- Organized a technical session on USUTC topics for the 55th U.S. Rock Mechanics/ Geomechanics Symposium, Houston for June 2021.
- Prepared the present article that describes our TC for the membership.
- Drafted and prepared for publication a formal peer-reviewed journal paper on USU. This will be one of only a handful of papers that knits together technical and energy-related product storage areas into a single comparative synthesis, and perhaps the only one to highlight geomechanics.

Technical Committee Benefits

The benefits delivered by the USUTC are aligned with ARMA's strategic goals and stakeholder expectations (e.g., Shenhar, 2004). Major benefits that accrue to ARMA include:

- Increased recognition of ARMA as a participant in promoting technical engagement in current and emerging issues of interest to underground storage and utilization.
- Cross-fertilization of key learnings to other TCs and activities within ARMA.
- Increased income through additional memberships, workshops or symposia that require fees and/or memberships for participation, and related activities.
- Stimulation of the next generation of practitioners and researchers in the field of underground storage and utilization geomechanics.
- Provision of ARMA members with a platform to raise awareness of USU technical advances and industry trends, share information about academic activities (conferences, workshops, academic sessions, forums, webinars, etc., which are not limited to those within ARMA or the TC), facilitate knowledge exchange, and promote cross-disciplinary collaborations.
- Collaborative or competing communities that may be pursuing similar objectives worldwide may be enriched by two-way engagement with the TC.
- Increased recognition and encouragement of ARMA's participation in the broader subsurface applications necessary to: (a) sustain security of energy storage and supply, (b) to contribute to

the global energy transition toward a net-zero economy, and (c) to focus on the definition and pursuit of technical breakthroughs required to allow broader commercialization of the subsurface.

Summary

The Underground Storage and Utilization Technical Committee (USUTC) was created in stages, beginning in Spring 2020, in response to a desire to connect energy storage-related areas within ARMA and by an enthusiastic confirmation by a sizeable fraction of active ARMA members. It has continued to grow in membership and influence since its establishment. The USUTC is an 'umbrella' group, with a matrix management structure, that associates five stored energy-related product types with four cross-cutting technical themes.

Communication both within and beyond ARMA is being augmented by hosting materials on social media platforms including LinkedIn® and YouTube. Both of these platforms are free of cost to ARMA. Building on the success of 2020 summer's 'Robe Talks' and webinars from other TCs, an energy storage-related webinar series was hosted with content distributed to the global geomechanics audience on a newly created set of channels on YouTube.

The USUTC fills a need for communication and sharing of information across the underground storage and utilization industry and, in joining with ARMA's other TCs, provides an additional outreach opportunity for ARMA that may contribute to increased interest and membership.

Acknowledgements

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working to design and produce YouTube channels for this, other technical committees, and ARMA. Gang Han, Sid Green, and Joe Morris contributed ideas that led to refinements in the TC's rationale and implementation.

Motivation for the design and deployment of our 2020–2021 webinar series was provided from ARMA's Hydraulic Fracturing Technical Committee's 'Robe Talks' series, organized by Gang Han and colleagues, as well as those from the Induced Seismicity Technical Committee. We thank all who graciously volunteered their time and expertise in making the entire effort happen.

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Induced Seismicity

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The Induced Seismicity Technical Committee was organized in 2017, the first of the five technical committees. The number of members in its Technical Community is estimated by its mailing list, consisting of almost 500 individuals, inviting participation in its monthly technical seminars.

Activities of the Committee for program year 2021 include:

Monthly Webinars. A regular webinar series was started in May 2020 during the pandemic shutdown, initially with bi-weekly webinars planned for a three-month period. The webinar series generated significant interest and so has evolved into a monthly webinar series. The Committee continues to get extremely high-quality individuals

to present, and the series is regularly described as the ‘premier webinar for induced seismicity’. Attendance varies in the range of 70–100 individuals. Plans are to continue the webinars while interest and attendance is maintained.

ARMA Sessions. Two induced seismicity sessions were included in the ARMA annual meeting, and were promoted within the technical community.

URTeC Presentation. The chair was invited to present at the “Best of ARMA” URTeC session, speaking on Induced Seismicity Best Practices.

Workshop. A workshop had been planned in conjunction with the annual symposium, but was unfortunately canceled when it was decided to hold the meeting online.

With regard to future plans, the main goal will be to continue the monthly webinars. Based on member feedback, sessions will feature presentations from regulators and high-level academics. More panel discussion formats are also being considered to discuss important technical topics.

Specific actions for 2022 include continuing the webinars, as well as plans to hold a workshop, possibly as part of support for the ongoing SEG/SPE series planned for 2022.

Hydraulic Fracturing

Submitted by Gang Han (Aramco Americas), John McLennan (University of Utah), and Joe Morris (Lawrence Livermore National Laboratory), Committee Co-Chairs

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There were a number of accomplishments of the Technical Committee (TCHF) in the past year, and a good deal of activity. The major activities included the following:

The Hydraulic Fracturing Community (HFC) grew to a 1000-person society -- the largest of its kind -- with members representing 332 international organizations, including 99 global universities, 31 national labs and research institutes, 79 energy operators, and 123 service providers.

In November, 2020, the committee held the first International Geomechanics Symposium online.

Evolved from the ARMA Middle East Hydraulic Fracturing Workshop in 2018, this event was co-hosted by ARMA, Dhahran Geoscience Society (DGS), and Society of Exploration Geophysicists (SEG). The conference had great success as the largest geomechanics event in the Middle East. Over 160 professionals from 50 international organizations in 16 countries attended. Four technical keynotes and 31 world-class presentations were selected from 82 abstracts.

During the pandemic in 2020, TCHF served thousands of professionals quarantined at home with more than 20 first-class “Robe Talks”, presented by TCHF and HFC members. With volunteers such as Dr. Wei Fu and Dr. Marisela Sanchez-Nigel, a free YouTube channel to host and record the presentations was established..

Following the Texas winter disaster in 2021, TCHF kicked off a volunteer effort named “Warm Up,” a series of biweekly technical webinars. Over a dozen speakers from TCHF and HFC shared technology advancements in hydraulic fracturing with hundreds of Community members.

Committee members issued over 30 HFC newsletters in 2020 and biweekly newsletters in 2021; these publications shared technology highlights, member research activities, collaboration requests, and job opportunities.

With regard to future plans for the Technical Committee, a full agenda is anticipated:

In 2021, committee members are organizing the 2nd International Geomechanics Symposium, to be held virtually on 1-3 November 2021. Again, it will be co-hosted by ARMA, DGS, and SEG; the meeting has also been endorsed by SPWLA and AAPG. Authors from more than 50 international organizations in 20 countries will present over 100 technical presentations. In addition, three ARMA Fellows and TCHF members will teach the leading-edge technologies in CO₂ Sequestration, Geothermal, and Smart Drilling.

In 2022, the third International Geomechanics Symposium in Abu Dhabi, UAE is scheduled. The conference becomes the largest geomechanics event in the Middle East.

The Committee expects to continue serving the

HFC members with latest technologies through newsletters, webinars, YouTube channel, and training opportunities. And members will strive to promote the applications of HF technologies in geothermal and other clean energy developments, identifying opportunities for HF in the low-carbon era.

From an organizational perspective, we plan to take actions and adopt policies that will promote diversity, equity, and inclusivity, and to engage more members in planning and organizing events. Further, members expect to establish five technical awards at the 2021 annual meeting (International Geomechanics Symposium) with selection criteria based on the legacy paper award guidelines at the ARMA Annual Symposium. And free geomechanics trainings to students, especially those from geomechanically underdeveloped regions, will be offered.

Tunneling

Submitted by Reza Hedayat and Jamal Rostami, Committee Co-Chairs, Colorado School of Mines.

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ARMA’s Technical Committee on Tunneling (TCT) was inaugurated in 2019 to offer technical expertise and specialization focused on rock tunneling, both to the tunneling industry stakeholders and ARMA members. The TCT is focused on the advancement of the rock tunneling practice by sharing technical knowledge on new concepts, design practices, construction methods, equipment, and materials for ground support to be used in tunneling and underground structures in rock.

This Committee leads the community of ARMA members interested in tunneling and underground construction in rocks. TCT’s goal is to advance the tunneling field by sharing technical knowledge on new methods, equipment, and materials for construction and support of underground excavations. The objectives of TCT are to organize technical sessions at annual symposia, develop and offer workshops and webinars on tunneling, and collaborate with

other committees in professional societies. Some of the Committee's planned activities are:

Create a Technical Community of both current and prospective ARMA members for the purpose of organizing seminar/webinar series.

Plan and organize technical sessions, specialty conferences, workshops, and short courses.

Solicit, prepare and/or review and edit papers, reports, manuals, and guidelines of practice.

Contribute to the ARMA Newsletter.

TCT is planning a series of Webinars as a platform for sharing ideas and experiences. ARMA members are invited to make a presentation or let us know if you have any topic of interest, so that the committee can arrange for a presentation on the topic. The Committee is currently working on securing speakers to talk about variety of topics from nuclear waste to storage caverns, seismic design, monitoring, challenging tunnels in rock, and case studies.

The first Webinar is scheduled for Wednesday, Oct. 20th at 2 pm EDT (12 pm mountain time).
Title: "Lesson's learned from some of the claims in recent Hard Rock TBM Tunneling Projects"
Speaker: Dr. Jamal Rostami

Note: Please register in advance through this link to receive calendar reminders and the meeting link: <https://mines.zoom.us/j/9478541763>

Drilling Mechanics and Engineering

Submitted by Emmanuel Detournay, Committee Chair; University of Minnesota

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The Technical Committee on Drilling Mechanics and Engineering (DME) was formed in October, 2018, now has ten members, and is actively seeking additional members. Recruiting will not only be focused on ARMA members, but also in efforts to organize a Technical Community among

those with an interest in drilling mechanics and engineering.

The technical activities in the current year included a session at the annual ARMA Symposium chaired by Haiying Huang and Julien Marck, and organized under the Interdisciplinary track. Members of the technical committee solicited and contributed papers to the session and all participated in the review process afterwards.

Inspired by the "Robe Talks" initiated by the Hydraulic Fracturing and Induced Seismicity Technical Committees, the Technical Committee also started a webinar series during Summer 2020. Three talks were organized. They attracted about 50 participants on average. Thanks to these talks we now have over 100 people in the contact list of a dedicated g-mail account through DMEARMA@gmail.com.

Upcoming events will include presenting a monthly webinar, leading in organizing technical sessions at the next ARMA Symposium (Santa Fe, 2022), more effort at recruiting members for the Committee, and establishing a foothold as a Technical Community.