GSCO2 in Focus

Newsletter for the Center for Geologic Storage of CO_2
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ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

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GSCO2 Center for Geologic Storage of CO_2

Small-scale Geologic Features Critical to Understanding Trapping Processes in CO_2 Reservoirs

The architecture of geologic formations is critical to understanding, and thus predicting, the movement of carbon dioxide (CO_2) when it is injected into the subsurface. Conceptual and quantitative models that accurately predict the location of injection CO_2 plumes offer better certainty when planning and conducting geologic carbon storage projects. Geologic formations with sedimentary architecture (formations that were formed when loose sediments were deposited and consolidated) are considered among some of the most promising candidates for geologic storage. Drs. Naum Gershenzon, Robert Ritzi Jr., David Dominic, Mohamadreza Soltanian (all from WSU), Edward Mehnert, and Roland Okwen (both from UIUC) published a paper on the importance of representing how small-scale features are organized within a hierarchy of larger-scale features and how properly modeling these features is critical to understanding trapping processes in some important candidate CO_2 reservoirs. The hierarchy of features ranged from cross sets at the smallest (decimeters thick to meters long) to channel-belt deposits (tens of meters thick and kilometers long). One challenge is perserving the small features in a geocellular model, like the one shown on the bottom left (the vertical exaggeration is 10×). The warmer colors represent higher permeability.

Trapping processes are one way injected CO_2 remains within a storage formation. They focused on capillary trapping, where CO_2 becomes trapped in immobile bubbles, and is influenced by the spatial difference of many factors in the formation, including permeability.

In their paper, they focus on a sedimentary formation that was deposited in a fluvial-type environment. The formation contains two different textural facies, sandstone and open-framework conglomerate cross sets, with different characteristic curves used for each when conducting reservoir simulations. The modeled heterogeneity structure and scales (and hence the geologic model) realistically reflect what has been observed and quantified in conglomeratic, fluvial-type reservoirs.

Capillary pressure and hysteresis effects are used in the reservoir simulations. Overall, 12 characteristic curves were used, including relative permeability and capillary pressure curves for drainage and imbibition for both brine and CO_2. Ultimately, they demonstrated that small-scale inclusions of high-permeability, open-framework conglomerate cross sets fundamentally control trapping processes and thus the shape and dynamics of the CO_2 plume.

The paper was published in *Water Resources Research* (you can find a full reference on page 3). To accomplish this work, the GSCO2 brought together researchers from the disciplines of geology and multiphysics flow and transport, as well as from two different institutions, the University of Illinois at Urbana-Champaign and Wright State University.

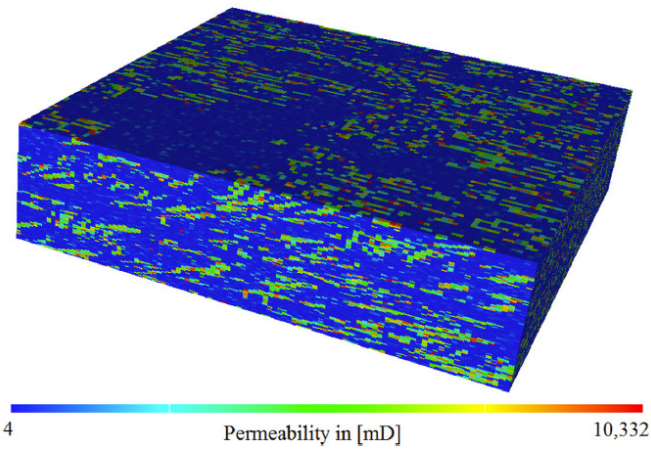


Figure 5 from Gershenzon et al., 2015, *Water Resources Research*, v. 51, see page 3 for full reference. Figure used with permission of John Wiley and Sons. ©2015 American Geophysical Union. All Rights Reserved.

In this Issue of the *GSCO2 in Focus*

This inaugural issue of the *GSCO2 in Focus* highlights the progress the GSCO2 has accomplished to date, the collaborative research in progress, and where the Center is headed. The next page contains a letter from the Director, Dr. Scott Frailey, about the goals and metrics of the Center as well as a brief overview of how the Center is structured.

Five GSCO2-supported publications have appeared in journals over the past months and many more are underway. You can find out more about them in the Publication Watch section on page 3.

Among the manuscripts currently submitted to peer-reviewed journals, several are under consideration for a special issue of the *Journal of Petroleum Science and Engineering* from the three carbon storage EFRCs. Driving these publications are the interconnected research efforts of the GSCO2's senior personnel, early career professionals, and students. We've highlighted one such student, Hassan Dashtian, in this issue's Portrait in a Paragraph: Students. Hassan is a member of the Multiphysics Flow and Transport theme and has contributed to studies on clay swelling and adsorption of CO_2. Another student, Charles Monson, is contributing to collaborative efforts on identifying stratigraphic controls on microseismicity. You can read about this work and other collaborative efforts on page 4. On the first page, you'll find an article about one of the papers published by GSCO2 researchers from the Geology and Multiphysics Flow and Transport themes.

The Center spent much of its time during the beginning of 2016 preparing for its Midterm Review, which occurred during the first week of March. The GSCO2 showcased the early results of its research, and how this research will ultimately contribute to technology that is safer, more predictable, and more reliable for geologic carbon storage. In addition, the end of March brought the second Annual Review Meeting, and the GSCO2 improved on the successes of last year's meeting (more on page 7). Members of the GSCO2's two external advisory committees, the Center Science Advisory Council and Center Industry Advisory Board (detailed on page 6), attended the Annual Review Meeting. Finally, at the 2016 North-Central Geological Society of America meeting in April, GSCO2 members presented on topics such as CO_2 trapping in reservoirs with fluvial sedimentary architecture and how relative permeability inputs and model complexity affect models of geologic carbon storage.

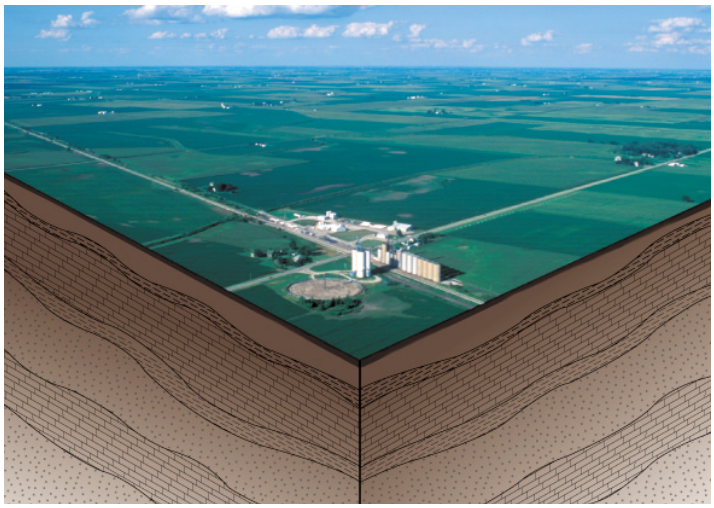


Photo credit: Joel Dexter, Illinois State Geological Survey (ISGS).
Illustration credit: Daniel Byers, ISGS.

Dr. Kenneth Christensen, principal investigator for the University of Notre Dame, was among the presenters at the North Central GSA meeting, and the Image of the Quarter (page 4) shows one of the heterogeneous micromodels from his ongoing research.

Portrait in a Paragraph: Students

Hassan Dashtian, MS
Multiphysics Flow and Transport Theme

Hassan Dashtian is a PhD student in chemical engineering at the University of Southern California. He holds both a BS and MS in petroleum engineering with an emphasis on drilling and production from Petroleum University of Technology and Sharif University of Technology, respectively. Currently, he is working on nano- and pore-scale simulation of salt precipitation in porous media using high performance computation. Hassan's other research interests include analysis of well log and seismic data and fluid flow and transport in porous media.

Publication Watch

GSCO2-supported publications available, listed by the most recent publication first, include:

- Ritzi, R.W., J.T. Freiburg, and N.D. Webb, 2016, Understanding the (co)variance in petrophysical properties of CO_2 reservoirs comprising sedimentary architecture: International Journal of Greenhouse Gas Control, v. 51, p. 423–434.

- Klokov, A., and B. Hardage, 2016, SV-P and S-S imaging at a CO_2 storage site using vertical seismic profiling data: International Journal of Greenhouse Gas Control, v. 46, p. 259–270.

- Gershenzon, N.I., R.W. Ritzi Jr., D.F. Dominic, M. Soltanian, E. Mehnert, and R.T. Okwen, 2015, Influence of small-scale, fluvial, sedimentary architecture on CO_2 trapping processes in deep saline aquifers: Water Resources Research, v. 51, no. 10, p. 8240–8256. doi:10.1002/2015WR017638.

- Laleian, A., A.V. Valocchi, and C.J. Werth, 2015, An Incompressible, Depth-averaged Lattice Boltzmann method for liquid flow in microfluidic devices with variable aperture: Computation, v. 3, no. 4, p. 600–615.

- Yoon, H., Q. Kang, and A.J. Valocchi, 2015, Lattice Boltzmann-Based approaches for pore-scale reactive transport: Reviews in Mineralogy and Geochemistry, v. 80, no. 1, p. 393–431.

The GSCO2 was featured in an article by Inside Illinois, a University of Illinois at Urbana-Champaign campus newspaper. The article, titled "Carbon dioxide storage is focus of new center's mission," discusses the goals and aims of the GSCO2. It appeared in the September 10, 2015, issue of the newspaper.

Director's Letter

It is a privilege and honor to be the Director of the Center for Geologic Storage of CO_2 (GSCO2), an Energy Frontier Research Center (EFRC), sponsored by the US Department of Energy (US DOE), Office of Science, Basic Energy Sciences Division. The GSCO2 is focused on use-inspired basic science in areas of further research identified during five different CO_2 injection pilot projects completed by the Illinois State Geological Survey (ISGS), through funding by the US DOE, Office of Fossil Energy, Carbon Capture and Storage Program. The ISGS is a division of the Prairie Research Institute at the University of Illinois at Urbana-Champaign.

The data collected and observations made at the five pilot projects is being used to validate hypotheses and test new models to increase certainty and confidence in the geologic storage of CO_2. To have a common basis for all aspects of our research, the lowermost Mt. Simon Sandstone was chosen and a specific depth is used for samples so that, as research results are available from the intratheme collaborations, intertheme research can integrate those results into a comprehensive, multidisciplinary approach.

The primary and most important metric of each EFRC is peer-reviewed publications. However, this published research must be the result of unique collaboration between researchers who would not likely work together if not for the Center. This synergistic approach is the essence of the EFRC program. The goal is to have better research in shorter periods of time. Opportunities for graduate students, post-doctoral students, and early career professionals are a vital part of the GSCO2 approach. We are expected to contribute to the education of the scientific workforce. We are expected to track the placement of our "alumni" into industry, academia, and research institutes, such as the national labs.

During the first year, much time was spent organizing the GSCO2 to be well aligned with the DOE's expectation for EFRCs and to find a unique identity for us. We have created several opportunities that will foster collaboration and introduce new and emerging research into the GSCO2. The GSCO2 Executive Committee, which consists of the Director, four Theme Coordinators, and four Theme Leaders,... (continued on page 5)

Research Highlights

Simulating brine and CO_2 flow in actual and modeled rock core

Dr. Pejman Tahmasebi (USC), Dr. Muhammad Sahimi (USC), Amir Kohanpur (UIUC), and Dr. Albert Valocchi (UIUC) have been simulating the flow of brine and CO_2 in reconstructed rock cores and comparing their results with data from the deep subsurface observatory, specifically samples of the Mt. Simon Sandstone. Properly characterizing the heterogeneity and variability of a candidate formation for geologic carbon storage often requires studying samples with time-consuming and costly three-dimensional (3D) imaging techniques. As an alternative to these 3D techniques, Dr. Tahmasebi and others developed and used a new computational approach that uses two-dimensional images of core samples to reconstruct a 3D sample—in other words, a model of the pore space. After creating the model of the pore space, they simulated two-phase flow of CO_2 and brine and quantitatively compared the connectivity of the pore space, permeability, and statistical properties of the reconstructed model with data from actual samples, which were taken from the deep subsurface observatory. They found the modeled samples accurately matched the actual samples. They have submitted a paper about their work to a journal.

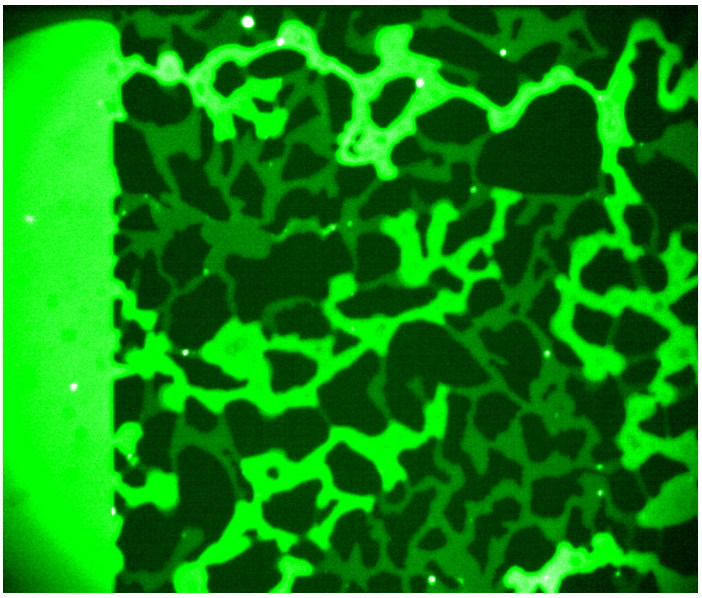
Relating microseismic events to the creation or reactivation of faults and fractures

Drs. Volker Oye and Bettina Goertz-Allmann (NORSAR); Sergey Stanchits (Schlumberger); Pierre Cerasi (SINTEF); and Robert Bauer (ISGS) have been investigating how the occurrence of microseismic events is related to the creation or re-activation of faults and fractures by stress changes imposed by pressure transients as a response to fluid injection. They combine laboratory-scale experiments with novel numerical modeling for upscaling and use acoustic emissions recorded in laboratory experiments to illustrate which attribute(s) trigger microseismicity. The results are related to field-scale observations of microseismicity. Detailed characterization of the type of microseismicity provides constraints on the pressure changes, extent, and stress front changes in geologic storage formations associated with the injection of CO_2. The ability to detect, locate, and characterize microseismic events provides a snapshot of the stress conditions within and around a geological reservoir. In addition, data on rapid stress changes like microseismic events can be used as input to hydro-mechanical models, often used to map fluid propagation. Dr. Oye presented their findings at the 2015 EFRC PI meeting.

Identifying stratigraphic controls on microseismicity

Charles Monson (UIUC), Jared Freiburg (UIUC), Drs. Robert Ritzi (WSU), Volker Oye (NORSAR), and Arjan Reesink (UIUC) have been investigating the relationship between depositional architecture, basement topography, and microseismicity. The Argenta Formation, a marine-influenced and topography-controlled unit, has been the focus of their efforts. The Argenta Formation underlies the Mt. Simon Sandstone, a sedimentary unit and CO_2 storage target at the GSCO2's deep subsurface observatory. Units like the Argenta can be barriers to flow and pressure propagation, which is linked to microseismicity. Moreover, an extensive amount of microseismic data, along with core and logs, makes the Argenta a good formation to investigate the interplay of depositional architecture and basement topography and microseismicity, and thus it can provide better understanding of the mechanism(s) that cause(s) microseismicity. Monson most recently presented their research progress as a poster at the GSCO2's Midterm Review Meeting, and a paper is in preparation.

Image of the Quarter



Sample image of water-CO_2 phase configuration as supercritical CO_2 displaces resident water at room temperature and a pressure of 80 bar in a two-dimensional heterogeneous micromodel. The bright green regions are CO_2, darker green regions are water, and the black-regions are the grains of the porous matrix. Bulk flow is from left to right. Image courtesy of Drs. Kenneth Christensen and Yaofa Li of the University of Notre Dame.

Using Vertical Seismic Profiling Data to Image SV-P and S-S Waves at a CO_2 Storage Site

In a 2016 *International Journal of Greenhouse Gas Control* publication, Drs. Alexander Klokov and Bob Hardage (both UT-Austin) describe their efforts to image a CO_2 storage site using vertical seismic profile (VSP) data, which was acquired from the GSCO2's deep subsurface observatory. Typically, only compressional (P) waves are used to image geologic formations at a CO_2 storage site because the costs of horizontal-force vibrators, which are needed to generate shear (S) wave images, are cost prohibitive. However, S-wave images provide important information about geologic formations, including porosity and permeability, and they are highly sensitive to fractures.

Drs. Klokov and Hardage described a methodology to extract S-waves emitted by vertical-force vibrators, and they compared the S and SV-P (converted shear) images with P, P-SV (converted compressional), and P-SH (converted compressional) images (The difference between SV and SH is that SV is oriented in the vertical plane passing through a source station and a receiver station and SH is oriented perpendicular to the vertical plane). They found all of these images to be consistent with each other. This suggests that it's possible to acquire S-wave images using only conventional P-P recording equipment, specifically vertical-force vibrators and vertical receivers. Thus, the method presented by Drs. Klokov and Hardage provides a low-cost option to acquire full seismic wavefield analysis for geologic formations, such as storage reservoirs at CO_2 storage sites. In their conclusion, they indicate their next step is to construct full three-dimensional VSP images for direct-P and direct-S waves using their methodology. To read more about this work, see their paper's full citation in the Publication Watch.

(continued from page 3) ...is tasked with guiding the GSCO2 to meet its research goals and metrics. Leaders direct and lead the research within their themes, and Coordinators ensure the functionality of their theme's research and progress towards the GSCO2 goals and metrics.

Regularly scheduled webinars are the impetus for fostering collaboration. Monthly, there are theme-specific meetings and student meetings to foster intratheme collaboration. Each theme has a monthly webinar with each researcher providing an update of his or her work for the month. Intertheme collaborations are encouraged via monthly meetings given by the theme leader or coordinator where all of the GSCO2 is invited; each theme presents every 4 months. To build research relationships between students, each month two to three students present their work to other GSCO2 students. To further foster collaborations with the students, the GSCO2 has an open solicitation to fund students for travel to other GSCO2 researchers' facilities, DOE facilities, or other EFRC scientists. We started a new internal RFP program to encourage existing GSCO2 principal investigators to propose new emerging basic research that may introduce new principal investigators to the GSCO2.

Though we had a slower than expected start to our research due to contracts and confidentiality agreements, data accessibility and availability from the pilot projects, and recruiting new students at the start of a new school year, we have now started to have several peer-reviewed journal publications submitted per month.

Besides the unique opportunity to delve into basic-research solutions to problems that are typically solved by "tweaking" current technology, directing the GSCO2 has allowed me to meet new researchers that I otherwise would never have had the opportunity to collaborate with. It is exciting to have the GSCO2 management infrastructure in place and now more effort can be spent on understanding the fundamental principles regarding the geologic storage of CO_2.

Scott

Did you know that the GSCO2...

- is one of 32 EFRCs representing most areas of energy-related research.
- is one of three EFRCs with a focus on the geologic storage of CO_2.
- uses results from one large demonstration project, three CO_2 enhanced oil recovery pilots, and one enhanced coalbed methane pilot.
- has 28 Senior/Key personnel, at five universities, two research institutes, one national lab, and one corporation.
- has 16 graduate students, four post-doctoral students, and three early career professionals.

GSCO2 Advisory Committees

Annually, the GSCO2 has an external review by the Center Science Advisory Council (CSAC) and Center Industry Advisory Board (CIAB). The CSAC is predominantly university professors with expertise in various aspects of each GSCO2 research theme but not necessarily specific to the geologic storage of CO_2. The CIAB represents natural gas storage, oil and gas industry (upstream services and consulting), and utilities. Their purpose is to provide advice to the Director and Executive Committee with regards to areas of research, research accomplishments, and relevance and usefulness of research.

Center Industry Advisory Board

Name	Company	Title	Term of Service
Charles Christopher	CO_2 Store	CO_2 Geological Storage Consultant	2014–2016
Tom Davis	WEC Energy Group	Supervisor, Petroleum Engineering Consultant	2014–2016
Richard Esposito	Southern Company	Program Manager–Geosciences, Carbon Storage and Utilization	2014–2016
Alberto Giussani	Oxy	Reservoir Engineer	2015–2017
George Koperna	Advanced Resources International	Vice President	2014–2016
Ian Lunt	Statoil	Principal Geologist	2015–2017
Yongqi Lu	Applied Research Laboratory; ISGS/UIUC	Chemical/Environmental Engineer	2014–2016
Shawn Maxwell	ITASCA-IMaGE	President/CTO	2014–2016
Carl Sisk	Ingrain	Chief Reservoir Engineer	2015–2017
Rob Trautz	Electric Power Research Institute	Principal Technical Leader	2014–2016
Robert (Bo) Tye	DeGolyer and MacNaughton	Vice President, Geological Advisor	2014–2016

Center Science Advisory Council

Name	Company/Institution	Title	Term of Service
Alexey Bezryadin	University of Illinois at Urbana-Champaign	Professor, Department of Physics	2015–2017
Donald DePaolo	Lawrence Berkeley National Laboratory	Associate Laboratory Director for Energy Sciences; Professor and Isotopic Geochemist; Director for Center for Nanoscale Controls on Geologic CO_2	2014–2016
Neeraj Gupta	Battelle Memorial Institute	Senior Research Leader	2014–2016
George Guthrie	Los Alamos National Laboratory	Program Manager for Applied Energy	2015–2017
William Harbert	University of Pittsburgh	Professor of Geophysics	2015–2017
Thomas Johnson	University of Illinois at Urbana-Champaign	Professor and Head of Department, Department of Geology	2015–2017
Young Shin Jun	Washington University in St. Louis	Associate Professor in the Department of Energy, Environmental, and Chemical Engineering; Director of Graduate Studies	2014–2016
Larry Lake	University of Texas at Austin	Professor, Petroleum and Geosystems Engineering; Director, Center for Frontiers of Subsurface Energy Security	2014–2016
John McBride	Brigham Young University	Professor and Chair, Department of Geological Studies	2014–2016
Mohammad Piri	University of Wyoming	Associate Professor of Petroleum Engineering	2014–2016
John Popovics	University of Illinois at Urbana-Champaign	Professor, Department of Civil and Environmental Engineering; Co-Director of Societal Risk Management Program	2015–2017
Henrique Reis	University of Illinois at Urbana-Champaign	Professor, Departments of Industrial and Enterprise Systems Engineering and of Civil and Environmental Engineering	2014–2016
Timothy Scheibe	Pacific Northwest National Laboratory	Senior Scientist and Lead Scientist for Multiscale Modeling and High-Performance Computing	2015–2017
Dorthe Wildenschild	Oregon State University	Professor, School of Chemical, Biological and Environmental Engineering	2014–2016
Lesli Wood	Colorado School of Mines	Endowed Chair Professor, Geology and Geological Engineering	2014–2016

2016 GSCO2 Annual Review Meeting

The GSCO2 hosted its annual review meeting in Champaign, IL, on March 30–31. All GSCO2 members were invited, and a total of 64 members attended. Members of the Center's two external advisory committees (see page 6) also attended. The meeting provided a forum to share research progress, accomplishments, and directions across the Center's four themes—Geology, Geophysics, Geomechanics, and Multiphysics Flow and Transport—as well as receive input from the advisory committees on research progress and directions.

The first day featured technical presentations by each principal investigator. The presentations were organized by themes and each theme began with an overview of the theme's activities and how these activities contribute to basic-science research and the GSCO2's two fundamental research questions. Theme Coordinators gave these overview presentations.

Following the technical presentations, GSCO2 students, post-docs, and early career professionals highlighted their research in a poster session. This session encouraged discussion between young scientists (graduate students, post-doctoral students, and early career professionals), senior researchers, and members of the advisory committees. Topics of the posters ranged from molecules to pores to large-scale geologic features.

On the second day, cross-theme and individual working meetings were held. Researchers discussed barriers to current collaborative efforts and developed a way forward in real time to ensure research progresses in a timely manner. Members of the advisory committees joined the working meetings to give input on the challenges facing each theme and to hear directly about the future direction of each theme's research. At the conclusion of the day, the advisory committees reported their observations and comments to all themes. Members of the advisory committees commented that the GSCO2 made substantial progress from its meeting last year.

Center Industry Advisory Board members (from left to right): Tom Davis, Robert (Bo) Tye, Richard Esposito, Charles Christopher, Shawn Maxwell, Carl Sisk, George Koperna, Yongqi Lu, and Alberto Giussani. Photo credit: Jonathan Cox, Illinois State Geological Survey.

Center Science Advisory Council members (from left to right): Young Shin Jun, Dorthe Wildenschild, Thomas Johnson, William Harbert, John Popovics, Alexey Bezryadin, and John McBride. George Guthrie attended the meeting but was not present for the picture. Photo credit: Jonathan Cox, Illinois State Geological Survey.

Left: GSCO2 Director Dr. Scott Frailey presenting on the Center's goals and organization. Above: Dr. Kristian Jessen, University of Southern California, presenting on multiphysics research. Photo credit: Jonathan Cox, Illinois State Geological Survey.

Who is the GSCO2?

Senior/Key Personnel

- Robert Bauer
- James Best
- Pierre Cerasi
- Kenneth Christensen
- Michael DeAngelo
- David Dominic
- Erling Fjaer
- Bruce Fouke
- Scott Frailey
- Naum Gershenzon
- Bettina Goertz-Allmann
- Angela Goodman
- Bob Hardage
- Kristian Jessen
- Michael Jordan
- Donald W. Lee
- Edward Mehnert
- Roland Okwen
- Volker Oye
- Robert Ritzi
- Muhammad Sahimi
- Diana Sava
- Sergey Stanchits
- Theodore Tsotsis
- Albert Valocchi
- Charles Werth
- Robert Will
- Donna Willette

Early Career Professionals and Students

- Sahar Bakhshian
- Peter Berger
- Gianluca Blois
- Julien Botto
- Yu Chen
- James Damico
- Hassan Dashtian
- Jared Freiburg
- Samantha Fuchs
- Ritu Ghose
- Alexander Klokov
- Amir Kohanpur
- Nadège Langet
- Yaofa Li
- Charles Monson
- Jami Moore
- Christopher Patterson
- Mahsa Rahromostaqhim
- Arjan Reesink
- Zhuofan Shi
- John Tudek
- Nathan Webb
- Ruisong Zhou

Partner Institutions

- Illinois State Geological Survey
- University of Illinois at Urbana-Champaign
- Wright State University
- University of Notre Dame
- NORSAR
- SINTEF
- University of Southern California
- Schlumberger
- National Energy Technology Laboratory
- University of Texas at Austin

Portrait in a Paragraph: Senior/Key Personnel

Albert Valocchi, PhD
Multiphysics Flow and Transport Theme
Senior/Key Person at UIUC

Dr. Albert J. Valocchi is the Abel Bliss Professor in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. He has been on the faculty at Illinois since 1981. Valocchi's research focuses upon computational modeling of pollutant fate and transport in porous media, with applications to groundwater contamination, geological sequestration of carbon dioxide, and impacts of model uncertainty on groundwater resources management. He received his BS in environmental systems engineering from Cornell University in 1975 and did his graduate studies at Stanford University in the Department of Civil Engineering, receiving his MS in 1976 and PhD in 1981. In 2009, he was recognized as a Fellow of the American Geophysical Union.

In the Next Issue

In addition to updates on research activities, the next issue of the *GSCO2 in Focus* will summarize the results of the Department of Energy's Midterm Review completed in June and our Annual Review Meeting held in March. Based on recommendations from these reviews, the GSCO2 decided to focus all research on mechanical properties of rocks and microseismicity associated with pressure perturbations associated with CO_2 storage. Our overarching research question is:

What are the mechanisms of injection-induced microseismicity, and can we control and predict its occurrence?

In support of this overarching research question, specific subquestions have been identified, and specific research plans will be developed in the next few weeks. Simultaneous to developing research with a new focus, we are reorganizing our structure from discipline-based themes to research question-based themes. Smaller multi-institute teams will ensure focused, collaborative research leads to multi-institute publications.

Newsletter by Dan Klen, Asst. Scientific Editor, ISGS
Contact: dklen2@illinois.edu