Gulf Coast Carbon Center

2014-2018 Retrospective

Capturing a cleaner and brighter future








Bureau of Economic Geology

Gulf Coast Carbon Center

These sponsors contributed during the 2014-2018 period.

Chevron

ExxonMobil

bp

ارامكو السعودية
Saudi Aramco

nrg
Carbon 360

JX

Schlumberger

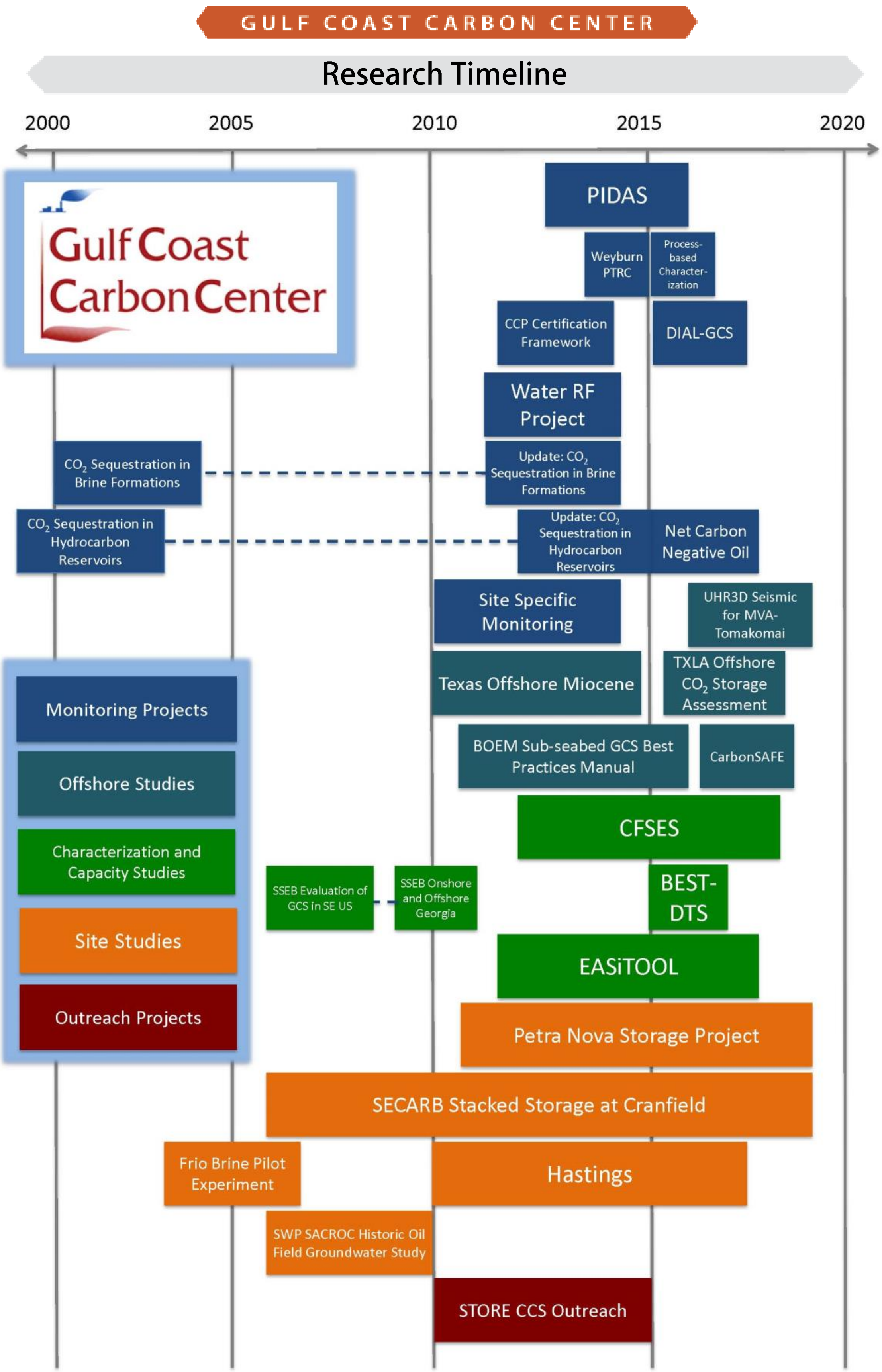
USGS
science for a changing world

CMG
COMPUTER MODELLING GROUP LTD.

TEXAS Geosciences
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Bureau of Economic Geology

Table of Contents


GULF COAST CARBON CENTER
Research Timeline
2000
2005
2010
2015
2020
Gulf Coast Carbon Center
PIDAS
Weyburn PTRC
Process-based Character-ization
CCP Certification Framework
DIAL-GCS
Water RF Project
CO2 Sequestration in Brine Formations
Update: CO2 Sequestration in Brine Formations
CO2 Sequestration in Hydrocarbon Reservoirs
Update: CO2 Sequestration in Hydrocarbon Reservoirs
Net Carbon Negative Oil
Site Specific Monitoring
UHR3D Seismic for MVA-Tomakomai
Texas Offshore Miocene
TXLA Offshore CO2 Storage Assessment
Monitoring Projects
Offshore Studies
Characterization and Capacity Studies
Site Studies
Outreach Projects
BOEM Sub-seabed GCS Best Practices Manual
CarbonSAFE
CFSES
SSEB Evaluation of GCS in SE US
SSEB Onshore and Offshore Georgia
BEST-DTS
EASiTOOL
Petra Nova Storage Project
SECARB Stacked Storage at Cranfield
Frio Brine Pilot Experiment
Hastings
SWP SACROC Historic Oil Field Groundwater Study
STORE CCS Outreach

Goals

Previous research on capacity has focused on static volumetric assessments at regional scales and modeled injection scenarios at reservoir scales. The fundamental research results suggest that capacity is generally available at the volumes and timescales needed. Results at reservoir scale indicate that challenges for representing heterogeneity remain, and that tools are needed for rapid but accurate screening of potential reservoir candidates.

Emerging capacity-related interests are:

- post-injection performance (during overpressure decay),
- understanding the impacts on capacity resulting from stratigraphic heterogeneity at meso-scales (continuum to reservoir block scale), and
- the potential for pressure build-up to limit injectivity.

The first two topics include aspects where fluid transport is likely to be dominated by buoyancy. The implications for key challenges for geologic carbon storage are significant: In buoyancy-dominated flow, CO_2 may travel much farther (**How Far?**) than anticipated by conventional modeling/simulation, thereby greatly decreasing volumetric storage efficiency (**How Much?**) and possibly reducing storage security (**How Fast?**). Pressure build up is most strongly related to boundary conditions at both regional and local scales. Figure 1 represents some of the conceptualized problem.

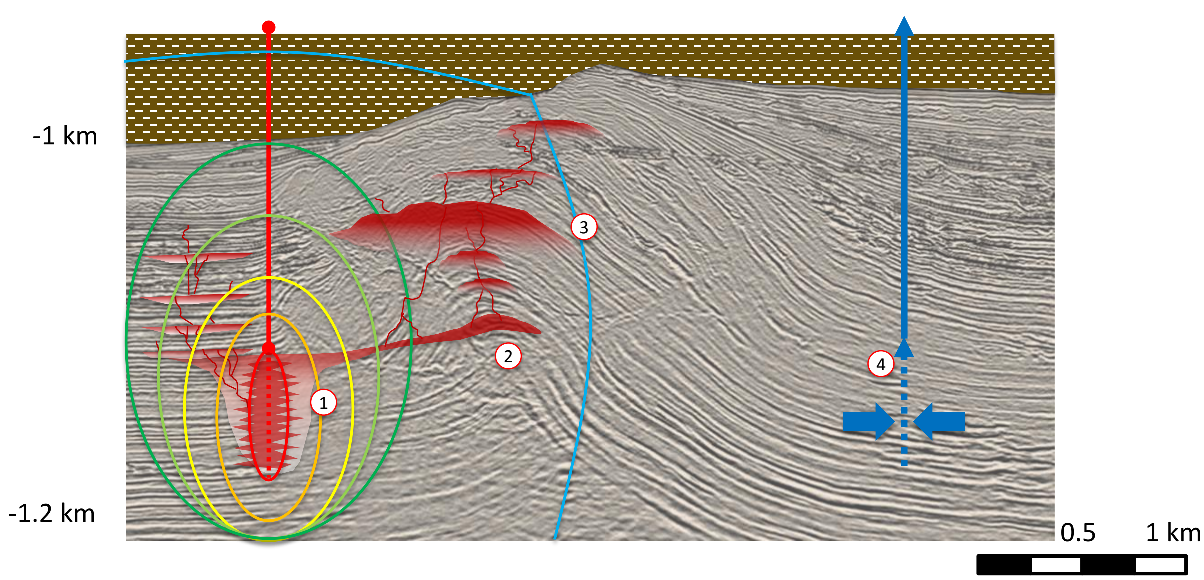


Figure 1. Conceptualization of problem. (1) Strong pressure gradients and inertia effects during the injection period limiting injectivity (2) Buoyancy, capillarity, and pressure gradients control plume behavior (3) Far-field region where buoyancy-capillary effects dominate (4) Pressure management and plume control strategy via brine extraction.

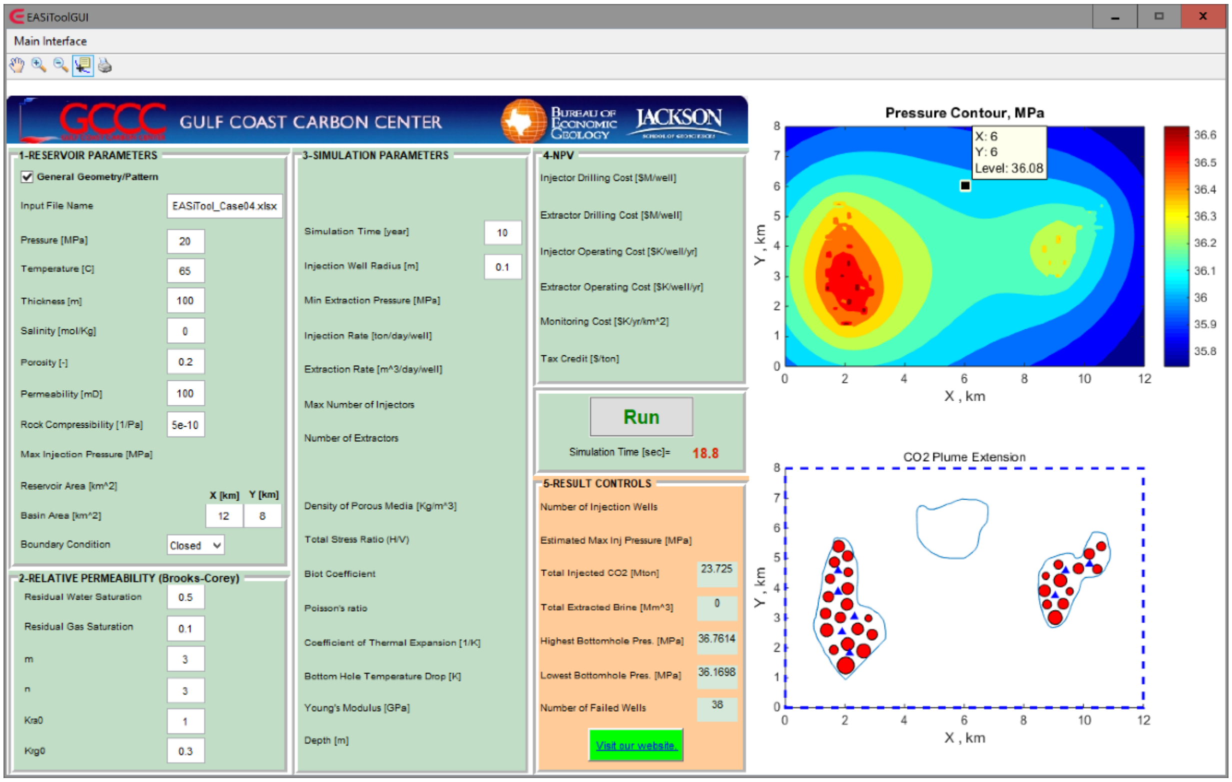


Figure 2. EASiTool interface.

Accomplishments

- Developed an Enhanced Analytical Simulation Tool (EASiTool) for simplified reservoir models with the following capabilities (Fig 2):
  - Estimate CO_2 storage capacity in saline aquifers limited by pressure buildup.
  - Estimate maximum injection pressure for a given formation.
  - Incorporate brine extraction into storage capacity estimation.
  - Provide sensitivity analysis for input parameters.

- Modeled and quantified saturation resulting from buoyant flow in high-resolution, small-scale, geologically-realistic clastic materials.

Accomplishments continued...

- Developed the laboratory experimental capability to visualize buoyant flow in engineered sandpacks with validation via numerical simulation (Fig 3).
- Identified key depositional geometries that influence CO_2 migration and retention in deltaic depositional systems at reservoir scale.

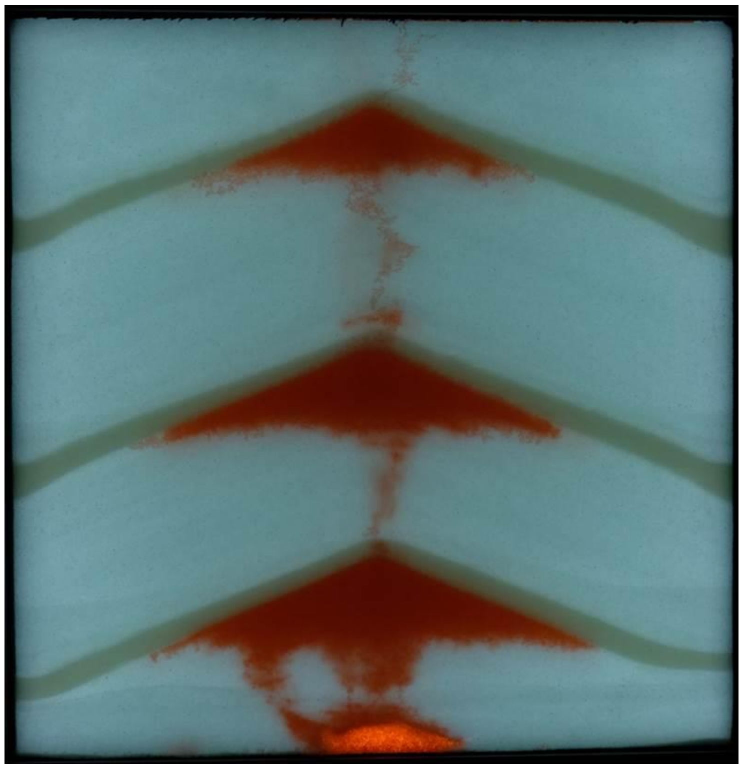


Figure 3. Sand-pack experiments.

Major Projects

- **Enhanced Analytical tool for CO_2 storage capacity estimation, funded by DOE.**
  A user-friendly software program was developed to estimate CO_2 storage capacity in saline formations. The main limiting factor in this software is dynamic pressure buildup in the formation over injection period.

- **Understanding buoyancy-dominated flow in heterogeneous clastic materials, Leveraged from CFSES.**
  Unique integration of simplified computational methods (analytical & IP) with observations from laboratory experiments under buoyancy, capillarity dominated flow regime.

Impacts & Key Findings

- Released a new scientific and user-friendly CO_2 storage capacity estimation tool for CCS community.
- Performed assessment and optimization of brine extraction on CO_2 storage capacity estimation.
- Discovered that recognition of expectations of flow behavior and resulting saturation are influenced by simulation technique (viscous versus buoyancy driven), and critical for understanding capacity and leakage risks.
- Validated invasion percolation techniques for simulating CO_2 migration under buoyant flow conditions.
- Developed predictive saturations resulting from local capillary trapping of buoyant flow at small scales.

Personnel

- Seyyed A. Hosseini
- Tip Meckel
- Reza Ganjdanesh
- Luca Trevisan
- Prasanna Krishnamurthy
- Akand Islam
- Emily Beckham
- Hoonyoung Jeong

Contact

Dr. Seyyed A. Hosseini
seyyed.hosseini@beg.utexas.edu, +1 512-471-2360

Selected Publications

Alfi, M., Hosseini, S.A., 2016. Integration of reservoir simulation, history matching, and 4D seismic for CO_2-EOR and storage at Cranfield, Mississippi, USA. Fuel 175, 116–128. https://doi.org/10.1016/j.fuel.2016.02.032

Alfi, M., Hosseini, S.A., Alfi, M., Shakiba, M., 2015. Effectiveness of 4D Seismic Data to Monitor CO_2 Plume in Cranfield CO_2-EOR Project. Presented at the Carbon Management Technology Conference, Carbon Management Technology Conference. https://doi.org/10.7122/439559-MS

Ambrose, W.A., Breton, C., Núñez-López, V., Gülen, G., 2015. EOR Potential from CO_2 Captured from Coal-Fired Power Plants in the Upper Cretaceous (Cenomanian) Woodbine Group, East Texas Basin, and Southeastern Texas Gulf Coast, USA. Nat Resour Res 24, 161–188. https://doi.org/10.1007/s11053-014-9242-z

Chang, K.W., 2013. Carbon dioxide storage in geologically heterogeneous formations. University of Texas, Austin, Tex.

Ganjdanesh, R., Hosseini, S.A., 2017. Geologic Carbon Storage Capacity Estimation Using Enhanced Analytical Simulation Tool (EASiTool). Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 4690–4696. https://doi.org/10.1016/j.egypro.2017.03.1601

Ganjdanesh, R., Hosseini, S.A., 2016. Potential assessment of methane and heat production from geopressured–geothermal aquifers. Geothermal Energy 4, 16. https://doi.org/10.1186/s40517-016-0058-4

Ganjdanesh, R., Hosseini, S.A., 2015. Impact of Brine Extraction and Well Placement Optimization on Geologic Carbon Storage Capacity Estimation. AGU Fall Meeting Abstracts 53, H53H–1764.

Goudarzi, A., Almohsin, A., Varavei, A., Taksaudom, P., Hosseini, S.A., Delshad, M., Bai, B., Sepehrnoori, K., 2017. New laboratory study and transport model implementation of microgels for conformance and mobility control purposes. Fuel 192, 158–168. https://doi.org/10.1016/j.fuel.2016.11.111

Goudarzi, A., Hosseini, S.A., Sava, D., Nicot, J.-P., n.d. Simulation and 4D seismic studies of pressure management and CO_2 plume control by means of brine extraction and monitoring at the Devine Test Site, South Texas, USA. Greenhouse Gas Sci Technol n/a-n/a. https://doi.org/10.1002/ghg.1731

Islam, A., Sun, A., Lu, J., 2016a. Simulating in-zone chemistry changes from injection time to longer periods of CO_2 storage. Environ Earth Sci 75, 1346. https://doi.org/10.1007/s12665-016-6153-9

Islam, A., Sun, A.Y., Yang, C., 2016b. Reactive Transport Modeling of the Enhancement of Density-Driven CO_2 Convective Mixing in Carbonate Aquifers and its Potential Implication on Geological Carbon Sequestration. Scientific Reports 6, 24768. https://doi.org/10.1038/srep24768

Islam, A.W., Meckel, T.A., Sun, A.Y., Krishnamurthy, P.G., 2016. Numerical experiments of density driven CO_2 saturated brine migration in heterogeneous two-dimensional geologic fabric materials. International Communications in Heat and Mass Transfer 71, 148–156. https://doi.org/10.1016/j.icheatmasstransfer.2015.12.019

Islam, A.W., Sun, A.Y., 2016. Corrosion model of CO_2 injection based on non-isothermal wellbore hydraulics. International Journal of Greenhouse Gas Control 54, 219–227. https://doi.org/10.1016/j.ijggc.2016.09.008

Jeong, H., Srinivasan, S., 2016. Fast assessment of CO_2 plume characteristics using a connectivity based proxy. International Journal of Greenhouse Gas Control 49, 387–412. https://doi.org/10.1016/j.ijggc.2016.03.001

Krishnamurthy, P.G., Senthilnathan, S., Yoon, H., Thomassen, D., Meckel, T., DiCarlo, D., 2017. Comparison of Darcy's law and invasion percolation simulations with buoyancy-driven CO_2-brine multiphase flow in a heterogeneous sandstone core. Journal of Petroleum Science and Engineering, Energy Frontier Research Centers for Investigating Carbon Sequestration 155, 54–62. https://doi.org/10.1016/j.petrol.2016.10.022

Lu, J., Mickler, P.J., Nicot, J.-P., 2014a. Geochemical Impact of Oxygen Impurity on Siliciclastic and Carbonate Reservoir Rocks for Carbon Storage. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 4782–4798. https://doi.org/10.1016/j.egypro.2014.11.509

Lu, J., Mickler, P.J., Nicot, J.-P., Yang, C., Darvari, R., 2016a. Geochemical impact of O_2 impurity in CO_2 stream on carbonate carbon-storage reservoirs. International Journal of Greenhouse Gas Control 47, 159–175. https://doi.org/10.1016/j.ijggc.2016.01.039

Lu, J., Mickler, P.J., Nicot, J.-P., Yang, C., Romanak, K.D., 2014b. Geochemical impact of oxygen on siliciclastic carbon storage reservoirs. International Journal of Greenhouse Gas Control 21, 214–231. https://doi.org/10.1016/j.ijggc.2013.12.017

Lu, J., Nicot, J.-P., Mickler, P.J., Ribeiro, L.H., Darvari, R., 2016b. Alteration of Bakken reservoir rock during CO_2-based fracturing—An autoclave reaction experiment. Journal of Unconventional Oil and Gas Resources 14, 72–85. https://doi.org/10.1016/j.juogr.2016.03.002

Lu, J., Ruppel, S.C., Rowe, H.D., 2015. Organic matter pores and oil generation in the Tuscaloosa marine shale. AAPG Bulletin 99, 333–357. https://doi.org/10.1306/08201414055

Meckel, T.A., Bryant, S.L., Ravi Ganesh, P., 2015. Characterization and prediction of CO_2 saturation resulting from modeling buoyant fluid migration in 2D heterogeneous geologic fabrics. International Journal of Greenhouse Gas Control 34, 85–96. https://doi.org/10.1016/j.ijggc.2014.12.010

Meckel, T.A., Trevisan, L., Krishnamurthy, P.G., 2017. A method to generate small-scale, high-resolution sedimentary bedform architecture models representing realistic geologic facies. Scientific Reports 7, 9238. https://doi.org/10.1038/s41598-017-09065-9

Mickler, P.J., Yang, C., Lu, J., Lankford, K.D., 2014. Laboratory Batch Experiments and Geochemical Modelling of Water-rock-super Critical CO_2 Reactions in Gulf of Mexico Miocene Rocks: Implications for Future CCS Projects. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 5512–5521. https://doi.org/10.1016/j.egypro.2014.11.584

Mukhopadhyay, S., Doughty, C., Bacon, D., Li, J., Wei, L., Yamamoto, H., Gasda, S., Hosseini, S.A., Nicot, J.-P., Birkholzer, J.T., 2015. The Sim-SEQ Project: Comparison of Selected Flow Models for the S-3 Site. Transp Porous Med 108, 207–231. https://doi.org/10.1007/s11242-014-0361-0

Nicot, J.-P., Lu, J., Mickler, P., Solano, S.V., 2015. Chapter 26: Impact of CO_2 impurities on storage performance and assurance, in: Gerdes, K.F. (Ed.), Carbon Dioxide Capture for Storage in Deep Geologic Formations, Results from the CO_2 Capture Project, Volume 4: CCS Technology Development and Demonstration Results (2009-2014). CPL Press, UK, pp. 385–400.

Soltanian, M.R., Amooie, M.A., Cole, D.R., Graham, D.E., Hosseini, S.A., Hovorka, S., Pfiffner, S.M., Phelps, T.J., Moortgat, J., 2016. Simulating the Cranfield geological carbon sequestration project with high-resolution static models and an accurate equation of state. International Journal of Greenhouse Gas Control 54, 282–296. https://doi.org/10.1016/j.ijggc.2016.10.002

Trevisan, L., Illangasekare, T.H., Meckel, T.A., 2017a. Modelling plume behavior through a heterogeneous sand pack using a commercial invasion percolation model. Geomech. Geophys. Geo-energ. Geo-resour. 3, 327–337. https://doi.org/10.1007/s40948-017-0055-5

Trevisan, L., Krishnamurthy, P.G., Meckel, T.A., 2017. Impact of 3D capillary heterogeneity and bedform architecture at the sub-meter scale on CO_2 saturation for buoyant flow in clastic aquifers. International Journal of Greenhouse Gas Control 56, 237–249. https://doi.org/10.1016/j.ijggc.2016.12.001

Trevisan, L., Pini, R., Cihan, A., Birkholzer, J.T., Zhou, Q., González-Nicolás, A., Illangasekare, T.H., 2017b. Imaging and quantification of spreading and trapping of carbon dioxide in saline aquifers using meter-scale laboratory experiments. Water Resour. Res. 53, 485–502. https://doi.org/10.1002/2016WR019749

Theme B: Evolution of Fluid Chemistry from Deep Reservoir to Near-Surface

Goals

Assessment of potential migration of fluid mixtures from depth to the near-surface is widely considered important for geologic storage projects. Information is needed to determine if and how a leakage signal might be detected, how upward migration of fluid mixtures might impact natural resources, and how upward migration could be quantified and remediated if needed. However, the complexity of the system is large and leakage processes generally have been oversimplified, removing considerations such as the rate at which leakage signal would evolve and changes in fluid composition during transport along a flow path. This research will probe the nature and importance of complex vertical migration processes and how these processes will impact a surface signal.

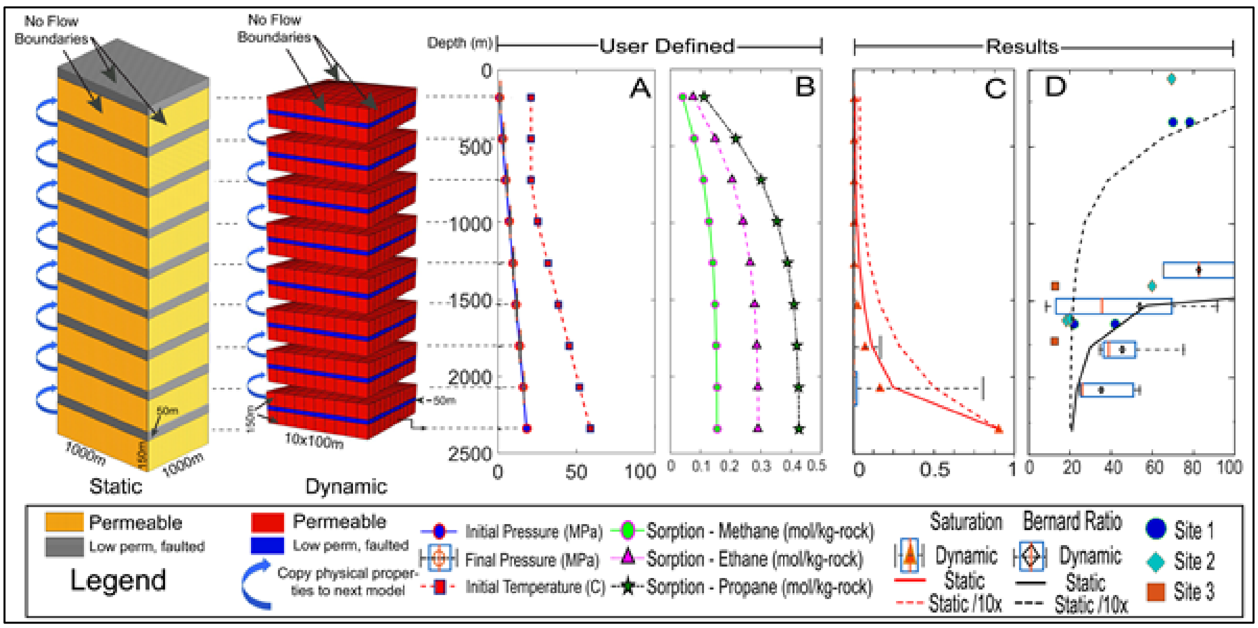


Figure 1. Numerical simulation design of potential geochemical alterations during vertical transport of CO2 through the overburden.

Accomplishments

- Collected relevant and innovative data sets from a variety of depths and under a variety of field conditions including at GCCC terrestrial field sites (e.g. Cranfield, Hastings, and West Ranch), a natural analog (Bravo dome), and a controlled-release test site (Brackenridge Field Laboratory). We also acquired a unique dataset from San Luis Pass, offshore of the Texas Gulf Coast, and from an area of fracking in Parker County, Texas.

- Validated field observations with laboratory simulations, including using the current two-phase flow reaction apparatus adaptable to a wide range of geological media, gas phase injection and dissolved gas saturations.

Accomplishments continued...

- Used robust and efficient models to combine and interpret results from experimental and field-based studies to understand geochemical processes that effect the chemical evolution of fluid-rock mixtures from deep reservoir to near-surface.

- Used example of well failure (Aliso Canyon natural gas leak), controlled releases, and natural migration of hydrocarbons as analogs to understand the processes influencing:
  - gas chemistry along a migration pathway, and
  - the footprint of leakage signals at the surface.

- Developed innovative approaches to documenting non-detection or quantifying leakage from depth to the surface with an emphasis on cost-effective, fast, and accurate implementation. (This accomplishment links to Theme D on monitoring commercialization).

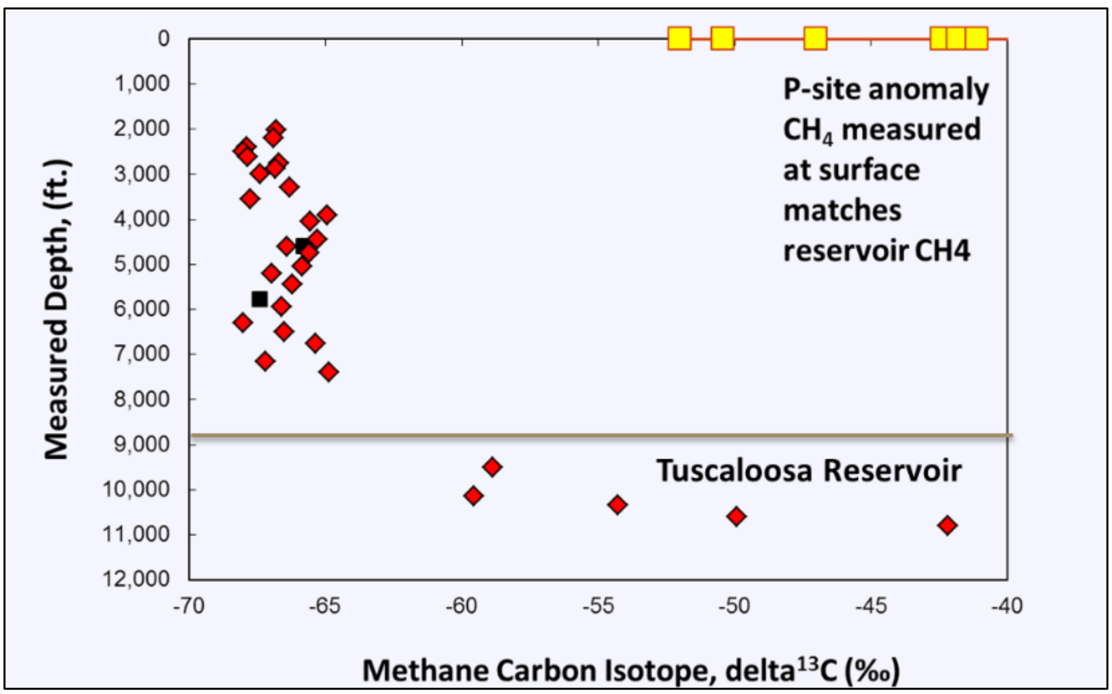


Figure 2. Fluid compositions collected throughout the geologic column at Cranfield suggested a geochemical match between the reservoir and the surface anomaly, however ^{14}C of the surface anomaly was > 100% modern carbon. This result illustrates the care that is required to correctly attribute surface anomalies.

Major Projects

- **Anomaly attribution at the SECARB Stacked Storage Project**
  6 years of monitoring a CO_2/CH_4 surface anomaly near a plugged and abandoned well using various methods for source attribution.

- **Numerical simulation of gas transport through the overburden**
  Quantification of alteration processes during gas migration resulting from phase changes and sorption and comparison with field datasets.

- **Assessment of shallow subsea hydrocarbons, offshore Texas Gulf Coast**
  Hydrocarbons extracted from the headspace gas within shallow cores above seismic anomalies is assessed for source attribution.

- **Cranfield, Hastings, and West Ranch project monitoring**
  Design and execution of monitoring plan for CO_2 storage at 3 large-scale CO_2 storage sites, including fluid compositional analysis from subsurface zones throughout the geologic columns.

- **Tracing natural gas transport into shallow groundwater in Parker County, Texas**
  Attribution of methane gas source in a shale gas analog using field measurements and geochemical modelling.

- **Two phase experiments to monitor compositional and isotopic changes of fugitive gas**
  Conducted experiments and numerical simulations to quantify changes in gas chemistry during transport in two-phase systems.

- **Sensitive subsurface areas in CCS**
  Designed, built, and validated cost-effective Intelligent Real-time In-situ Network (RICO2M Net) to monitor geochemical parameters for highly sensitive and accurate detection of CO_2 in groundwater capable of covering large areas and detecting small changes from background concentrations in the subsurface.

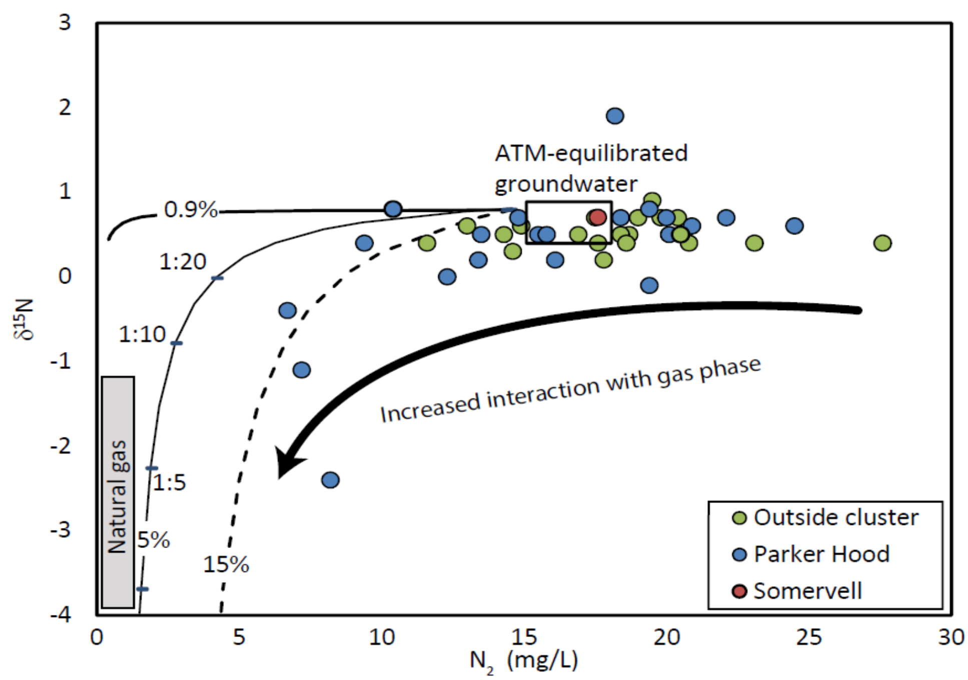


Figure 3. Infiltration of natural gas into shallow ground water has the effect of "stripping" the dissolved nitrogen from groundwater. The flux of natural gas is correlated to decreases in dissolved nitrogen concentrations and isotope values of dissolved nitrogen.

Impacts & Key Findings

- Discovered that leakage is unlikely to be found through groundwater monitoring. Attenuation of CO_2 signal in shallow groundwater is too large, making the required density of wells impractical and uneconomical.
- Constructed forward models of CO_2 migration showing that phase changes are important in attenuating CO_2 within the overburden. For hydrocarbons, sorption and oxidation are the most important processes during transport.
- Hydrocarbon geochemical parameters must be used with great caution in leakage assessments because of the effects of oxidation.
- In the expected cases where the CO_2 is from fossil fuel sources, the noble gas signal is not easily separated from other signals. Process-based ratios used in combination with carbon 14 shows great promise for attribution.
- Even in well failures, leakage signals may manifest as localized areas that surface far from the release due to lateral migration in the subsurface. Regulations will require quantification apart from "baseline" and process-based ratios applied to surface flux measurements may be used to fulfill this regulatory requirement and delineate areas of surface leakage.

Theme B: Evolution of Fluid Chemistry from Deep Reservoir to Near-Surface

Personnel

- Jacob Anderson
- Katherine Romanak
- Tip Meckel
- Changbing Yang
- Toti Larson

Contact

Dr. Katherine Romanak
katherine.romanak@beg.utexas.edu, +1 512-471-6136

Selected Publications

Anderson, J.S., Alfi, M., Hovorka, S.D., in review. Light hydrocarbon and noble gas migration as an analog for potential CO_2 leakage.

Anderson, J.S., Romanak, K.D., Meckel, T., in revision. Assessment of Shallow Subsea Hydrocarbons as a Proxy for Leakage at Offshore Geologic CO_2 Storage Sites. International Journal of Greenhouse Gas Control.

Anderson, J.S., 2017. Compositional Changes of Light Hydrocarbons during Migration through Overburden: Proxy for Assessing Potential Leakage from Geological Carbon Storage.

Anderson, J.S., Romanak, K.D., Yang, C., Lu, J., Hovorka, S.D., Young, M.H., 2017. Gas source attribution techniques for assessing leakage at geologic CO_2 storage sites: Evaluating a CO_2 and CH_4 soil gas anomaly at the Cranfield CO2-EOR site. Chemical Geology 454, 93–104. https://doi.org/10.1016/j.chemgeo.2017.02.024

Hannis, S., Lu, J., Chadwick, A., Hovorka, S., Kirk, K., Romanak, K., Pearce, J., 2017. CO_2 Storage in Depleted or Depleting Oil and Gas Fields: What can We Learn from Existing Projects? Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 5680–5690. https://doi.org/10.1016/j.egypro.2017.03.1707

Larson, T.E., Nicot, J.-P., Mickler, P., in review. Tracing natural gas transport into shallow groundwater using dissolved nitrogen and alkane chemistry in Parker County, Texas. Water Resources Research.

Lu, J., Larson, T.E., Smyth, R.C., 2015. Carbon isotope effects of methane transport through Anahuac Shale — A core gas study. Journal of Geochemical Exploration 148, 138–149. https://doi.org/10.1016/j.gexplo.2014.09.005

Sathaye, K.J., Larson, T.E., Hesse, M.A., 2016. Noble gas fractionation during subsurface gas migration. Earth and Planetary Science Letters 450, 1–9. https://doi.org/10.1016/j.epsl.2016.05.034

Goals

To study issues related to larger-than-usual volumes of CO_2 associated with the commercial implementation of CCUS and the extent to which these larger volumes not only impose operational changes on conventional CO_2-EOR operations, but also add environmental value to EOR technologies.

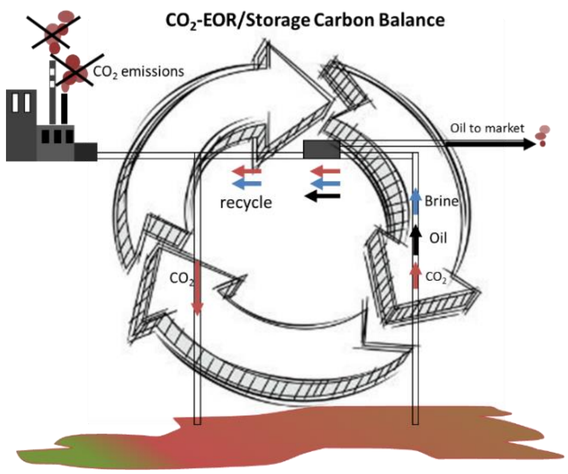


Figure 1. Lifecycle anaysis and carbon balance of CO_2-EOR.

Accomplishments

- Developed a clear, comprehensive, repeatable and widely applicable methodology for making the determination of whether the oil produced in an EOR operation can be classified as Net Carbon Negative Oil (NCNO) and applied the methodology to a case study.
- Developed a reservoir mass accounting methodology inclusive of CO_2 losses at the surface through operating equipment and in the subsurface outside a pre-established CO_2 storage complex.
- Assessed the impact on carbon balance of critical geotechnical and operational parameters, such as solvent flood performance (CO_2 utilization ratios), gas separation technologies, and fluid handling, which are often overlooked in carbon lifecycle studies and their repercussion on cradle-to-grave carbon systems.
- Completed numerical simulation studies to assess the contributions of the different CO_2 trapping mechanisms (structural, solubility, and capillary/residual) to both CO_2 geologic storage and oil production.
- Completed comparative analysis of CO_2 injection strategies and their effect on trapping mechanism partitioning, as well as comparative analysis of these on clastic versus carbonate reservoir settings.
- Evaluated the increase in minimum miscibility pressure (MMP) in offshore Gulf of Mexico reservoirs with high methane content.
- Assessed the impact of methane contamination on CO_2-EOR potential of offshore Gulf of Mexico.

Impacts & Key Findings

- Validated CO_2-EOR as a greenhouse gas emission reduction technology.
- Obtained results that show how in our case study (Cranfield) all CO_2-EOR injection strategies start producing NCNO[1] and at some point transition into producing net carbon positive oil (NCPO).
- The length of the NCNO period (with beneficial implications for carbon credits or tax deduction) can be engineered to last longer, as it is highly dependent on the CO_2 injection strategy (Fig. 2).

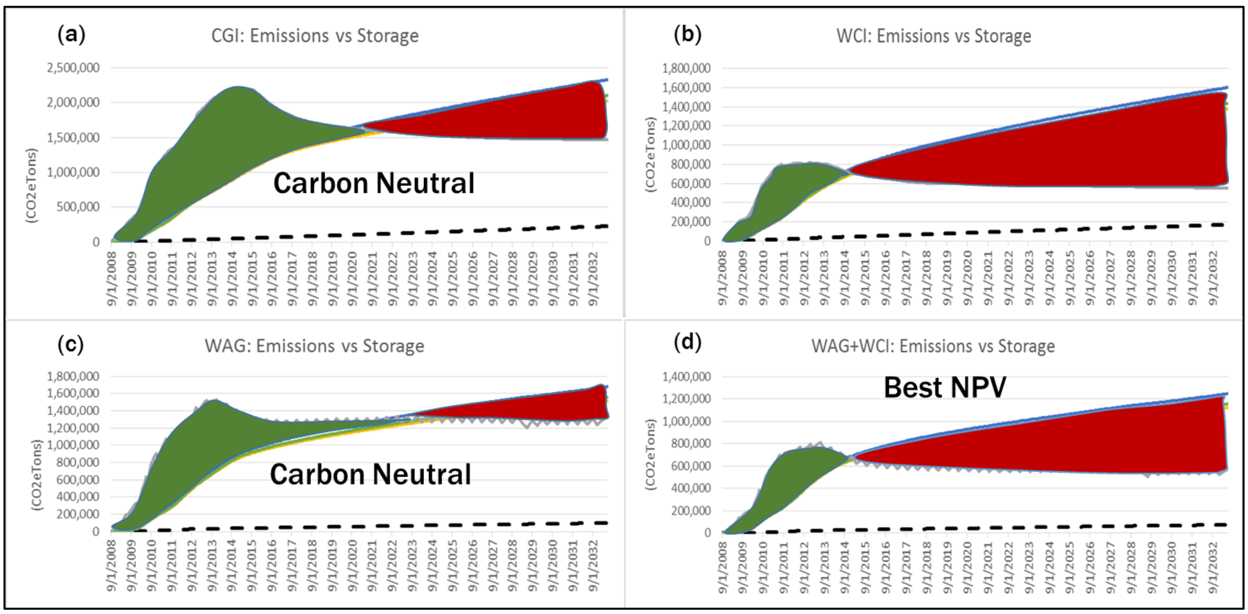


Figure 2. Carbon emissions and storage evolution showing net carbon storage (green) indicating Net Carbon Negative Oil production periods (when carbon storage is larger than carbon emissions); and positive emissions (red) indicating Net Carbon Positive Oil production periods (when carbon emissions are larger than carbon storage), for: (a) continuous gas injection CGI, (b) water curtain injection WCI, (c) water alternating gas WAG, and (d) WAG + WCI.

- Showed the significant impact of the different CO_2-EOR field development strategies -continuous gas injection (CGI), water alternating gas (WAG), water curtain injection (WCI)- on the relative importance of each trapping mechanism (structural, solubility, residual/capillary) for oil production and carbon storage.
- Concluded that WAG offers the most balanced field development by producing more oil while storing large volumes of CO_2 with the lowest gross utilization ratio.

[1] Based on carbon emissions within the gate-to-grave system (EOR site + refinery + product combustion).

Impacts & Key Findings continued...

- Showed how WAG, the most common CO_2 injection strategy, improves storage security by reducing the amount of mobile oil (Fig. 3).

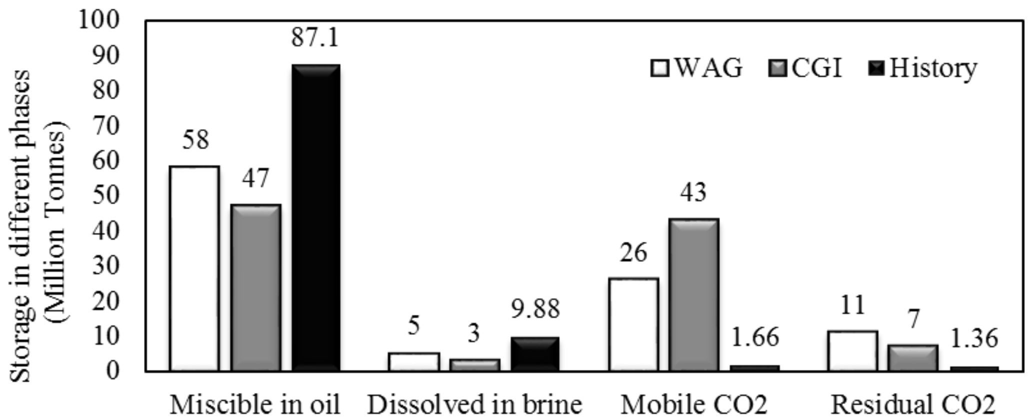


Figure 3. CO_2 stored by different trapping mechanisms by end of 2010 in SACROC assuming WAG at a ratio or 1 (six months of CO_2 injection followed by six months of water injection), CGI, and historic real data.

- Showed the extent to which methane contamination impacts CO_2-EOR in offshore GoM sands and how shallow reservoirs are greatly limited by their methane content (Fig. 4).

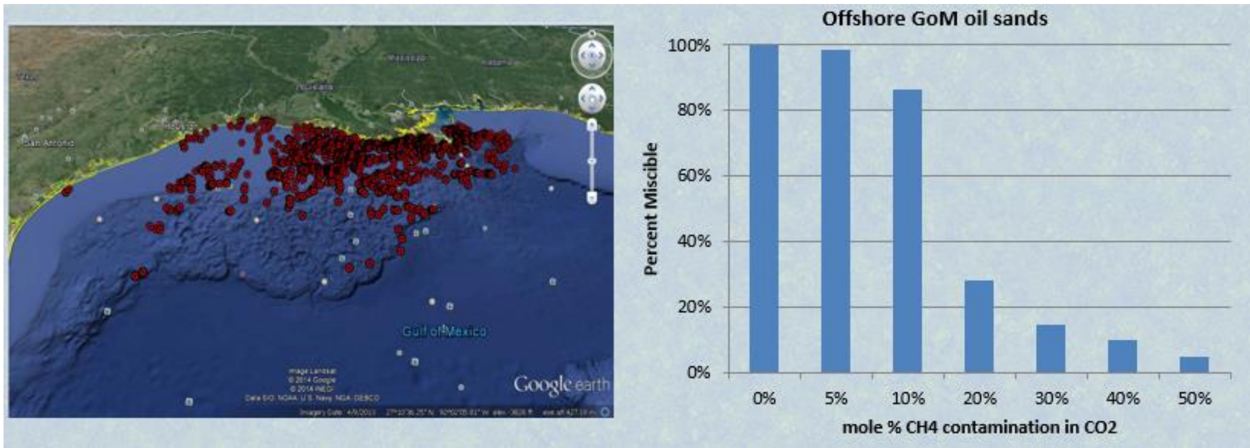


Figure 4. Minimum miscibility decreases as a function of methane content in offshore Gulf of Mexico oil sands.

Major Projects

- **Carbon lifecycle analysis of CO_2-EOR**
  Accurate carbon storage/emission assessment to understand the carbon balance of CO_2-EOR cradle-to-grave systems and its environmental and economic implications.

- **CO_2 storage trapping mechanism assessments**
  Simulation study to understand the distribution of CO_2 into the reservoir fluid phases and the relative significance of the different trapping mechanisms for both carbon storage and oil production.

- **Effect of methane contamination on CO_2-EOR potential**
  Master's thesis to assess the effect of methane on minimum miscibility pressure (MMP) of contaminated hydrocarbons of offshore reservoirs.

Personnel

- Vanessa Nuñez-López
- Seyyed Hosseini
- Ramon Gil-Egui
- Pooneh Hosseininoosheri
- Prisca Ogbuabuo

Contact

Vanessa Nuñez-López
vanessa.nunez@beg.utexas.edu, +1 512-471-5825

Selected Publications

Hannis, S., Lu, J., Chadwick, A., Hovorka, S., Kirk, K., Romanak, K., Pearce, J., 2017. CO_2 Storage in Depleted or Depleting Oil and Gas Fields: What can We Learn from Existing Projects? Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 5680–5690. https://doi.org/10.1016/j.egypro.2017.03.1707

Hannis, S., Lu, J., Chadwick, A., Hovorka, S.D., Kirk, K., Romanak, K.D., Pearce, J., 2016. Case studies of CO_2 storage in depleted oil and gas fields, IEA CON/15/231: Contract Report prepared for British Geological Survey and IEAGHG.

Hosseini, S.A., Alfi, M., Nicot, J.-P., Nuñez-Lopez, V., 2018. Analysis of CO_2 storage mechanisms at a CO_2-EOR site, Cranfield, Mississippi. Greenhouse Gas Sci Technol. https://doi.org/10.1002/ghg.1754

Hosseininoosheri, P., Hosseini, S.A., Nuñez-Lopez, V., Lake, L.W., submitted. Evolution of CO_2 Utilization Ratio and CO_2 Storage under Different EOR Operating Strategies: A Case Study on SACROC Unit (Permian Basin). Society of Petroleum Engineers.

Hosseininoosheri, P., Hosseini, S.A., Nuñez-Lopez, V., Lake, L.W., submitted. Modeling CO_2 Partitioning at a Carbonate CO2-EOR Site: Permian Basin Field (SACROC Unit). Society of Petroleum Engineers.

Nuñez-López, V., Gil-Egui, R., Gonzalez-Nicolas, A., Hovorka, S., 2017. Carbon Balance of CO_2-EOR for NCNO Classification. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 6597–6603. https://doi.org/10.1016/j.egypro.2017.03.1803

Ogbuabuo, P.C., 2015. The role of methane in limiting CO_2 EOR: case study of offshore Gulf of Mexico oil reservoirs.

Goals

Streamlining monitoring design for industrial-scale projects to advance beyond previous research-oriented and pilot projects. Development of monitoring network optimization strategies under a risk-informed paradigm and tested in commercial field sites and connected to evolving regulation and certification frameworks. Prioritization of monitoring spatially and temporally considers sensitivity to material impacts at site specific characteristics. Models for fast adaptive monitoring, realistic cost, and monitoring tool demonstration were developed.

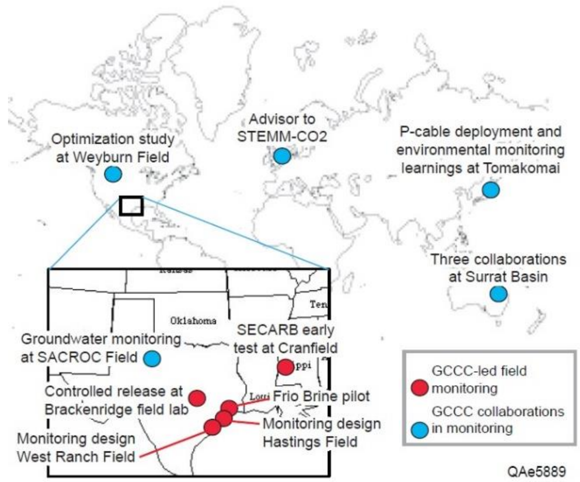


Figure 1. Areas where monitoring field studies have been conducted

Accomplishments

- Monitoring design and testing for two commercial EOR projects:
  - 1MMT CO_2/year captured at Air Products steam methane reformer and stored as part of EOR operations at Denbury's Hastings Field (Frio Fm.).
  - 1.6MMT CO_2/year captured at NRG's coal-fired W. A. Parish plant and stored as part of Hilcorp's EOR operations at West Ranch Field (Frio Fm.).
- Final field work and extensive additional data analysis was completed at SECARB's Early Test at Cranfield:
  - CO_2 geothermal test led by LBNL.
  - Groundwater reactive transport modeling.
  - Laboratory soil gas studies to validate process-based methods developed in the field.

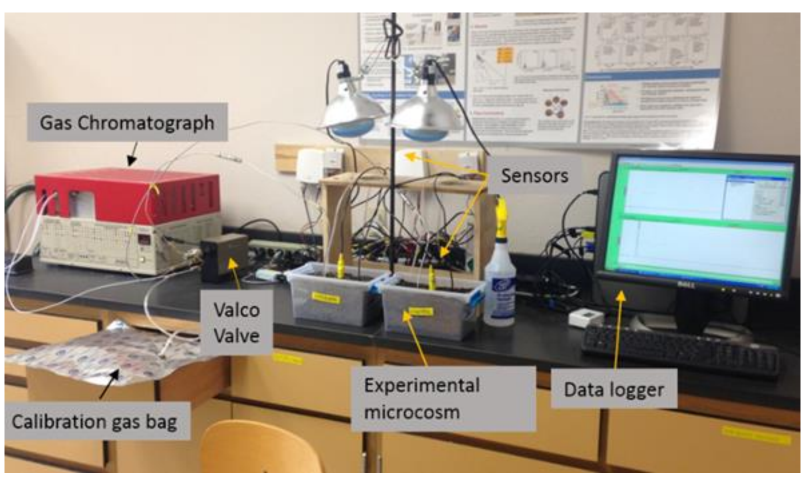


Figure 2. Laboratory set-up for testing process-based soil gas anomaly detection.

Accomplishments continued...

- Data from previous field tests at SACROC and Frio Test Pilot were further assessed.
- Field testing of the P-Cable seismic system in the Gulf of Mexico and at Tomakomai, Kyushu, Japan -- described in Theme E.
- Experiments at University of Texas Brackenridge field lab allowed field studies in controlled release setting.
- Study comparing pressure-based and geochemically-based surveillance of Above-Zone Monitoring intervals (AZMI) was funded by GCCC.
- Pressure-based Inversion and Data Assimilation System (PIDAS) used theoretical and numerical analysis, laboratory experiments, and field tests at Cranfield of oscillatory pulse testing technique for leakage detection.
- Data Integration, Assimilation, and Learning framework for managing geologic carbon sequestration projects (DIAL).

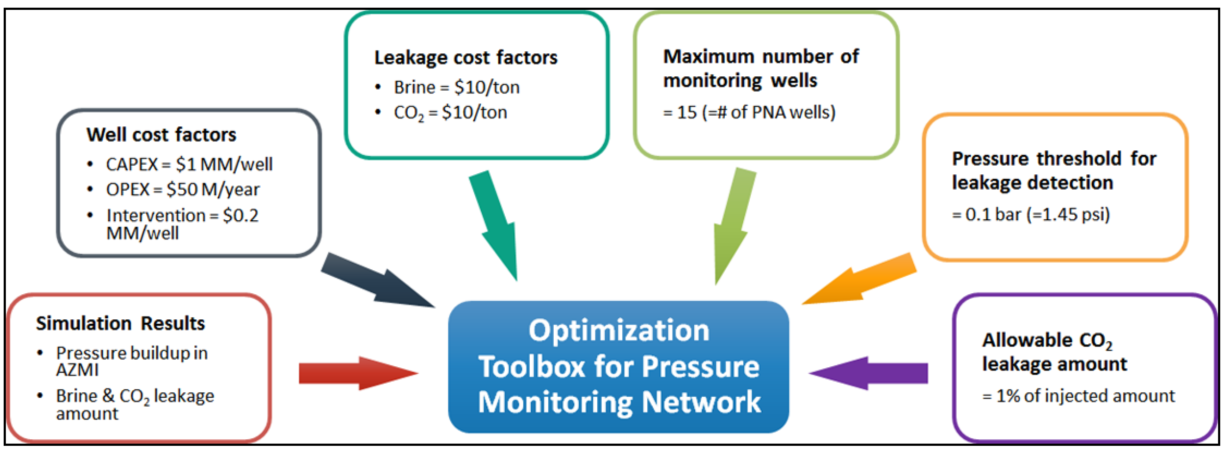


Figure 3. DIAL. A pressure-based optimal well placement solution was developed to enable optimal monitoring well placement. The toolbox allows incorporation of multiple cost constraints and user-defined performance criteria.

- Identified a representative dataset for long-term monitoring at the Weyburn CO_2-EOR site, Saskatchewan, Canada (funded by PTRC Canada).
- Practical isotopic analyzer for subsurface gases – tool development and field testing instrumentation for soil gas under Small Business Innovation Research (SBIR) with Mesa Photonics, LLC.
- Fiber optic detection of CO_2 in groundwater with optical fiber experiments in collaboration with Intelligent Optical Systems (IOS).

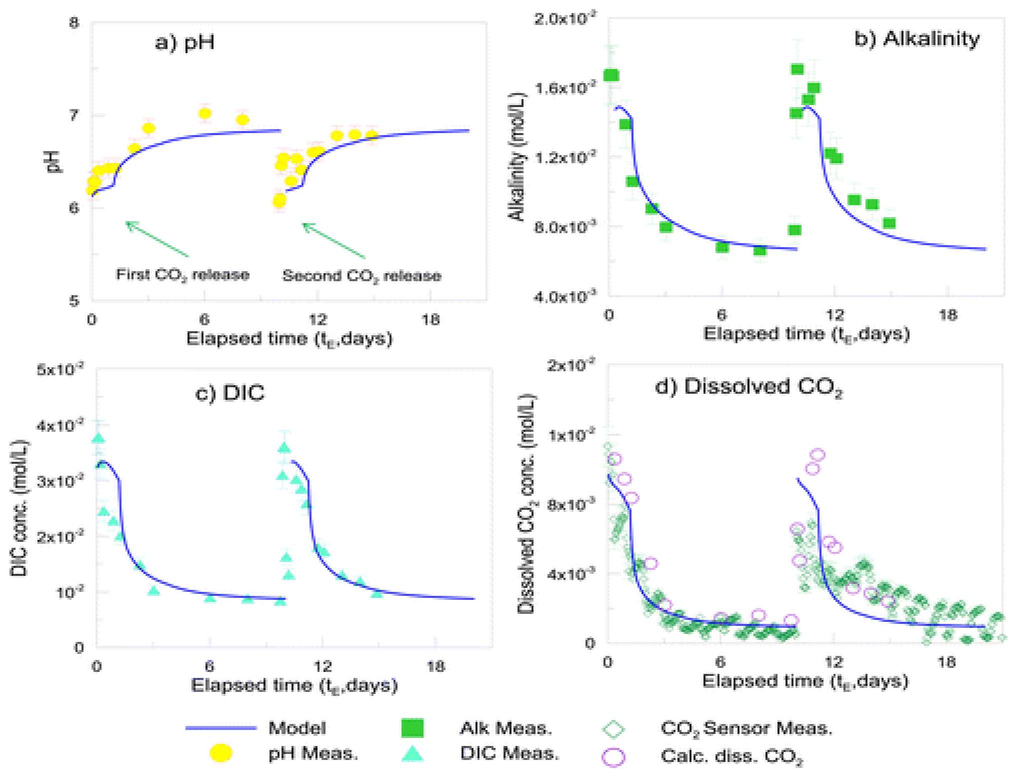


Figure 4. CO_2 controlled release into groundwater comparing modelled measured via sampling, and fiber optical measurements from Yang et al, 2014 experiments at Brackenridge field site.

Accomplishments continued...

- Initial environmental characterization at Glenhaven - This project delivered an environmental characterization at the Glenhaven site to support CTSCo Surat Basin CCS demonstration project's compliance with environmental requirements for Monitoring and Verification (M&V), Queensland Australia (funded by ANLEC).

- Three additional projects have been recently funded by Australian National Low Emission Carbon Coal (ANLEC) R&D: CTSCo Surat Basin Australia, Deploying systems to enable "Process Based Monitoring" on soil gas, Monitoring using isotopes in the Surrat Basin, and Monitoring Headspace in wells.Collaboration (as advisor) to two projects:
  - EU-Funded Strategies for Environmental Monitoring of Marine Carbon Capture and Storage STEMM-CCS, and
  - the Norwegian CCS Research Centre.

Impacts & Key Findings

- Assessment of Low Probability Material Impact (ALPMI) provides the repeatable and site–specific method for minimizing temporal and spatial monitoring while still allowing a robust statement of project success.
  - Forward modeling system response to unacceptable events and designing the monitoring to detect these responses optimizes monitoring array.
  - Used in commercial projects.

- Comparison of geochemical and pressure based measurements shows lower cost and faster detection with pressure under average site conditions.

- Attribution is recognized as an essential step in monitoring to determine if observed anomalies result from the CO_2 injection project or other changes in the area.
  - Groundwater and soil gas role in attribution monitoring supersede previous baseline and surveillance for anomaly methods.
  - Weaknesses of dependence on baseline.
  - Temporal lag and spatial limits of near surface signal limit value for surveillance.
  - Need for pre-determined rapid response when anomalies observed.

- Augmented pressure-based methods.
  - Time-lapse pressure-based leakage detection method developed.
  - Time-lapse diffusivity monitoring method for leakage detection using pressure data developed and deployed in Hastings and West Ranch.
  - Principal Component Analysis (PCA) to detect anomalies with measurement noise in pressure data that conventional approaches do not detect.

- Limit and values of thermal methods for leakage detection at focused leakage assessed.

Major Projects

- **SECARB's early test at Cranfield**
  Multiyear, multimillion-ton injection with a focus on the water leg of an EOR project.

- **Hastings CO_2-EOR field monitoring**
  Monitoring design for large-scale storage (1MMT/year) of CO_2 captured from Air Products methane steam reformer as part of EOR operations.

Major Projects continued...

- **West Ranch CO_2-EOR field monitoring**
  Monitoring design for large-scale storage (1.6MMT/year) of CO_2 captured at NRG's coal-fired W. A. Parish plant and stored as part of Hilcorp's EOR operations at the West Ranch Field.

- **Pressure-based Inversion and Data Assimilation System (PIDAS)**
  Field and laboratory demonstration of an oscillatory pulse testing technique for pressure-based leakage detection.

- **Data Integration, Assimilation, and Learning framework for managing geologic carbon sequestration projects (DIAL)**
  Developed high-performance, monitoring network optimization capabilities by leveraging recent developments in machine learning technologies, anomaly detection, and model reduction.

- **Weyburn**
  Developed a framework for guiding data collection during post-EOR monitoring.

- **Process-based monitoring**
  Developed and expanded process-based soil gas monitoring methods using data mined from literature and collected at multiple field sites and coupled with laboratory and numerical simulations. Outcomes indicate and quantify the effects of variable gas dissolution on process-based ratios. The matrix is being expanded to include attribution of legacy industrial signals.

Personnel

- Alex Sun
- Seyyed Hossieni
- Susan Hovorka
- Jiemin Lu
- J.P Nicot
- Katherine Romanak
- Vanessa Nunez

Students and post docs

- Akand Islam
- Behni Bolhassani
- Hoonyoung Jeong
- Julie Ditkof

- Mary Hingst
- Mausoud Alfi
- Seunghee Kim
- Sean Porse

Affiliated researchers

- Tim Dixon (IEA GHG R&D Programme)
- Mehdi Zeidouni (now LSU)
- Changbing Yang (now Edwards Aquifer Authority)
- Tim Dixon (University South Florida)
- Xianjin yang (LLNL)
- Makiko Takagish (RITE)

Contact

Dr. Susan Hovorka
susan.hovorka@beg.utexas.edu, +1 512-471-4863

Dr. Alexander Sun
alex.sun@beg.utexas.edu, +1 512-475-6190

Dr. Katherine Romanak
katharine.romanak@beg.utexas.edu, +1 512-471-6136

Selected Publications

Bolhassani, B., Hovorka, S.D., Hosseini, S.A., Young, M.H., Anderson, J.S., Yang, C., 2017. Model-based Assessment of the Site-specific Cost of Monitoring. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 5316–5319. https://doi.org/10.1016/j.egypro.2017.03.1652

Ditkof, J.N., 2013. Time-lapse seismic monitoring for enhanced oil recovery and carbon capture and storage field site at Cranfield field, Mississippi.

Dixon, T., Romanak, K.D., 2015. Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring. International Journal of Greenhouse Gas Control 41, 29–40. https://doi.org/10.1016/j.ijggc.2015.05.029

Gao, R.S., Sun, A.Y., Nicot, J.-P., 2016. Identification of a representative dataset for long-term monitoring at the Weyburn CO_2-injection enhanced oil recovery site, Saskatchewan, Canada. International Journal of Greenhouse Gas Control 54, 454–465. https://doi.org/10.1016/j.ijggc.2016.05.028

Gilbert, K., Bennett, P.C., Wolfe, W., Zhang, T., Romanak, K.D., 2016. CO_2 solubility in aqueous solutions containing Na^+, Ca^{2+}, Cl^-, SO_4^{2-} and HCO_3^-: The effects of electrostricted water and ion hydration thermodynamics. Applied Geochemistry Complete, 59–67. https://doi.org/10.1016/j.apgeochem.2016.02.002

Hingst, M.C., 2013. Geochemical effects of elevated methane and carbon dioxide in near-surface sediments above an EOR/CCUS site.

Hosseini, S.A., 2014. Time Lapse Compressibility Monitoring for Detection of CO_2 Leakage in Brine Aquifers. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 4459–4463. https://doi.org/10.1016/j.egypro.2014.11.481

Hosseini, S.A., Alfi, M., 2016. Time-lapse application of pressure transient analysis for monitoring compressible fluid leakage. Greenhouse Gas Sci Technol 6, 352–369. https://doi.org/10.1002/ghg.1570

Hosseini, S.A., Kim, S., Zeidouni, M., 2014. Application of multi-well analytical models to maximize geological CO_2 storage in brine formations. Energy Procedia 63, 3563–3567. https://doi.org/10.1016/j.egypro.2014.11.385

Hovorka, S.D., 2017a. Assessment of Low Probability Material Impacts. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 5311–5315. https://doi.org/10.1016/j.egypro.2017.03.1648

Hovorka, S.D., 2017b. Monitoring after Closure: A Case of the Horse Already Out of the Barn. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 3754–3756. https://doi.org/10.1016/j.egypro.2017.03.1504

Hovorka, S.D., 2015. Low-Probability Material Impacts Assessment. Greenhouse Gas Sci Technol 5, 223–224. https://doi.org/10.1002/ghg.1519

Hovorka, S.D., Nicot, J.-P., Zeidouni, M., Sava, D., Yang, C., Sun, A.Y., Remington, R.L., 2014a. Workbook for developing a monitoring plan to ensure storage permanence in a geologic storage project, including site-specific tool selection, Integrated Design, Modeling, and Monitoring of Geologic Sequestration of Anthropogenic Carbon Dioxide to Safeguard Sources of Drinking Water and with funding from the Carbon Capture Project. Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas.

Hovorka, S.D., Nicot, J.-P., Zeidouni, M., Sun, A.Y., Yang, C., Sava, D., Mickler, P.J., Remington, R.L., 2014b. Expert-Based Development of a Site-Specific Standard in CO_2 Sequestration Monitoring Technology | Research Project Database | Grantee Research Project | ORD | US EPA, EPA-G2008-STAR-H1: Integrated Design, Modeling, and Monitoring of Geologic Sequestration of Anthropogenic Carbon Dioxide to Safeguard Sources of Drinking Water. Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin.

Hovorka, S.D., Zeidouni, M., Sava, D., Remington, R.L., Yang, C., 2015. Chapter 31: Site-specific optimization of selection of monitoring technologies, in Carbon dioxide storage in deep saline formations, in: Gerdes, K.F. (Ed.), Carbon Dioxide Capture for Storage in Deep Geologic Formations, Results from the CO_2 Capture Project, Volume 4: CCS Technology Development and Demonstration Results (2009-2014). CPL Press, UK, pp. 531–566.

Islam, A., Sun, A.Y., 2015. Quantification of CO_2 masses trapped through free convection process in isothermal brine saturated reservoir. International Journal of Heat and Mass Transfer 87, 128–137. https://doi.org/10.1016/j.ijheatmasstransfer.2015.03.083

Islam, A.W., Sun, A.Y., 2017. Detecting CO_2 leakage around the wellbore by monitoring temperature profiles: A scoping analysis. International Journal of Thermal Sciences 118, 367–373. https://doi.org/10.1016/j.ijthermalsci.2017.04.030

Jenkins, C., Chadwick, A., Hovorka, S.D., 2015. The state of the art in monitoring and verification—Ten years on. International Journal of Greenhouse Gas Control, Special Issue commemorating the 10th year anniversary of the publication of the Intergovernmental Panel on Climate Change Special Report on CO_2 Capture and Storage 40, 312–349. https://doi.org/10.1016/j.ijggc.2015.05.009

Karegar, M.A., Dixon, T.H., Malservisi, R., Yang, Q., Hossaini, S.A., Hovorka, S.D., 2015. GPS-based monitoring of surface deformation associated with CO_2 injection at an enhanced oil recovery site. International Journal of Greenhouse Gas Control 41, 116–126. https://doi.org/10.1016/j.ijggc.2015.07.006

Kim, S., Hosseini, S.A., 2017. Study on the ratio of pore-pressure/stress changes during fluid injection and its implications for CO_2 geologic storage. Journal of Petroleum Science and Engineering 149, 138–150. https://doi.org/10.1016/j.petrol.2016.10.037

Kim, S., Hosseini, S.A., 2015. Hydro-thermo-mechanical analysis during injection of cold fluid into a geologic formation. International Journal of Rock Mechanics and Mining Sciences 77, 220–236. https://doi.org/10.1016/j.ijrmms.2015.04.010

Kim, S., Hosseini, S.A., 2014a. Above-zone pressure monitoring and geomechanical analyses for a field-scale CO_2 injection project in Cranfield, MS. Greenhouse Gas Sci Technol 4, 81–98. https://doi.org/10.1002/ghg.1388

Kim, S., Hosseini, S.A., 2014b. Geological CO_2 storage: Incorporation of pore-pressure/stress coupling and thermal effects to determine maximum sustainable pressure limit. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 3339–3346. https://doi.org/10.1016/j.egypro.2014.11.362

Nuñez-Lopez, V., Muñoz-Torres, J., Zeidouni, M., 2014. Temperature monitoring using Distributed Temperature Sensing (DTS) technology. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 3984–3991. https://doi.org/10.1016/j.egypro.2014.11.428

Oldenberg, C.M., Nicot, J.-P., Jordan, P.D., Zhang, Y., Pan, L., Houseworth, J.E., Meckel, T., Carr, D.L., Bryant, S.L., 2015. Chapter 32: Health, safety, and environmental risk assessment of geologic carbon sequestration: Overview of the certification framework, example application, and selected special studies 2010-2014 ring method, in: Gerdes, K.F. (Ed.), Carbon Dioxide Capture for Storage in Deep Geologic Formations, Results from the CO_2 Capture Project, Volume 4: CCS Technology Development and Demonstration Results (2009-2014). CPL Press, UK, pp. 569–592.

Porse, S.L., 2013. Using analytical and numerical modeling to assess deep groundwater monitoring parameters at carbon capture, utilization, and storage sites (Thesis).

Rinehart, A.J., Dewers, T.A., Broome, S.T., Eichhubl, P., 2016. Effects of CO_2 on mechanical variability and constitutive behavior of the Lower Tuscaloosa Formation, Cranfield Injection Site, USA. International Journal of Greenhouse Gas Control 53, 305–318. https://doi.org/10.1016/j.ijggc.2016.08.013

Romanak, K., 2017. Initial Site Characterisation and Assessment of Environmental M&V at Glenhaven, prepared for Australian National Low Emissions Coal Research and Development (ANLEC R&D), under contract no. 7-1116-0297.

Romanak, K., Womack, G.L., Bomse, D.S., Dodds, K., 2014. Field Practical Guide to Environmental and Leak Characterization Using a Process-Based Soil Gas Monitoring Method, CO_2 Capture Project (CCP), SMV-037 BP Agreement Reference: 61798. Gulf Coast Carbon Center, Bureau of Economic Geology, The University of Texas at Austin.

Romanak, K., Yang, C., Darvari, R., 2017. Towards a Method for Leakage Quantification and Remediation Monitoring in the Near-surface at Terrestrial CO_2 Geologic Storage Sites. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 3855–3862. https://doi.org/10.1016/j.egypro.2017.03.1517

Romanak, K., Zhang, T., Darvari, R., 2016. Practical isotopic analyzer for subsurface gases, prepared for Mesa Photonics under contract DE-FOA-0001366.

Romanak, K.D., Wolaver, B., Yang, C., Sherk, G.W., Dale, J., Dobeck, L.M., Spangler, L.H., 2014a. Process-based soil gas leakage assessment at the Kerr Farm: Comparison of results to leakage proxies at ZERT and Mt. Etna. International Journal of Greenhouse Gas Control 30, 42–57. https://doi.org/10.1016/j.ijggc.2014.08.008

Romanak, K.D., Womack, G.L., Bomse, D.S., 2014b. Field Test of in Situ Sensor Technology for Process-based Soil Gas Monitoring. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 4027–4030. https://doi.org/10.1016/j.egypro.2014.11.433

Shakiba, M., Hosseini, S.A., 2016. Detection and characterization of CO_2 leakage by multi-well pulse testing and diffusivity tomography maps. International Journal of Greenhouse Gas Control 54, 15–28. https://doi.org/10.1016/j.ijggc.2016.08.015

Smyth, R.C., Hovorka, S.D., Romanak, K.D., Wolaver, B.D., Mickler, P., Yang, C., 2014. Monitoring CO_2: The quest for a clean signal (examples from UT Austin BEG research). Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 4035–4042. https://doi.org/10.1016/j.egypro.2014.11.435

Sun, A.Y., Lu, J., Freifeld, B.M., Hovorka, S.D., Islam, A., 2016. Using pulse testing for leakage detection in carbon storage reservoirs: A field demonstration. International Journal of Greenhouse Gas Control 46, 215–227. https://doi.org/10.1016/j.ijggc.2016.01.015

Sun, A.Y., Lu, J., Hosseini, S.A., Hovorka, S.D., 2014. Toward Incorporating Pressure-based Leakage Detection into Monitoring Programs at Geologic Carbon Sequestration Sites.

Sun, A.Y., Lu, J., Hovorka, S., 2015. A harmonic pulse testing method for leakage detection in deep subsurface storage formations. Water Resour. Res. 51, 4263–4281. https://doi.org/10.1002/2014WR016567

Sun, A.Y., Lu, J., Islam, A., 2017a. A laboratory validation study of the time-lapse oscillatory pumping test for leakage detection in geological repositories. Journal of Hydrology 548, 598–604. https://doi.org/10.1016/j.jhydrol.2017.03.035

Sun, A.Y., Wheeler, M.F., Islam, A., 2017b. Identifying attributes of CO_2 leakage zones in shallow aquifers using a parametric level set method. Greenhouse Gas Sci Technol 7, 649–664. https://doi.org/10.1002/ghg.1665

Takagishi, M., Hashimoto, T., Toshioka, T., Horikawa, S., Kusunose, K., Xue, Z., Hovorka, S.D., 2017. Optimization Study of Seismic Monitoring Network at the CO_2 Injection Site – Lessons Learnt from Monitoring Experiment at the Cranfield Site, Mississippi, U.S.A. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 4028–4039. https://doi.org/10.1016/j.egypro.2017.03.1543

Yang, C., Dai, Z., Romanak, K.D., Hovorka, S.D., Treviño, R.H., 2014a. Inverse Modeling of Water-Rock-CO_2 Batch Experiments: Potential Impacts on Groundwater Resources at Carbon Sequestration Sites. Environ. Sci. Technol. 48, 2798–2806. https://doi.org/10.1021/es4041368

Yang, C., Hovorka, S.D., Delgado-Alonso, J., Mickler, P.J., Treviño, R.H., Phillips, S., 2014b. Field Demonstration of CO_2 Leakage Detection in Potable Aquifers with a Pulselike CO_2-Release Test. Environ. Sci. Technol. 48, 14031–14040. https://doi.org/10.1021/es5044003

Yang, C., Hovorka, S.D., Treviño, R.H., Delgado-Alonso, J., 2015a. Integrated Framework for Assessing Impacts of CO_2 Leakage on Groundwater Quality and Monitoring-Network Efficiency: Case Study at a CO_2 Enhanced Oil Recovery Site. Environ. Sci. Technol. 49, 8887–8898. https://doi.org/10.1021/acs.est.5b01574

Yang, C., Hovorka, S.D., Young, M.H., Trevino, R., 2014c. Geochemical sensitivity to CO_2 leakage: detection in potable aquifers at carbon sequestration sites. Greenhouse Gas Sci Technol 4, 384–399. https://doi.org/10.1002/ghg.1406

Yang, C., Jamison, K., Xue, L., Dai, Z., D. Hovorka, S., Fredin, L., H. Treviño, R., 2017a. Quantitative assessment of soil CO_2 concentration and stable carbon isotope for leakage detection at geological carbon sequestration sites. Greenhouse Gas Sci Technol 7, 680–691. https://doi.org/10.1002/ghg.1679

Yang, C., Romanak, K.D., Reedy, R.C., Hovorka, S.D., Trevino, R.H., 2017b. Soil gas dynamics monitoring at a CO_2-EOR site for leakage detection. Geomech. Geophys. Geo-energ. Geo-resour. 3, 351–364. https://doi.org/10.1007/s40948-017-0053-7

Yang, C., Treviño, R.H., Hovorka, S.D., Delgado-Alonso, J., 2015b. Semi-analytical approach to reactive transport of CO_2 leakage into aquifers at carbon sequestration sites. Greenhouse Gas Sci Technol 5, 786–801. https://doi.org/10.1002/ghg.1527

Zeidouni, M., 2014. Analytical model of well leakage pressure perturbations in a closed aquifer system. Advances in Water Resources 69, 13–22. https://doi.org/10.1016/j.advwatres.2014.03.004

Zeidouni, M., Nicot, J.-P., Hovorka, S.D., 2014. Monitoring above-zone temperature variations associated with CO_2 and brine leakage from a storage aquifer. Environmental earth sciences.

Theme E: Offshore Storage Source-Sink Synergies

Goals

To study the near-offshore CO_2 storage resource, its primary risk elements and technical and economic barriers to utilization, and its potential to increase global deployment of CCS. In particular, we focused on the inner shelf of the Gulf of Mexico (GoM), with emphasis on southeastern Texas and southwestern Louisiana. Efforts also include the U.S. Atlantic, northern Japan, southern China, North Sea, and Nigeria.

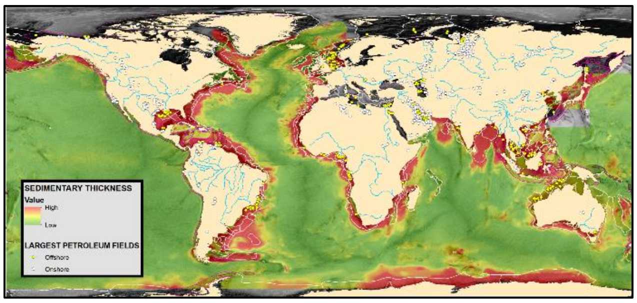


Figure 1. Globally abundant offshore geologic storage capacity on continental shelves.

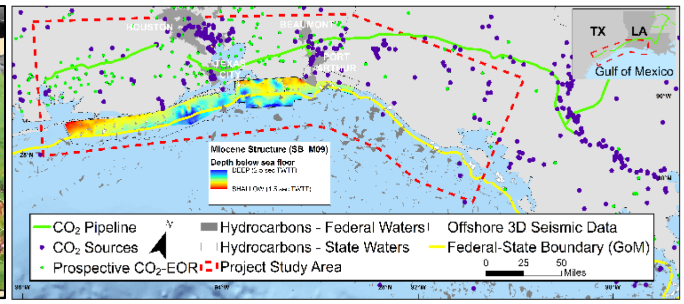
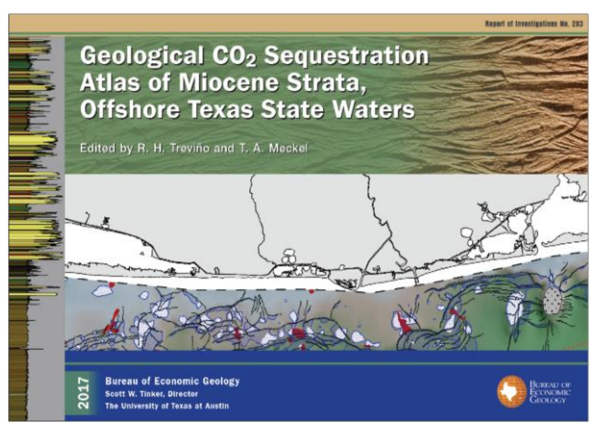


Figure 2. Geographic focus of regional and site-specific studies for near-offshore CCS in GoM.

Accomplishments

- Published *Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters*, Bureau or Economic Geology Report of Investigations No. 283, 80 p. It is the first-of-a-kind resource for understanding storage capacity and potential risks for inner-shelf GoM.
- Assisted US DOE prepare two CSLF reports on global offshore technical barriers and R&D opportunities for saline offshore storage and offshore EOR
- Developed and attracted funding for follow-on projects, workshops, and publications to increase knowledge and awareness of global storage potential.
- Incentivized consideration of field tests in offshore settings and participated in international monitoring project at Tomakomai. Applied and expanded GCCC expertise on characterization, storage capacity (e.g. EASiTool), fluid flow, geomechanical, and monitoring (seismic and geochemical).
- Developed capability of novel high-resolution 3D seismic (HR3D P-cable) for characterizing and monitoring injection sites.



Impacts & Key Findings

- GCCC is an internationally-recognized research group leading the topic of offshore CCS in the U.S.
- GCCC has reduced barriers to global utilization of passive continental margins for CCS through technical work, communication in international forums, and engagement of developing economies.
- GCCC developed and initiated the International Offshore CCS Workshop series in Texas, with the third meeting to be hosted by Norway in 2018.
- GCCC focused DOE's attention on the advantages of offshore storage and attracted significant DOE funding to advance research on the topic.
- GCCC pioneered the deployment of novel marine seismic monitoring technology for CCS application.

Major Projects

- **GoMCARB**
  Broad academic-industry partnership for advancing CO_2 storage in the Gulf of Mexico—similar to the U.S. DOE NETL RCSP Program. This is the current vehicle for developing offshore CCS research in the U.S.

- **CarbonSAFE**
  Pre-feasibility study for an integrated CO_2 capture, transportation, and storage project with industry participation (southeastern Texas focus).

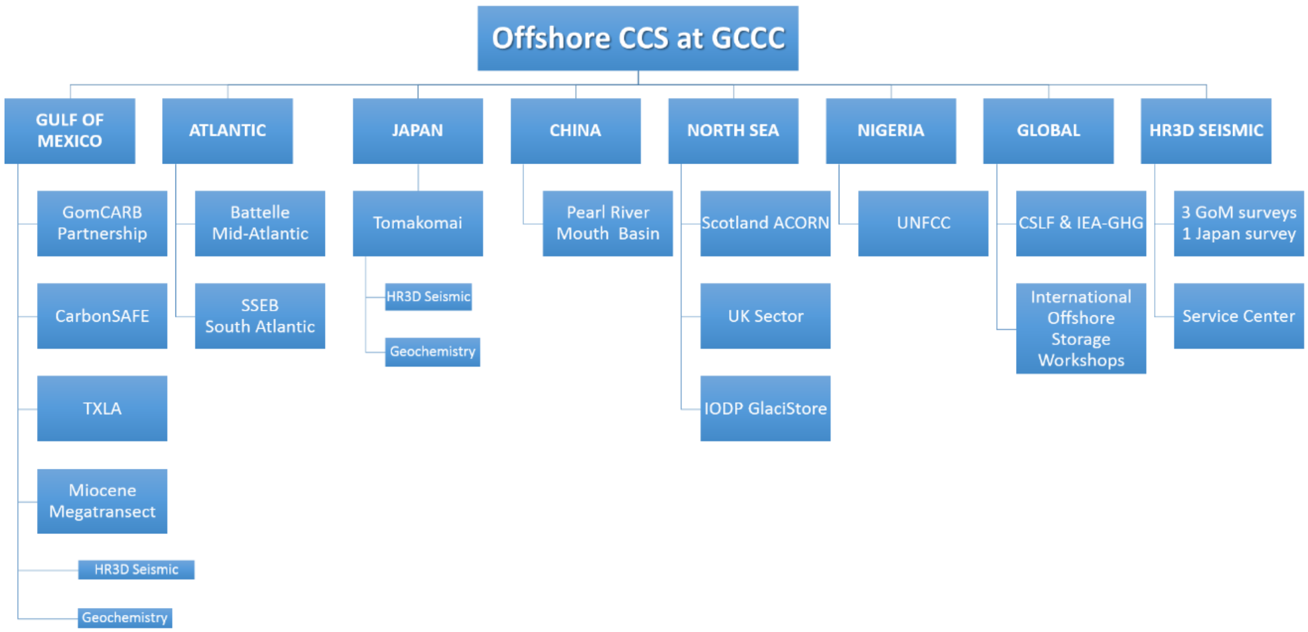
- **TXLA Characterization**
  Regional geologic and structural characterization in southeastern Texas and southwestern Louisiana, with identification of potential 50 Mt sites.

- **Texas Offshore Megatransect**
  Offshore state lands Miocene capacity: integration of unique, HR3D seismic datasets and commercial 3D seismic with extensive well data and limited, valuable rock data.

- **Tomakomai**
  Field validation of MVA tools for offshore CCS – Novel high-resolution 3D (HR3D) marine seismic technology with integrated shallow sediment geochemistry and environmental monitoring.

Major Projects continued...

- **Atlantic**
  Advisor to Battelle on their DOE-funded regional characterization project in the mid-Atlantic, and prior collaboration with Southern States Energy Board.



Personnel

- Tip Meckel
- Ramon Trevino
- Susan Hovorka
- Katherine Romanak

Affiliated personnel

- Tim Dixon (IEAGHG)

Graduate Students

- Izaak Ruiz

- Jacob Anderson
- Emily Beckham
- Reinaldo Maciel
- Johnathon Osmond
- Francis Mulcahy
- Kerstan Wallace
- Andrew Nicholson

Contact

Dr. Tip Meckel
tip.meckel@beg.utexas.edu, +1 512-471-4306

Selected Publications

Anderson, J.S., Romanak, K.D., Meckel, T.A., in revision. Assessment of Shallow Subsea Hydrocarbons as a Proxy for Leakage at Offshore Geologic CO_2 Storage Sites. International Journal of Greenhouse Gas Control.

Carr, D.L., 2017. Appendix A: Regional Cross Sections, Miocene Strata of the Offshore Texas State Waters, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 62–74.

Carr, D.L., Rhatigan, C.H., 2017. Chapter 6: Field-scale example of a potential CO_2 sequestration site in Miocene sandstone reservoirs, Brazos Block 440-L Field, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 47–56.

Carr, D.L., Wallace, K.J., Nicholson, A.J., Yang, C., 2017. Chapter 5: Regional CO_2 Static Capacity Estimate, Offshore Miocene Saline Aquifers, Texas State Waters, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 37–46.

Carr, D.L., Wallace, K.J., Yang, C., Nicholson, A.J., 2016. CO_2 Sequestration Capacity Sectors in Miocene Strata of the Offshore Texas State Waters 5, 130.

Klokov, A., Treviño, R.H., Meckel, T.A., 2017. Diffraction imaging for seal evaluation using ultra high resolution 3D seismic data. Marine and Petroleum Geology 82, 85–96. https://doi.org/10.1016/j.marpetgeo.2017.02.002

Lu, J., Carr, D.L., Rhatigan, J.L., Fifariz, R., 2017. Chapter 3: Evaluation of Lower Miocene Confining Units for CO_2 Storage, Offshore Texas State Waters, Northern Gulf of Mexico, USA, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 14–25.

Maciel, R.S., 2017. Pre-injection reservoir characterization for CO_2 storage in the inner continental shelf of the Texas Gulf of Mexico.

Meckel, T., Mulcahy, F., 2016. Use of novel high-resolution 3D marine seismic technology to evaluate Quaternary fluvial valley development and geologic controls on shallow gas distribution, inner shelf, Gulf of Mexico. Interpretation 4, SC35-SC49. https://doi.org/10.1190/INT-2015-0092.1

Meckel, T.A., Nicholson, A.J., Trevino, R.H., 2017. Chapter 4: Capillary aspects of fault seal capacity for CO_2 storage, Lower Miocene, Texas Gulf of Mexico, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 26–36.

Meckel, T.A., Rhatigan, J.L., 2017. Chapter 2: Implications of Miocene Petroleum Systems for Geologic CO_2 Sequestration beneath Texas Offshore Lands, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 7–13.

Merzlikin, D., Meckel, T.A., Fomel, S., Sripanich, Y., 2017. Diffraction imaging of high-resolution 3D P-cable data from the Gulf of Mexico using azimuthal plane-wave destruction. First Break 35, 35–41. https://doi.org/10.3997/1365-2397.2017002

Mulcahy, F.J., 2015. Use of high resolution 3D seismic data to evaluate Quaternary valley evolution history during transgression, offshore San Luis Pass, Gulf of Mexico.

Osmond, J.L., 2016. Fault seal and containment failure analysis of a Lower Miocene structure in the San Luis Pass area, offshore Galveston Island, Texas inner shelf.

Smyth, R.C., Thomas, P.G., Heiligenstein, C., 2014. Concerning Offshore Geologic Storage of Carbon Dioxide in the U.S.A. Energy Procedia, 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 63, 5822–5826. https://doi.org/10.1016/j.egypro.2014.11.615

Trevino, R.H., Rhatigan, J.L., 2017. Chapter 1: Regional Geology of the Gulf of Mexico and the Miocene Section of the Texas Near-Offshore Waters, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 3–6.

Wallace, K.J., Meckel, T.A., Carr, D.L., Treviño, R.H., Yang, C., 2014. Regional CO_2 sequestration capacity assessment for the coastal and offshore Texas Miocene interval. Greenhouse Gas Sci Technol 4, 53–65. https://doi.org/10.1002/ghg.1380

Wallace, K.J., Rhatigan, C.H., Trevino, R.H., Meckel, T.A., 2017. Chapter 7: Estimating CO_2 Storage Capacity in a Saline Aquifer Using 3D Flow Models, Lower Miocene, Texas Gulf of Mexico, in: Trevino, R.H., Meckel, T.A. (Eds.), Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Bureau of Economic Geology, The University of Texas at Austin, pp. 57–61.

Yang, C., Treviño, R.H., Zhang, T., Romanak, K.D., Wallace, K., Lu, J., Mickler, P.J., Hovorka, S.D., 2014. Regional assessment of CO_2-solubility trapping potential: a case study of the coastal and offshore Texas Miocene interval. Environ. Sci. Technol. 48, 8275–8282. https://doi.org/10.1021/es502152y

Goals

To transmit GCCC research results to stakeholder groups though diverse effective communication strategies. The selection of outreach activities for GCCC participation is guided by the following criteria:

1) High-profile programs that engage key stakeholders, decision-makers, informal and formal education professionals and students, relevant industry and regulatory participants, or new programs that have the potential for filling a gap.
2) Relevant to topics in which we conduct active research as informed by the other themes.
3) Provide peer review.
4) Engage prospective sponsors or attract sponsored research.
5) Enhance the reputation of the GCCC.

GCCC students Luca Trevisan and Jacob Anderson outreach to elementary school children on CCS at UT Explore

Susan Hovorka presents at the 3rd CCUS Workshop U.S.-China Climate Change Working Group.

Accomplishments

- Student training: GCCC provided partial support for 2-6 students and post docs per year on research projects that supported elements of the four-year plan.
- Participated in selected peer and expert reviews.
- Gave presentations and attended events at meetings and workshops: GCCC support allowed for dissemination of many projects and studies undertaken by staff and students and supported project development.
- Developed and maintained selected outreach collaborations.
- Conducted training and education through organizations that engage CCS stakeholders.

Accomplishments continued…

- Developed and maintained an active website: www.gulfcoastcarbon.org which includes:
  - news and events,
  - Bookshelf for public posting publications and selected presentations,
  - GCCC Forum, which is a password-protected site for sponsor access, and a
  - technical project area.
- Published a quarterly "News Flash" to provide sponsors with the newest GCCC information ahead of the general public.
- Published a blog to provide discussion of issues relevant to our research.
- Provided outreach through STORE www.storeco2now.com and http://www.co2facts.org/.
- Developed "Portrait of a Leak" game, an interactive activity that highlights the difficulties of cost effective monitoring and pitfalls of signal attribution.

Impacts & Key Findings

- Mexico
  - Developed CCS/CCUS training and capacity building program for the Ministry of Energy in Mexico (SENER).
  - Invited by Mexico's electric company (CFE) to join them on a tender for developing the Mexican Center for CCUS.
  - Collaboration with Pemex and SENER on a proposal for conducting monitoring, verification, and accounting on their first planned CO_2-EOR project.
- Interjected GCCC technical expertise into ISO standards, California Air Resource Boards quantification regulations, and Mission Innovation.
- Used UNFCCC funding mechanisms to stimulate CCS projects in developing countries – (Nigeria, Ghana, and Trinidad/Tobago).
- Guided the first submission of a proposal for capacity building funds for CCS program development by a country (Nigeria) to the UN Climate Technology Centre and Network (CTCN). This resulted in the first-ever funds by CTCN for CCS.
- Held a mini training course for countries on the CTCN funding mechanism.
- Successfully secured and held the only official UNFCCC side event on CCS at the UNFCCC COPs (2014-2017).
- Held several international study tours and activities (Botswana, Korea, China Clean Coal Development Forum, Yanchang Petroleum, China National Petroleum Company).
- Invited to conduct Portrait of a Leak Game at several international trainings and workshops.

Major Projects

- **Offshore Initiative/CSLF**
  BEG spearheaded the formulation of International Offshore CO_2 Storage Initiative at CSLF and has since held two International workshops and secured a $4 million project to oversee an offshore storage partnership.

- **Mission Innovation: technical advisors**
  GCCC researchers served as technical panelists and provided insight into priority research directions (PRD) for monitoring, injectivity and capacity.

- **International Standards Organization**
  Involved in a working group developing consensus on a method of accounting for CO_2 injected for oil recovery as part of a CO_2-EOR process.

- **UNFCCC COPs**
  6 years of informing COPs with the only official CCS side event including getting CCS accepted in the Clean Development Mechanism (Durban, Doha, Lima, Paris, Marrakech, Fiji/Bonn).

- **Otway post-site closure plume stabilization assessment**
  Proposal accepted.

- **China**
  Guangdong CCS Centre; Climate Change Working Group**.**

- **International advisory boards**
  STEMM-CCS (UK), Special Advisory Group of Norwegian CCS Research Centre, Mexican Center for CCUS (in proposal stage).

- **Mexico**
  CCS/CCUS Capacity Development support as part of a specialized training program led by the Ministry of Energy in Mexico (SENER).

- **IEAGHG Research Network Steering Committees**
  Monitoring Network, and Environmental Research Network.

- **Summer schools**
  Presented at IEAGHG Summer School (hosted by GCCC in co22014) and Research Experience in Carbon Sequestration (RECS).

Major Projects continued...

- **GHGT-12**
  Hosted the international conference in Austin, TX (2014) with UT Austin CCS groups.

- **Expert Reviewers and GHGT Technical Programme Committee**

- **Explore UT**
  GCCC regularly presents CCS at Austin's giant open house with our booth called *What to do with CO_2?*

- **Informing policy**
  California Air Resources Board, EPA Class VI rule, US Congressional Series, UNFCCC COPs.

Personnel

- Susan Hovorka
- Hilary Olson
- Juli Berwald
- Katherine Romanak
- Vanessa Nunez

Students and post docs

- Jacob Anderson

Affiliated researchers

- Tim Dixon (IEA GHG R&D Programme)

Contact

Dr. Katherine Romanak
katherine.romanak@beg.utexas.edu, +1 512-471-6136

Selected Publications

Dixon, T., Romanak, K., Neades, S., Chadwick, A., 2013. Getting Science and Technology into International Climate Policy: Carbon Dioxide Capture and Storage in the UNFCCC. Energy Procedia, GHGT-11 Proceedings of the 11th International Conference on Greenhouse Gas Control Technologies, 18-22 November 2012, Kyoto, Japan 37, 7590–7595. https://doi.org/10.1016/j.egypro.2013.06.703

Dixon, T., Romanak, K.D., 2015. Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring. International Journal of Greenhouse Gas Control 41, 29–40. https://doi.org/10.1016/j.ijggc.2015.05.029

Olson, H.C., Olson, Jon E., Bryant, S.L., Lake, L.W., Bommer, P., Romanak, K., Hovorka, S.D., Smyth, R.C., Williams, I., 2013. Meeting the Grand Challenge for Future Carbon Management Engineers and Scientists: Stimulating Workforce Capacity Through Teacher Professional Development. Energy Procedia, GHGT-11 Proceedings of the 11th International Conference on Greenhouse Gas Control Technologies, 18-22 November 2012, Kyoto, Japan 37, 7265–7272. https://doi.org/10.1016/j.egypro.2013.06.664

Romanak, K., Yang, C., Darvari, R., 2017. Towards a Method for Leakage Quantification and Remediation Monitoring in the Near-surface at Terrestrial CO_2 Geologic Storage Sites. Energy Procedia, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland 114, 3855–3862. https://doi.org/10.1016/j.egypro.2017.03.1517