

Gulf Coast Carbon Center Multi-year Plan

This multi-year work plan creates a menu of choices for the Gulf Coast Carbon Center (GCCC) Partners. The plan emphasizes development of specific reports and deliverables that further the GCCC's mission. We review what has been accomplished in 2007-2008 under this plan and goals that will be pursued in 2009

Available Match Money and Research Funding:

Many of these objectives have been and will be partly or entirely completed using funds from other sources. We have received DOE funding to support research in Phase II and Phase III demonstration projects through 2017 as part of the Regional Carbon Sequestration Partnership. Post Doctoral fellows and JSG graduate students doing work related to GCCC tasks have been 50% funded by the Jackson School of Geosciences. In addition, we seek other funds as needed to complete these tasks.

Goal 1.0: To Educate the Next Generation of Carbon Management Professionals and Regulators

Objective 1.1 *Train undergraduate and graduate students with expertise in carbon capture and storage (CCS) to provide skilled workers and researchers.*

Problem:

For carbon management to reach its potential a large increase in the number of well educated professional geoscientists and engineers familiar with various aspects of CO₂ sequestration will be needed.

Strategies:

- (1) Creation of internship program at undergraduate, MA/MS, and PhD levels.
- (2) Work with Jackson School of Geosciences (JSG) and other departments within the University to develop undergraduate and graduate courses and research opportunities in CSS issues.

Anticipated benefits:

- Potential staff hires for GCCC member companies
- Increase national and international reputation of GCCC by producing high quality well trained graduates

Goal 2.0: To Develop Selection Criteria for Commercial CO₂ Sequestration

Objective 2.1: *Create a rigorous, comprehensive manual with pragmatic guidance in non-technical language on best practices for selecting a geologic sequestration site (saline and / or oil and gas bearing reservoirs).*

Problem:

Developing best practices for locating geologic sequestration projects will be a key undertaking for energy industries in a future carbon constrained world. Identifying sequestration prospects and assessing their adequacy for achieving goals (volume,

injectivity, containment, etc.) requires expertise and an orderly process of data collection and evaluation. Uncertainty remains because the permitting process is still immature.

Strategies:

(1) Synthesize the knowledge gained from permitting injection wells, sequestration pilot projects (BEG-led, DOE-funded, and international), FutureGen siting experience, and the BEG's extensive knowledge of subsurface characterization.

(2) Create best practices manual for site evaluation.

Anticipated benefits:

- First step towards developing a plan for a full scale sequestration project.
- Best practices manual will provide support for State and Federal efforts to develop regulatory guidance.

Objective 2.2: *Reduce current uncertainty in estimates of the capacity of brine reservoirs for CO₂ storage.*

Problem:

Methodologies for estimating the CO₂ storage capacity of brine reservoirs undergoing large-volume, long-term injections of CO₂ are immature. Capacity is limited by acceptable risk. For example, restrictions on the areal footprint of the plume, the amount of pressure increase in the zone of endangering influence, or rate of fluid displacement may limit the amount of CO₂ that can be injected and securely stored. What portion of the reservoir is accessed by the injected fluid in multi-well injection scenarios? What role does reservoir heterogeneity have on the sweep efficiency? What are the effects of pressure on leakage of top and fault seals? A number of researchers worldwide are working on developing better capacity estimates. GCCC will undertake improvement of the methods for making these estimates through modeling and field validation of selected elements.

Strategies:

(1) Leverage results and modeling being done as part of Frio Pilot Projects and ongoing SECARB and SW Carb Partnership projects to address the uncertainty of capacity estimates.

(2) Compile research being done by GCCC staff on capacity estimation, and put it in a form readily usable by GCCC partners.

Anticipated benefits:

- Increased confidence in viability of CCS as a method for reducing greenhouse gas (GHG) emissions.
- Ability to make accurate capacity estimates for potential projects

Goal 3: To Define an Adequate and Reliable Monitoring and Verification Strategy Applicable to Long Term Storage

Objective 3.1: *Evaluate existing approaches for monitoring and verification of CO₂ storage in brine reservoirs by assessing sensitivity, accuracy and precision of tools relative to plausible leakage signals.*

Problem: Pilot injection projects (e.g. Frio Pilot) have used a large variety of techniques for monitoring CO₂ injection into brine reservoirs. We seek to determine the strengths

and weaknesses of available monitoring techniques to determine their relative ability to assure storage and detect leakage signals. We are particularly interested in monitoring techniques deployed at depth, close to the primary seal.

Strategies:

- (1) Use data from Frio I, Frio II, Carbon Partnership field projects and international projects to evaluate the sensitivity, accuracy, and precision of various techniques in detecting CO₂ leakage and / or verifying CO₂ storage.
- (2) Test use of key physical and geochemical parameters in future field projects.
- (3) Prepare publications and report to the GCCC Partners.

Anticipated benefits:

- Increased effectiveness and reliability of monitoring by selecting the optimal set of technologies for future projects.
- Provide direction for development of new monitoring techniques.

Objective 3.2: *Develop and Evaluate Innovative Geophysical Technologies for “Early Warning” Detection of CO₂ Leakage*

Problem:

Developing early-warning capabilities to demonstrate security of storage and seal integrity is a highly desirable element of sequestration monitoring. There is a need to develop and deploy through-plume, borehole-to-borehole or borehole-to-surface electrical methods, as well as above-the-primary-seal monitoring of pore fluid pressure, and down-hole passive acoustic monitoring, which can be used in real-time mode.

Strategies:

- (1) Use existing expertise within the BEG in shallow earth geophysics to develop innovative approaches to early-warning of CO₂ leakage.
- (2) Collaborate with specialty instrument and equipment manufacturers to enhance existing technologies for CO₂ detection purposes in planned injection experiments.

Objective 3.3: *Test an innovative approach for monitoring and verifying of CO₂ storage by combining measurements of deformation with geomechanical modeling.*

Problem: Geomechanical approaches using surface and subsurface deformation combined with measurements from high resolution gravity surveys and down-hole tilt meters offer the possibility of direct detection of the area of high pressure, a source of risk and unique potential for detection of CO₂ mass in place.

Strategies:

- (1) Develop capability of coupled geomechanical and fluid flow modeling of CO₂ injection using off-the-shelf software.
- (2) Assess feasibility of measuring deformation utilizing tilt meters, geodetic grade GPS, and InSAR (Interferometer Synthetic Aperture Radar) related to CO₂ injection at various depths.
- (3) Develop capability to invert fluid flow/geomechanical model using surface and subsurface deformation data as constraints.

Anticipated benefits:

- Direct estimates of pressure and CO₂ mass.

- Improved understanding and prediction of plume evolution through coupled geomechanical and fluid flow modeling
- Geomechanical modeling provides critical insights into fault stability in reservoirs undergoing CO₂ injection as well as behavior of fractures during injection.

Goal 4: To Evaluate Sources of Risk and Potential Liability Associated with CO₂ Sequestration

Objective 4.1: *Write a primer based on literature review on risk and liability potentially associated with CO₂ sequestration in the Gulf Coast*

Problem: Risk and liability are perceived as the main factors other than economics that are obstacles to developing a carbon sequestration industry in the Gulf Coast. Texas has nearly four decades of experience with CO₂ injection for EOR and an even longer history of injection of water co-produced with oil and gas. As a result Texas has a long record of court decisions (case law) that is applicable to CO₂ sequestration. This case law can provide an excellent basis to predict future evolution of liability actions.

Strategies:

- (1) Compile information from literature sources and experts on the sources of risk to health, safety and property arising from CO₂ sequestration.
- (2) Compile information from literature sources and experts on case law relevant to liability for injections in Texas, Louisiana and other Gulf Coast states.
- (3) Write a Primer based on information collected from the first two strategies.

Anticipated benefits:

- Establishing that the liability for the consequences of injecting is limited by established law and precedent in Texas and Louisiana.
- Provide guidance for regulators in other Gulf Coast states.

Objective 4.2: *Develop a predictive ability to evaluate the risk of leakage across a seal from a brine reservoir during and after injection.*

Problem:

Predictive ability to evaluate seal quality is needed to assure CO₂ retention in an area that lacks hydrocarbons. Uncertainty in quantitative analogy with methane accumulations and limited petrophysical parameters such as wettability and interfacial tension (IFT) are lacking for CO₂- brine systems and limit predictive capability. Establishing minimum thickness vs. fluid pressure for various types of seal rocks is of particular interest.

Strategies:

- (1) Examine the geologic characteristics of high quality seals, addressing both stratigraphic (lateral facies changes, and diagenesis) and structural (fault) seal types.
- (2) Predict the CO₂ column height that various seals can support, and evaluate the dynamic conditions before, during, or after injection that may contribute to seal integrity.
- (3) Measure petrophysical properties and estimate seal capacity (maximum sustainable pressure and associated supported column height).

Anticipated benefits:

- Better regional assessments of seal quality for potential brine sequestration projects

- More accurate modeling of retention in brine reservoirs

Objective 4.3: *Assess the effectiveness of “phase trapping” (nonwetting-phase residual saturation) in lowering long term leakage risk under various injection conditions.*

Problem:

If large amounts of CO₂ are phase trapped in pore spaces, the risk of CO₂ leakage in large scale injections will be greatly reduced. Although CO₂ residual saturation was first recognized as a significant trapping mechanism for CO₂ sequestration by GCCC staff four years ago, we still have no methodology to predict which reservoirs may maximize residual trapping.

Strategies:

- (1) Design lab experiments to quantify CO₂ residual-phase saturations for representative, well characterized, samples of potential Gulf Coast brine reservoirs in collaboration with a petrophysical technology provider.
- (2) Construction of an online electronic rock properties catalogue containing data from literature together with new data
- (2) Develop numerical model simulations of residual saturation of CO₂ in sands with various pore geometries

Anticipated benefits:

- Better understanding of residual saturation will lead to less risk of leakage from brine reservoirs and greater public confidence in sequestration
- Understanding of factors controlling residual saturation will enable injections to be designed to maximize phase trapping

Objective 4.4 *Assess the risk of CO₂ storage in brine reservoirs to the quality of fresh water resources*

Problem:

Risks to fresh water resources derive from the large amount of critical CO₂ that must be injected. Two aspects of this are: (1) pressure build-up in the injection formation may displace saline water into fresh water aquifers, and (2) the geochemical interaction between CO₂ and fresh water aquifers and/or surface water may degrade their water quality. Pressure build-up effects are most likely to impact the updip sections of the injected formation(s), possibly far away from the injection zone, while geochemical interactions are more likely to take place close to the general footprint of the injection zone.

Anticipated benefits:

A thorough understanding of water displacement by injected CO₂ and interaction between leaking CO₂ and fresh water aquifers will help in determining risks associated with carbon storage.

Strategies:

- (1) Develop numerical models to assess pressure build-up from injection
- (2) Integrate reservoir models with regional aquifer models to address the “far field” effects of CO₂ injection in pushing brines up-dip towards fresh water.

(3) Use of laboratory experiments and aquifer materials to determine the impact of CO₂ followed by experiments on cores from the Gulf Coast to validate predictive geochemical modeling.

(4) Use of analogs such as injection of produced water from oil and gas industry.

Anticipated benefits:

- Understanding risk to fresh water resources will alleviate uncertainty on topic of great concern to the general public and to regulators.
- Data on possible geochemical effects of CO₂ on aquifers will help alleviate a major public concern.

Goal 5: To Evaluate Economic Potential of CO₂ to Enhance Oil and Gas Recovery in the Gulf Coast

Objective 5.1: *Create more accurate predictions of oil-production and CO₂ usage for CO₂ EOR floods in Gulf Coast clastic reservoirs*

Problem:

Current estimates for the CO₂ EOR potential of the Gulf Coast need to be more carefully evaluated both at a regional and reservoir scale. Potential exists to improve CO₂ EOR methods in Gulf Coast clastic reservoirs. Improved understanding can increase oil production per MCF of CO₂. In addition, numerical simulations provide a way to predict the movement of CO₂, and estimate the capacity of the reservoirs to store CO₂.

Strategies:

- (1) Model recovery efficiency for CO₂ EOR in Gulf Coast clastic reservoirs by comparing traditional methods, the new non-parametric model developed by the GCCC, and full numerical simulations.
- (2) Assess the impact of gravity stable flooding on EOR in Gulf Coast reservoirs.
- (3) Assess the possible role of fractures on CO₂ flow patterns and sweep efficiency.
- (4) Consider the possible effects of water alternating gas (WAG) and foam/water alternating gas (FWAG), compared to continuous injection on CO₂ EOR recovery in Gulf Coast reservoirs.
- (5) Develop new criteria for determining suitability of reservoirs for CO₂ EOR and test these criteria against detailed analysis of a representative sample of Gulf Coast oil fields.
- (6) Systematically evaluate the effect of a number of old well penetrations, lack of unitization, urbanization, and abandonment status of fields on viability of EOR projects.

Anticipated benefits:

- More accurate catalogue of potential oil recovery by CO₂ EOR from the Gulf Coast (current estimates are likely overestimates)
- More accurate estimates of potential oil recovery by EOR from individual Gulf Coast clastic reservoirs
- Preliminary analysis of possible role of fractures, gravity drainage and heterogeneity on recovery rates

Objective 5.2: *Quantify the sequestration potential and feasibility of enhanced gas recovery for depleted gas reservoirs in Texas.*

Problem: The Gulf Coast is estimated to have produced 246.6 TSCF of natural gas. Many of the larger onshore gas reservoirs are now depleted in pressure and no longer can be produced. Assuming that CO₂ can be substituted on a volume-for-volume basis for previous volume of gas produced, and an average reservoir depth of 8,000 ft, an average formation volume factor of 0.00807 is obtained. This suggests that gas fields in Texas have a potential CO₂ sequestration capacity of 34.4 billion metric tons. This projected capacity is more than an order of magnitude larger than the sequestration potential of oil fields (based on the GCCC's assessments for the Gulf Coast). Although not all of this sequestration capacity is equally accessible, the very large volume and known seal quality make these reservoirs an attractive target. Issues to be resolved include: (1) to what extent does CO₂ mix with methane or serve as a cushion gas, (2) what is the sweep efficiency and maximum saturation of CO₂ in the complex system, gas + residual gas/water + residual oil/water + brine.

Strategies:

- (1) Create an inventory of initial and depleted gas resource for Gulf Coast natural gas reservoirs with data needed to better estimate volumetrics and estimate the feasibility of enhanced recovery of natural gas using CO₂ injection.
- (2) Learn from ongoing gas storage projects, in order to generalize results. Ongoing projects are Otway, In Salah, K-12B and Rosetta. This might include GCCC staff participating in these projects in a minor way.
- (3) Modeling and theoretical assessment of gas reservoir dynamics on CO₂ storage. Role of water drive, mixed hydrocarbon compositions

Anticipated benefits:

- Quantify the distribution of potential CO₂ storage volumes in Gulf Coast.
- Understand the potential for offsetting costs for sequestration through enhanced recovery of natural gas.

Goal 6: To Develop Market Framework and Economic Models for CO₂ Capture and Storage in the Gulf Coast

Objective 6.1: *Provide to the GCCC partners scenarios and analysis of the policy options under consideration at the State and Federal levels.*

Problem:

Evolution of a CO₂ value chain in the Gulf Coast will create significant business opportunities. However, much uncertainty exists about the regulatory frameworks and tax regimes that will define its structure and thus increase the underlying risks that businesses face. For example, there are at least three different cap-and-trade bills under consideration by the Congress. There are also those who favor a carbon tax; various interest groups favor different approaches to taxation (upstream vs. downstream, or even an import tariff in the case of the steel industry, which will leave domestic CO₂ emissions mostly untouched). **Strategies:**

- (1) Track the different policy initiatives being proposed at the Federal and State level with regard to Carbon and Electricity Market restructuring/deregulation.
- (2) Evaluate different federal policy proposals likely to become law and their potential impact on CO₂ markets

Anticipated benefit of this activity:

- Understanding the impact of the different carbon related policies under consideration and how they impact the evolution of energy and CO₂ value chains can help GCCC member companies in defining their strategic plans

Objective 6.2: *Model possible evolutionary pathways for CO₂ pipeline networks in the Gulf Coast and their impact on CO₂ value chains*

Problem:

Basic economic models that characterize the possible components of a CO₂-EOR value chain in the Gulf Coast have been developed. The simple source to sink model can serve as the initial basis for CO₂ models. However, different pipeline network configurations connecting different sources and sinks can evolve. The handling of uncertainty of the performance of the different value chain components, the structure of the value chain itself, and the policies that will govern its evolution need to be developed.

Strategies:

- (1) Create and evaluate model pipeline configurations that link CO₂ sources around the Gulf Coast and link to the largest oil reservoirs with EOR potential
- (2) Consider impact of siting of gasification plants on optimal CO₂ pipeline configurations based on plans for expansion of coal based power generation
- (3) Extend the concept of the Permian Basin CO₂ market and other analogues to more comprehensive market frameworks for a future CO₂ market in the Gulf Coast
- (4) Develop models for future CO₂ value chains that include EOR, EGR and sequestration under different carbon related policies.
- (5) Examine potential linkages between coal gasification, coal to liquids, coal to methane, coal to chemicals and the CO₂ value chain that may evolve in the Gulf Coast
- (6) Incorporate the characterization of uncertainty and its impact on CO₂ investment related decisions

Anticipated benefit of this activity:

- Availability of plausible models for build out of CO₂ pipeline networks that can help informed decision making by both the public and private sector
- Evaluation of impacts of carbon policies on CO₂ related investment decisions.

Goal 7: GCCC Service and training to partners

Objective 7.1: *Build GCCC/Sponsor/stakeholder relationships and understanding by responding directly to Sponsor concerns. This initiative anticipates Sponsors' needs to uniformly increase awareness and understanding of sequestration concepts throughout their organizations, in the public arena and with other stakeholders.*

Strategies:

Activities facilitated by GCCC related to this initiative can take several forms:

- (1) **Training tailored to Sponsor requests.** This involves short course/workshop delivery, seminars, and working group forums, ranging from formal to informal with flexible participation numbers. These are opportunities to have staff from BEG deliver focused and timely information to appropriate Sponsor audiences

covering Sponsor-specified subjects. Such activities may include site visits, phone conferencing, password protected web forums/peer groups, etc.

(2) **Public materials.** Public acceptance is critical for sequestration activities to flourish. GCCC excels at interfacing with the public and disseminating reliable and accurate information to stakeholders. Activities will focus on outward training and publication to bring a perspective beneficial to the partners to wider public acceptance.

(3) **Specific data sets developed for Sponsors.** In the past GCCC has collected and summarized data of specific interest to member companies (for example: source-sink matching around proposed sites). Previously this has been done under separate funding so that the results are available to only the Sponsor supporting the request.

Anticipated benefits:

Improved sponsor access to and utilization of GCCC products.

- The University of Texas School of Law Climate Change Conference