2022–2026 GULF COAST CARBON CENTER (GCCC) MULTI-YEAR "BIG PLAN"
September 26, 2022

The GCCC's Multi-year Plan outlines an aspirational research design, which poses a series of questions and then describes research approaches to answer them. This research outline spans a 4-year timeline, and because of rapidly increasing interest and needs for carbon capture, utilization, and storage (CCUS) we expect to update, amend, and adapt our plan during this 4-year timeline. In the 2022–2026 plan herein we define several overarching principles followed by five specific research themes.

OVERARCHING PRINCIPLES

- The GCCC seeks to use our geotechnical skills and university research assets for the goal of supporting and advancing development and deployment of commercial large-volume CO_2 storage (CCS).
- The GCCC uses field testing of storage tools and approaches, as elements of both commercial projects and targeted R&D projects to solve problems needed to accelerate commercial investment. We also deploy physical and numerical modeling tools and approaches to solve these problems.
- The GCCC strives to leverage sponsors' annual membership contributions by seeking additional funding aligned with the multi-year plan. We will consider external funding available from the US DOE as well as diverse federal, state, foundation, corporate and other funding sources.
- The GCCC supports targeted student projects and makes other contributions to the carbon storage career pipeline.
- The GCCC educates stakeholders across the entire spectrum of interested groups via publication of findings, formal and informal classes, short courses, lectures, and presentations, diverse media (i.e., to provide technically robust and accessible information on components of storage). We apply our traditional educational skills to current concerns about the intersection of environmental and societal issues of CCS."

2022–2026 MAJOR RESEARCH THEMES

1. Optimizing Storage in Space and Time
2. Business Enablers
3. Getting the Message Out on CCS
4. Providing Storage Assurance for Everybody
5. Hunting Success - Where Next?

Each theme has goals, questions to be answered and refined, and some proposed work elements and approaches provided. Theme topics are highly interconnected.

THEME 1: OPTIMIZING STORAGE IN SPACE AND TIME

Goal: CCS project success includes the injection of large volumes of CO_2 to significantly reduce emissions. This requires high injection rates, sustained over decades (e.g., due to the complete project life), which results in an array of anticipated technical issues.

Problem statement: What issues arise when multiple injection wells, multiple zones and multiple projects operate in the same strata near each other? How do subsurface issues, in this context, intersect infrastructure and other surface issues? At large-scale, what problems need to be solved to successfully manage risks?

Work Elements

1a. Pressure effects on a large scale: How do we predict needed pressure-space to sustain a project?

- Optimizing well and project spacing to avoid interference
- Tools for characterizing boundary conditions
- Tools for defining maximum acceptable pressure and pressure distribution
- Injectivity, permeability upscaling, water handling
- Injection into depleted fields and their specific challenges. Issues include low pressures at start up and compaction effects.

1b. Trapping

• Tools to maximize fetch-area trapping, including approaches to maximizing the contact of CO_2 and brine

• Techniques to minimize the mobility of stored CO_2 when desirable.

• Assessment of the kind and degree of heterogeneity favorable to maximize trapping using pore scale and bed scale physical and numerical models

1c. Defining the limits on high-volume subsurface use.

• Rapid and confident assessment of subsurface features that can limit the amount and location of injection will improve speed and investor confidence in site selection, characterization, operation, monitoring, and closure. Examples of relevant rate-limiting subsurface features are faults which can be barriers to flow or focus flow, anisotropy and

heterogeneity of the flow units which can create focused migration pathways or baffles to flow, and geomechanical properties of rocks in contact with fluids.

• Definition of confining system capacity in terms of CO2 column height that can be retarded, characterization and testing of the performance of these zones.

• Definition of boundary conditions that constrain the connected volumes, including rate and fluid variability. This impacts pressure response to injection over the project duration and includes decadal and post-injection response.

• The risk of unacceptable seismicity limits the rate and duration of wastewater injection in some areas, and the relevance of this finding to CO2 injection needs assessment.

• Well management is an increasingly critical issue as projects expand in injection rates and duration. A focus on qualifying acceptable evaluation and corrective actions for existing penetrations is needed. Well integrity for existing penetrations can be established but has a cost, where is the optimum?

• Approaches to defining and managing the acreage to be leased to host CO2 injection and stabilization, management of pressure-space around the CO2 plume, and well access issues in the area of review are needed to maximize subsurface uses. Improvements of modeling approaches to define and evaluate uncertainty in AOR and CO2 plume delineation is needed.

Approaches

• GCCC plans to use field tests, physical models, and numerical modeling using full physics and machine learning-based models

• We plan to optimize the GCCC's engagement with DOE-funded CarbonSAFE, CarbonStore "accelerator" project opportunities, Regional Partnerships and Initiatives, state agency and foundation funding.

THEME 2: BUSINESS ENABLERS

Goal: Storage technologies are available now, but the novelty of the goals and mechanisms creates questions and doubts for investors. In this theme we explore these questions and then implement improvements in the technologies that can raise investor confidence. Theme 2 focuses on questions that need R&D work to provide a robust answer and has a strong interaction with the theme 3 "Getting the word out."

Problem statement: What uncertainties and risks hold back investment in CCS? Some questions have arisen and we expect that more questions will come forward in the next

four years. GCCC will listen to commercial project developers, financers, regulators, and governments to identify geotechnical problems and then develop technical approaches that reduce these limiting factors.

Work Elements (Examples)

• Dry hole risk management. Exploring for storage resource is lower risk than exploring for hydrocarbons, however experience shows that pre-drill predictions of injectable reservoir at a well may be inaccurate and target zone be thinned, missing, or not permeable. What can we do to quantify and decrease this risk?

• Despite historic performance to the contrary, leakage of injected CO_2 continues to be a significant worry across a broad spectrum of stakeholders. What can we do to quantify this risk and demonstrate security?

• Insurance and bonding are required for permits and are a principal element of a CCS business model. Research to define the distribution and mean of realistic and constrained failure case cost distribution is needed to support insurance and bonding. This also links to risk reduction strategies in other themes.

• Miocene core along the Gulf Coast is needed to obtain accurate porosity to permeability transforms and formation-specific capillary entry pressure and residual saturation curves.

• Updating GCCC's dynamic capacity estimation online tool (EASiTool) https://gccc.beg.utexas.edu/easitool) has been requested by a number of stakeholders and is classified as a business enabler in this plan.

• Proactive management, accurate costing, best practices and risk for storage beneath wetland areas, including lakes, bays, wetlands, and shorelines. For example, shoreline crossings are sensitive elements linking onshore and offshore. This links to monitoring in such settings described in Theme 4.

• Monitoring has been a GCCC focus in past decades. In this 2022–2026 plan we classify monitoring in part as a business enabler because of its role in managing risk, increasing public acceptance and mitigating concerns linked to environmental justice, and sustaining project compliance under permits. Expanding monitoring to consider offshore in Gulf of Mexico conditions, in shallow lakes and bays, and in wetlands is needed and includes the deep subsurface, protected aquifer resources, and surface environments and users. Monitoring is also included in theme 4, storage assurance.

• Infrastructure reuse is a major business risk, in terms of repurposing former hydrocarbon fields which have numerous penetrations, as well as a potential benefit in terms of lowering cost and increasing public acceptance. We are developing a concept "Infrastructure-led storage" (ILS) that considers value and feasibility of platform and pipeline reuse.

• Working internationally to accelerate the development of CCS capabilities in emerging economies to strengthen capacity for global collaboration in CCS-related markets including hydrogen, DAC and BECCS, shipping and transport fuels and other areas where regional co-operation among industry, government and academia can expand business prospects.

• A key element of theme 2 is to continue vigorous dialog with project developers and financers both in a general context and via participation in multiple field deployments in order to continue to listen for questions which GCCC has geotechnical skills to contribute. These questions can be added to this list and addressed.

Approaches

A major approach to developing business enablers is to work with others on as many commercial projects as feasible. Interaction with commercial projects is valuable at any stage from feasibility through permitting, to operations and closure. GCCC can interact via filling many roles: We may work as a project lead, as a partner with an operator, as a guest of the operator, as a reviewer or outside party, or as a contributor of special project elements. The GCCC will select projects that move CCS forward, support work elements that benefit more than one project and lead to publication of transferable results.

THEME 3. GETTING THE MESSAGE OUT ON CCS

Goal: GCCC will have a goal of continuing and increasing to provide technical information about CCS with a focus on large volume storage in the near term. We will make technical data relevant to policy and commercial advances but stop short of making specific policy recommendations or commercial investment decisions. A strong linkage with all the other themes is recognized.

Problem Statement: A growing number of stakeholders are now in some ways involved in CCS and in order to progress they need good information about the technology targeted to meet their needs. In addition, availability of increased funding and resulting deployment of projects intrinsically raise concerns from diverse stakeholders. Concerns are best managed by getting factual information about CCS to leaders of diverse groups who influence opinion and decision-making in communities.

Work Element Examples

GCCC will use our assets as university and state geologic survey experts to 1) hear needs and concerns, and 2) provide relevant information in response. We will maintain an element of independent evaluation and work to increase trust with stakeholders. The tools

for stakeholder engagement will continue to include the whole portfolio of options already in use for GCCC outreach, including peer reviewed technical papers, white paper and data sets releases, accessible non-technical information, a web and social media presence, in-person and online events, workshops, panels, presentations, participation in selected conferences, working groups, task forces, and other organizations. In response to high demand, GCCC will continue to develop and present materials to train others, including providing technical resources to sponsors and participants in other parts of the CCS value chain. We will continue to provide semester courses, short courses and training in formats designed to serve key stakeholders. We will strive to provide high quality information and approaches to increase the number of well-informed practitioners at levels from national to local and to inform many community members, students, teachers, regulators, and policy developers.

Approaches

Stakeholders that GCCC aspires to work with include policymakers at state and federal level, US DOE staff including their developing visions for energy transition; environmental justice (EJ) and related field practitioners and leaders at local to national levels, investors and other market elements, regulators at federal, regional, and state level and including onshore and offshore, land owners and land managers, technical experts who are bringing subsurface and environmental expertise into CCS, and educators at all levels from local school districts to our pears at colleges and universities. We will also continue to input technical information into global forums such as UNFCC.

THEME 4. PROVIDING STORAGE ASSURANCE FOR EVERYONE

Goal: Geologic storage in suitable settings has intrinsically low risk and high permanence, and good site selection and proper operation assures most of this value. Additional assurance can be obtained via risk.

assessment and then systematic risk reduction using engineering approaches and monitoring. GCCC will continue our work toward providing tools that can be effectively and confidently applied to reduce risks.

Problem Statement: Monitoring tools have been extensively developed over the past several decades, and methods for deploying them have been well demonstrated. However, most storage projects conducted to date have been single-well injections in highly favorable settings, operated for a limited time (although durations are increasing as more projects continue to operate). Some risk elements, especially those relevant to widespread, long-duration, large-scale injections have been incompletely probed so far. In this theme, the GCCC will advance strategies to support storage assurance in large volume

deployment in areas where storage is needed (with some focus on Gulf of Mexico conditions).

Work Element Examples

Some of the risk elements that can be evaluated in this theme include:

• Fault seal performance, including cross-fault boundary definition for CO_2 and pressure, along-fault preferred flow, or up fault migration on damaged zones or fractures with open aperture remains an area where storage assurance methods need maturation. Both characterization of risk and monitoring approaches to reduce risk are needed.

• Wells provide the most rapid pathways from the deep subsurface to near-surface settings. Most wells are constructed to provide zonal isolation during use and at the end of use are plugged and abandoned (P&A). Regulatory experience in managing non-isolating well risk is mature. However, because this is the main feature that threatens storage assurance in some sites, especially along the Gulf Coast, techniques to improve characterization and monitoring of zonal isolation in wells are of high value. The GCCC will seek opportunities to evaluate tools that can be used prior to and during injection and at depth and near the surface. Issues such as injection prospects above the top of production cement and surveillance of P&A wells are nominated for consideration.

• Surface monitoring is complicated by active carbon cycling in the ecosystem as well as other processes that are dynamic on daily, seasonal and long-term trends. Creating tool sets to that attribute leakage signal to separate it from other variably is a success of past GCCC monitoring development, and further work to create user-friendly tools that stakeholders can readily evaluate is needed. Application of monitoring approaches to aqueous environments is identified as a gap; these include groundwater and shallow surface waters in bay, lake, wetland and shallow marine settings. Tools such as conductivity, thermal signal and fluid signature that are characteristic of the deep-subsurface as well as continued use of high-resolution seismic are prospective work elements.

• Tools to optimize and target subsurface monitoring are also in consideration, building upon recent evaluation of sparse, remotely operated and low impact low cost, and long duration deployments, reducing costs and increasing confidence.

• As field projects mature, approaches to quick and effective troubleshooting are elevated needs. Well control specific to CO2-rich fluids, unexpected results from monitoring, and evaluation of public concerns are areas that may be valuable to develop.

• As discussed in theme 1, GCCC will continue to develop both traditional and non-traditional concepts for definition of and limits on performance of confining systems as well as in-reservoir fluid flow and trapping at various scales as key components of storage

assurance. Providing this data to regulators and other stakeholders is an important near-term task.

Approaches

GCCC expects to integrate conceptual models, physical models, fluid flow models at multiple scales, and field tests to advance confidence in storage assurance in applicable settings. GCCC will leverage rapidly evolving approaches including big data and machine learning, as well as stay aware of as practical adopt new approaches tools and technologies developed elsewhere.

THEME 5. HUNTING SUCCESS - WHERE NEXT?

Goal: This theme is designed to probe the frontiers of current storage project experience to look for new ways to support widespread and rapid deployment of CCS.

Problem statement: Assumptions that storage projects will be similar to those previously tested may leave some high-quality storage potential undeployed. In this task we consider where GCCC efforts on increasing storage options can have high impact.

Work Element

This work element may expand during the four-year evolution of the 2022–2026 plan. Elements proposed so far include consideration of:

• New global CCS markets and technologies

• Evolving transportation options such as availability of CO_2 ships or limits on new pipelines construction

• Emerging trends, including methods for removing CO_2 from the atmosphere such as direct air capture or bioenergy CCS,

• Storage associated with EOR remains of interest. The implications of more widespread captured CO_2 and industrial decarbonization options may lead to research ideas in this domain.

• Integration of CO_2 storage in evolving low-carbon roadmaps such as hydrogen hubs or with geothermal resources will be considered.

• Reuse of infrastructure such as new wells that access unconventional (fractured) reservoirs

• Development of CCS-specific exploration tools with application to new regions as evolving global interests warrant

Approaches

This theme is intentionally left underspecified in order for the GCCC to respond to rapid evolution of interest in low-carbon ecosystems. The GCCC's skills and expertise as well as critical evaluation of the prospective value of research outcomes will guide selection of research in the "hunting success" theme.