Synergy between industry intelligence and technological innovation to address our climate goal

Sougata Halder[1*], James Keay[1], John Xie[2], Meridee Fockler[2], Matt Mayer[1] and Phil Hargreaves[3] demonstrate why access to expansive subsurface well and seismic data and decades of oil and gas exploration experience give the geoscience industry a unique advantage in developing integrated best-in-class, basin-wide interpretation solutions to reduce the risk, time, and cost of the CCS life cycle.

Introduction

Climate modelling by the International Energy Agency recommends the optimal approach for stabilizing global climate incorporating Carbon Capture and Storage (CCS) at the multi gigatonne (Gt) scale by the middle of this century. All the pathways to limit global warming to 1.5°C above pre-industrial levels, developed by the Intergovernmental Panel on Climate Change (IPCC), show the necessity for a rapid decrease in emissions, leading to net zero by the middle of this century, along with 5-10 Gt of CO_2 removal from the atmosphere each year in the second half of the century to offset the hard to avoid emissions, such as from agriculture and air travel and to correct for the overshoot of the total load of greenhouse gases in the atmosphere. Further, all the long-term energy emission scenarios with near-zero greenhouse gas rely on a combination of renewable energy, nuclear power, and fossil energy coupled to CCS for electric power generation.

Comprehensive and bold steps are required to reach climate neutrality by 2050, and CCS technology will be a key part in that effort. CCS is a proven and safe technology that prevents carbon dioxide (CO_2) from being released from point sources into the atmosphere or removes it directly from the atmosphere. The technology involves capturing (purifying) CO_2 produced by industrial plants (such as steel mills, chemicals plants and cement plants), coal and natural gas-fired power plants, and oil refineries, compressing it for transportation and then injecting it deep underground – at least 800 m below the surface – into a geological storage site, where it will be trapped and permanently stored in the porous rock.

Synergy between the industry intelligence and CCS technologies is critical to achieve our ambitious climate goal. The extension and enhancement of the tax credit through the Inflation Reduction Act of 2022, will support innovation and new deployments for a range of technologies, including CCS. This will help to ensure strong commercial interest and provide a basis for potential large-scale deployment of CCS technologies. Geophysical companies can play a crucial role in various aspects in the deployment of large-scale CCS technologies. Leveraging subsurface data and knowledge base built through years of industry experience, subsurface intelligence products, such as comprehensive storage resource assessment tools, can be developed to de-risk CCS investments. Through providing CO_2 injection monitoring solutions they can also address storage

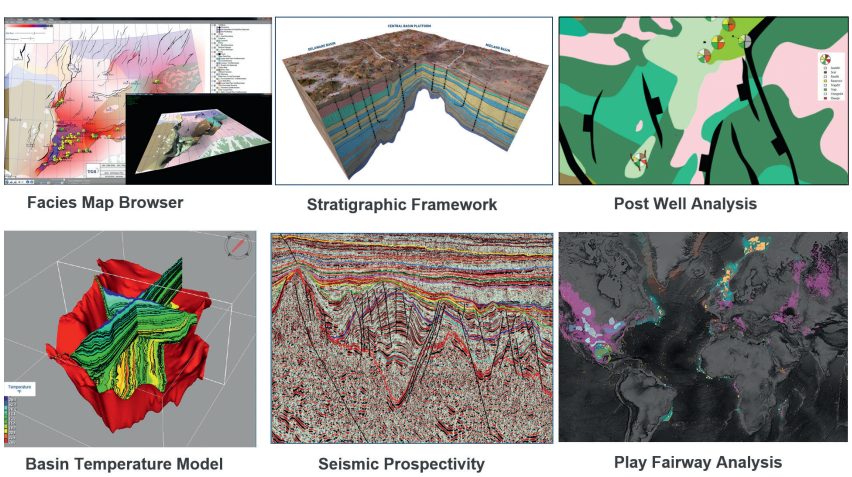

Figure 1 Subsurface interpretation products relevant to prospecting for CO_2 storage.

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containment and conformance. Further, the experience of geophysical companies could be leveraged to bridge the transition from site assessment to injection through providing insights on permitting and regulatory liaising.

Data-driven Insights

Access to expansive subsurface well and seismic data and decades of oil and gas exploration experience provide our industry with a unique advantage of developing integrated best-in-class, basin-wide interpretation solutions to reduce the risk, time, and cost of the CCS life cycle. Figure 1 shows some of the subsurface intelligence products in the market that could be leveraged in developing insights for subsurface storage, which would be the primary focus for this article.

As with conventional oil and gas, subsurface data and insights are in the core of the decision making for identifying appropriate CO_2 storage locations. Repurposing of well and seismic information for subsurface CO_2 storage can provide valuable insights on prospective storage estimation and manage risk and uncertainties of CCS projects. This study provides workflow for development of a large-scale regional database of estimated volumetrics for storage potential of injected CO_2 in depleted oil and gas reservoirs.

Areas of Interest

The assessed area extends across heavily explored petroleum producing regions of southern Texas, Louisiana, and Mississippi. The area lies within the heavily industrialized region in the southern US and the US Gulf Coast where large numbers of industrial CO_2 emission sources exist. Presence of numerous local point emission sources, along with the existing infrastructure with low cost of CO_2 storage, assessed by US Department of Energy, make US Gulf Coast an attractive area for CO_2 storage.

Data

The purpose of this study was to supplement existing regional studies with a detailed consistent dataset useful for reference and screening for CO_2 storage at the hydrocarbon reservoir/pool scale. Data available for this study includes well data, well production performance and reservoir/fluid data, and proprietary geologic and temperature models (Figure 2). Project challenges were fundamentally around data standardization and accessing sufficient reservoir/fluid attributes to perform consistent storage capacity calculations across a large area. Reporting inconsistencies of public well records required significant quality control. Accurate reservoir attributes are rare in public data, therefore unique workflows were developed to enable a successful result. Development of the database involved analysis of cumulative and forecasted production, and completion records in more than 150,000 wells within the area of interest. Available proprietary databases were integrated with data from trusted academic and industry resources.

Analysis

The study was intended to identify and compare storage opportunities over a large geographic area and assess uncertainties and associated potential risks of storage. Key to the project was assignment of production for each well to a standardized set of formations as a process of delineating producing pools and calculating cumulative production from each pool. Figure 3 shows the subsurface analysis workflow used in this study for depleted hydrocarbon reservoir storage. Regional screening of oil reservoirs for Enhanced Oil Recovery (EOR) suitability has also been added as an extension to the project.

Various subsurface data analysis workflows and proprietary models were integrated to define storage attributes for hydrocarbon pools. The key workflow for this subsurface analysis was development of the production database involving analysis of cumulative and forecasted production and allocation of production at the producing intervals along the wellbores. The producing well intervals from public-domain records required normalization to new standardized formation names. The production allocation at various formation levels was quality controlled using desktop geoscience interpretation software through visualizing the well perforations with relevant well logs and gridded stratigraphic surfaces.

Reservoir P and T data are necessary to calculate CO_2 density and effective CO_2 storage capacity. The study area covers three proprietary high resolution Basin Temperature Models (BTMs), from which temperature data were extracted at defined producing intervals along the wellbores. Equally important was the pressure data. Our internal pressure database was supplemented with the pressure data available from the academic resources to extract pressures at the producing intervals along the wellbores.

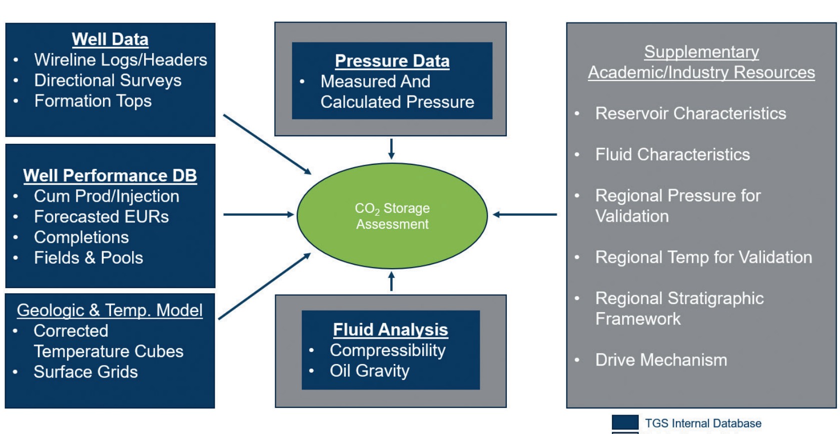

Figure 2 Data Inventory for subsurface analysis.

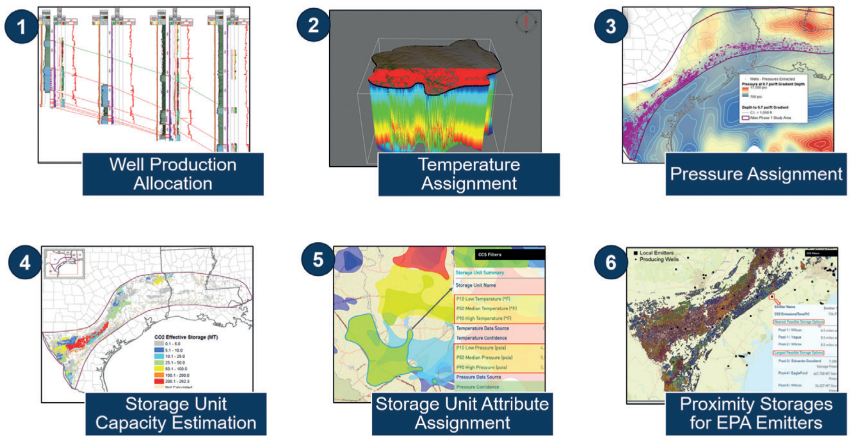

Figure 3 Subsurface analysis workflow for depleted reservoir storage.

Hydrocarbon pools were generated at 27 formation levels, using more than 150,000 producing wells within the area of interest. GIS buffering function was used to generate pools combining wells producing from the same geologic formation. Reservoir/fluid and production (cumulative and forecasted EUR) data from the wells within each pool were captured as a range, presenting values for the low, medium, and high case, and were appended back to the pool as their attributes (Figure 4). A data confidence attached to these attributes was based on the how the data were sourced to generate the attributes. The term 'storage units' was introduced to rename individual pools, as well as a defined groupings of laterally contiguous/overlapping pools in the same stratigraphic zone where the potential of lateral migration/communication during CO_2 injection exists.

A material balance technique has been used for the effective storage capacity estimation for the storage units using the methodology presented by Bachu (2006). A Monte Carlo simulation proved to be a versatile volumetric approach as it allowed weighting of various parameters and confidence, providing P10, P50, and P90 ranges of storage outputs. Additional attributes, such as the number of well penetrations, including the inactive, shut-in, abandoned wells, in each storage units were also calculated as input for further risk assessment.

The dataset compiled for this analysis also provided the opportunity for a region-wide screening of oil reservoirs for CO_2-EOR based on the methodology presented in Bachu (2015). Several proprietary datasets were integrated to gather relevant attributes, resulting in categorizing oil pools into three different classes, categorized as in-boundary, near-boundary, and outside boundary conditions. Based on the reservoir characteristics suitable for miscible CO_2 EOR, more than 5500 oil pools have been screened down to 814 pools that are better suited for further miscible CO_2-EOR assessment.

Project outcome

The analysis resulted in a GIS database of estimated storage capacity of individual depleted hydrocarbon pools, at 27 formation levels, along with their relevant storage attributes. An interactive web application was developed later to combine the subsurface analysis with above-ground information that provided critical information to help assess technical and commercial viability of CCS projects within the area of interest. The application helps to visualize/reference storage opportunities within the area of interest, along with other spatial layers, such as local emitters, pipelines, protected and forested lands and local power plants and refineries for context (Figure 5). Property ownership details have also been added to build understanding of ownerships of the subsurface pore spaces.

Adding yearly emissions from the local CO_2 emission sources provided an opportunity for a proximity analysis of nearby storge opportunities for the local emitters, based on their available total storage capacities. The analysis provided a database of identified nearby storages for each local emitter. For each local CO_2 emission sources, the proximity analysis identified three nearest feasible and three largest feasible CO_2 storage options available within the 30-mile radius (Figure 6).

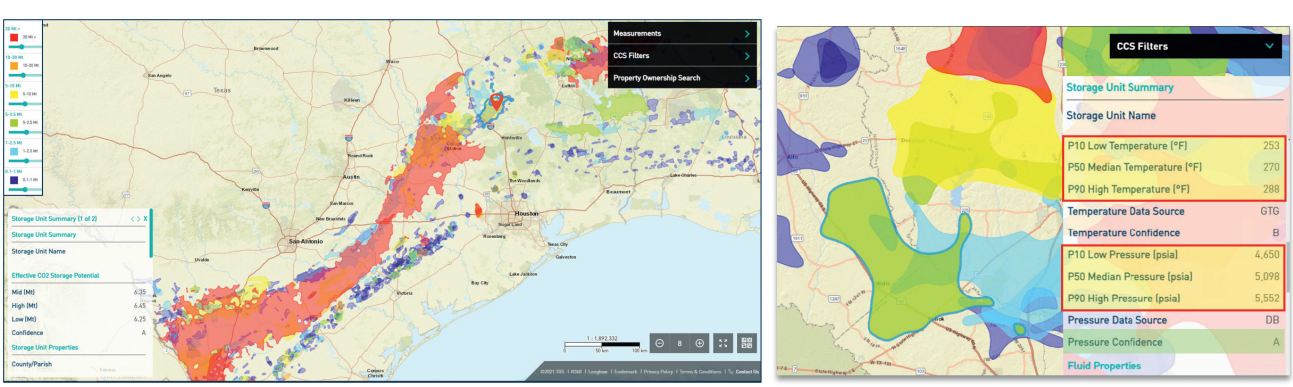

Figure 4 Hydrocarbon pools and their associated reservoir and fluid attributes for comparing CO_2 storage opportunities.

Risk Assessment and Controlling

Identification of potential risks are essential for any regional assessment study. Key parameters adding risk for CO_2 storage are depth of CO_2 injection and CO_2 density, which is dependent on subsurface temperature and pressure. The efficiency of CO_2 storage and storage safety increases with increasing CO_2 density. With increasing depth, the density of CO_2 increases, and relative volume of CO_2 decreases. At about 2600-ft depth (~1084 psi pressure and 88°F temperature) CO_2 reaches a supercritical state (NETL, 2021), after which relative volume of CO_2 decreases dramatically with depth, leading to an increase in storage efficiency. The recommended range of CO_2 densities for supercritical CO_2 storage is 600-800 kg/m^3. Therefore, the storage units that are deeper than 3000 ft with calculated CO_2 densities less than 600 kg/m3 within our area of interest may pose a storage safety concern and potential uncertainties in storage efficiency related to that. These units should be investigated further to better constrain subsurface parameters relevant to their storage.

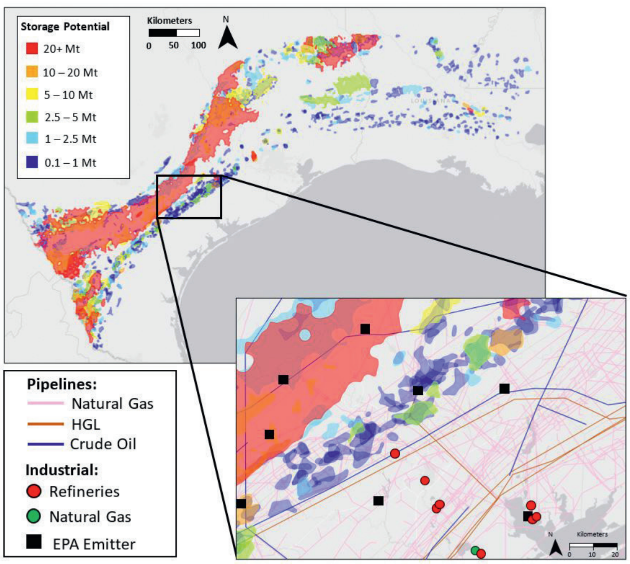

Figure 5 GIS database of subsurface analysis combined with above-ground information.

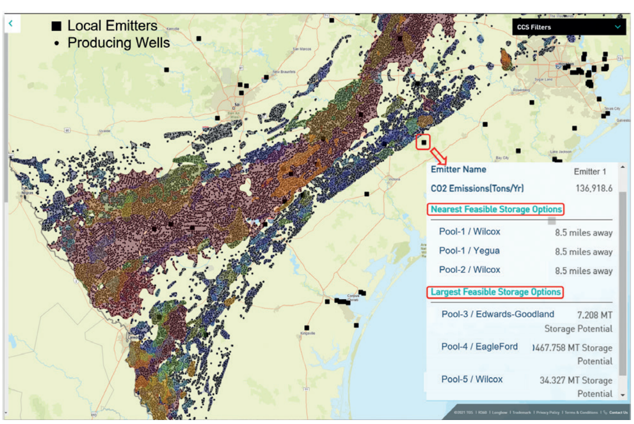

Figure 6 Identified nearby feasible storage opportunities for local CO_2 emission sources within the area of interest.

Another critical aspect of storage safety is the number of well penetration within these storage units. The number of well penetration into these reservoirs/pools, including non-active wells, such as shut-in, abandoned, etc. along with the producer wells, could provide valuable insights on risk management involving potential leakage through these wells. Assessment of mechanical integrity of existing wellbores would be essential at the site-specific risk management evaluations, along with a mitigation plan for wells with higher leakage risks.

As the world moves towards our ambitious goal for emission reductions along with removal of CO_2 from the atmosphere and geologic sequestration, there is a multitude of ongoing efforts at all parts of the CCS value chain for driving down the costs and risks though application of innovative technologies. Subsurface pressure and injection monitoring, along with near-surface and atmospheric technologies, such as fluid sampling and remote sensing, are some of the available subsurface and surface technologies that could play a crucial role in reducing uncertainties and risks of CO_2 storage. One critical aspect of geologic storage is monitoring CO_2 in the subsurface for containment of CO_2 in the targeted reservoirs and conformance with the predicted model of CO_2 migration and associated changes in reservoir and pressure conditions. Developing cost effective 4D monitoring solutions through building a forward model from the baseline survey are well known for safe storage of CO_2 in the subsurface.

Various seismic technologies can play a crucial role to meet the demands of CCS storage monitoring requirements. Technologies, such as Distributed Acoustic Sensing (DAS), using in-well optical cables and ultra-high-resolution P-Cable 3D seismic imaging surveys (Figure 7), can be applied as a long-term monitoring solution. Distributed Acoustic Sensing (DAS)-Vertical Seismic Profile (VSP) could provide a cost-effective, higher resolution frequent monitoring solution for CO_2

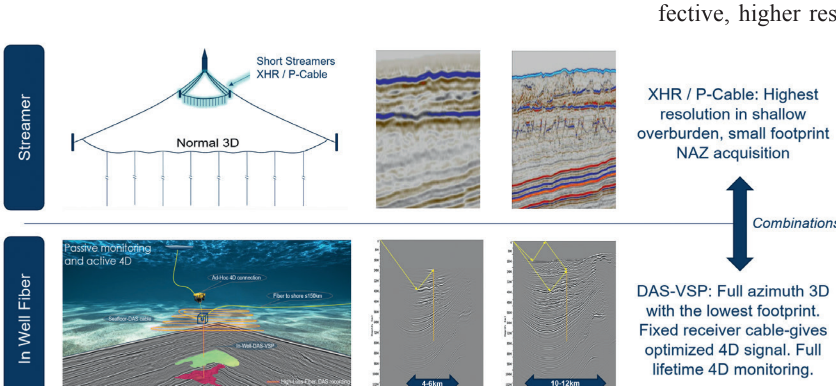

Figure 7 A comprehensive repeatable, low-cost monitoring solution at the right resolution.

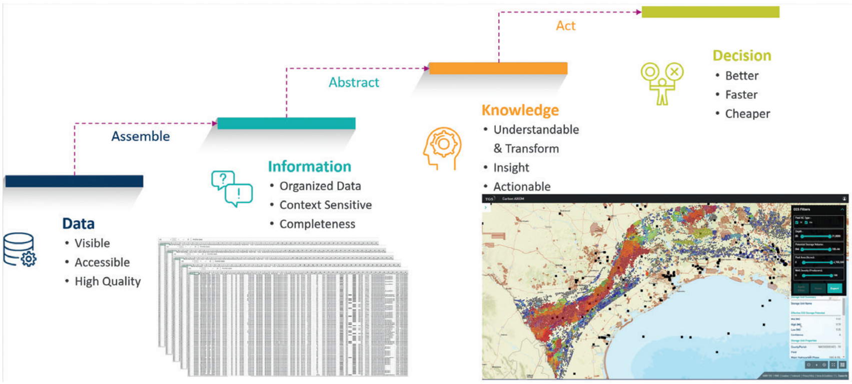

Figure 8 Digitalization: from data to informed decision making.

injection, along with infrequent 4D surface seismic monitoring. The technology associated with DAS for vertical seismic profile (VSP) acquisition has been advancing rapidly. It is a faster, safer, frequent 4D monitoring solution throughout the lifetime of the CCUS project with reduced exposure time and equipment needs through permanently installed fibre-optic cables along the wellbores. In many cases, fibre-optic cable is installed by permanently cementing it behind the casing or by clamping it to production tubing in the well for other applications, such as distributed temperature sensing. The ability to access this cable without requiring well intervention enables the possibility of using the cable to acquire VSP data using DAS for a single survey, as well as for time lapse studies, while reducing both cost and rig time. A comprehensive monitoring solution would be a combination of short streamer XHR/P-Cable with multiple imaging of DAS-VSP surveys. The highest resolution of XHR/P-cable in shallow overburden combined with frequent optimized DAS-VSP 4D monitoring could help in providing assurance to regulators and other stakeholders for further CCUS adoption.

Digitalization

Digital transformation would play a key role in energy transition through transforming data and information into meaningful, actionable insights for effective decision making to reduce cost, risk, and cycle times. Existing subsurface database and knowledge acquired through decades of oil and gas industry experience could be enhanced further using our digital capabilities. Repurposing of available expansive well and seismic information, combined with available surface information provide opportunities for developing prospecting/screening tools for subsurface storage for both depleted reservoirs and saline aquifers. Digitalization of this current study provided the opportunity to access the comprehensive subsurface knowledge developed through integration of various subsurface data and analysis, combined with above-ground information in an interactive web-based platform to help assess feasibility of new CCS projects efficiently (Figure 8). Digitalization of our data and intelligence and transforming information into meaningful insights would lead the pathway forward for successful CCS deployment.

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