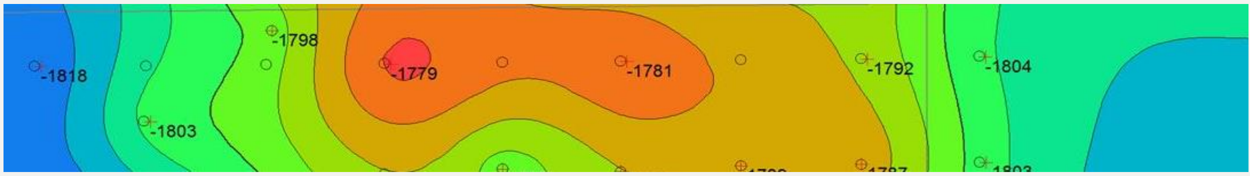
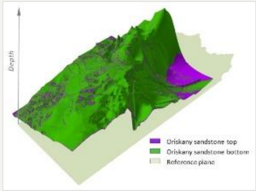
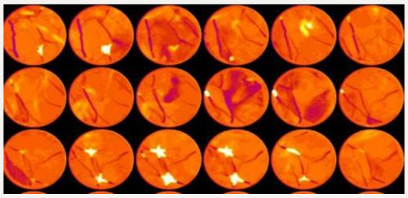
## DISCLAIMER











# FECM/NETL Offshore $CO_2$ Saline Storage Cost Model Version 1 – QuickStart Guide

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***Derek Vikara[1,2]; Taylor Vactor[1,2]; Mackenzie Mark-Moser[1]; David Morgan[1]; Luciane Cunha[1]***

[1]National Energy Technology Laboratory (NETL) support contractor
[2]NETL

Corresponding contact:

- MacKenzie Mark-Moser – mackenzie.mark-moser@netl.doe.gov

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# LIST OF EXHIBITS

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AoR | Area of review |
| BOEM | Bureau of Ocean Energy Management |
| BSEE | Bureau of Safety and Environmental Enforcement |
| $CO_2$ | Carbon dioxide |
| CO2_S_COM | Onshore Carbon Dioxide ($CO_2$) Saline Storage Cost Model |
| CO2_S_COM_Offshore | Offshore Carbon Dioxide ($CO_2$) Saline Storage Cost Model |
| DOE | Department of Energy |
| FECM | Office of Fossil Energy and Carbon Management |
| GOA | Gulf of America |
| IRR | Internal rate of return |
| NETL | National Energy Technology Laboratory |
| NPV | Net present value |
| O&M | Operations and maintenance |
| OCS | Outer Continental Shelf |
| QSG | QuickStart Guide |
| tonne | Metric ton (1,000 kg) |

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# 1 Model Overview

The purpose of this QuickStart is to assist users in operating the Office of Fossil Energy and Carbon Management/National Energy Technology Laboratory (FECM/NETL) Offshore Carbon Dioxide ($CO_2$) Saline Storage Cost Model (CO2_S_COM_Offshore) Version 1. This manual outlines the major outputs, provides an overview of how the outputs are calculated, and provides a more detailed understanding of how a user can edit the inputs to affect outputs for the purpose of evaluating a storage project aimed for conducting operations in the Outer Continental Shelf (OCS) of the Gulf of America (GOA).

CO2_S_COM_Offshore is a screening-level model and has been developed for evaluating the cost for a $CO_2$ transport and storage project in an offshore, saline-bearing formation via pipeline transport. Version 1 of the CO2_S_COM_Offshore is tailored specifically to consider the nuances of offshore projects operating in the shallow shelf of the GOA. The current version is focused specifically for analyzing storage options in the OCS with water depths less than 650 feet (ft) (200 meters [m]) [1]. CO2_S_COM_Offshore was developed as a technoeconomic, macro-based Microsoft Excel® spreadsheet that calculates the first-year break-even cost of offshore geologic $CO_2$ storage (in 2024$/tonne of $CO_2$), accounting for capital (CAPEX), operating (OPEX), and other financing costs. It calculates revenues and costs from the perspective of the operator of a single saline storage project in the offshore GOA OCS. Cost result outputs from CO2_S_COM_Offshore are considered comparable to the Association for the Advancement of Cost Engineering Class 5 level cost estimates [2, 3]. The model has been developed to have a similar appearance and functionality as NETL's widely used CO2_S_COM cost model [4] for onshore geologic storage in saline formations; a key difference between the models is the inclusion of offshore pipeline $CO_2$ transport in CO2_S_COM_Offshore.

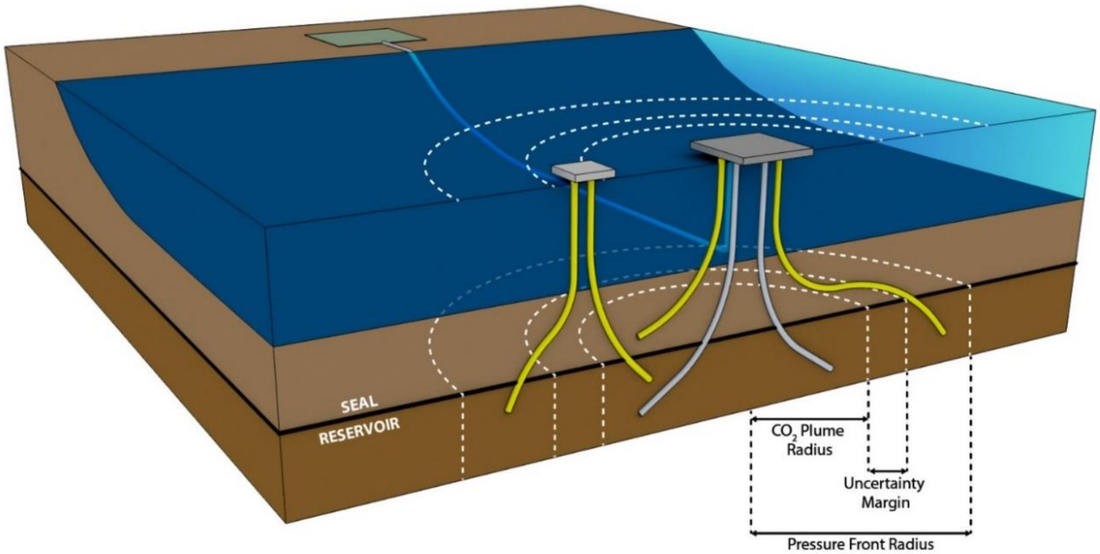
The model comprehensively incorporates multiple facets of offshore geologic storage projects, from regional evaluation and site selection to permitting, transport, operations, monitoring, site closure, and decommissioning (Exhibit 1-1). Key inputs include offshore storage formation options, $CO_2$ injection rate and duration, infrastructure types, monitoring intensity, project financing, and post-injection site care duration. Supporting cost algorithms within CO2_S_COM_Offshore were compiled utilizing S&P Global's QUE$TOR™ cost estimation software [5] alongside a variety of open-source scientific literature. CO2_S_COM_Offshore has been developed to include the cost drivers associated with offshore storage operations. These include a given project's water column depth and distance from shore, platform infrastructure types (including primary platform and monitoring satellites), directional drilling capability, decommissioning, capital and operational expenses, and estimation of the areal extent of the $CO_2$ plume and pressure front.

Offshore $CO_2$ storage projects modeled by CO2_S_COM_Offshore comprise onshore (beach) and offshore facilities connected by a dedicated $CO_2$ pipeline. Onshore operations begin at the onshore custody transfer meter and include buildings and equipment to support offshore operations. An onshore booster pump maintains pipeline pressure to ensure that $CO_2$ transported via offshore pipeline remains in a supercritical state when arriving at the offshore injection site. Injection occurs at the offshore primary structure, either a caisson or jacket (depending on water depth and well slot needs), via vertical or directional injection well(s). A minimum of two monitoring locations are included in all modeled scenarios: monitoring above the formation seal near the injection point, and monitoring of both above the seal and in the reservoir somewhere within the pressure front area. Additional monitoring wells can be located on the primary structure or a satellite structure. Satellite structures provide the only option for supporting water production and water disposal wells and may also be used for additional monitoring wells in the pressure front or uncertainty area (Exhibit 1-2).

***Exhibit 1-1. Concept of an offshore $CO_2$ storage project utilized as part of CO2_S_COM_Offshore design***

| Item | Offshore $CO_2$ Storage Project Phases | | | | | | |
|---|---|---|---|---|---|---|---|
| | Site Screening | Site Selection & Lease Acquisition | Characterization | Permitting & Construction | Operations | Post-Injection Site Care & Closure | Long-Term Stewardship |
| Duration | 1 to 3 years for all three phases | | | 3 years | 1 to 50 years | 10 to 50 years | Rest of Civilization |
| Actions: Technical | Purchase, acquire, and analyze existing<br><br>Ranking of candidate locations based on available data<br><br>Preliminary modeling of storage resource, pressure front, and $CO_2$ plume | Select a prospective site<br><br>Determination of lease size needs from modeling<br><br>Public outreach campaign<br><br>Storage development planning (pre-FEED) | Purchase, acquire, and analyze additional data<br><br>Seafloor (hydrogeographic) evaluation – shore to site<br><br>Biological and environmental surveys<br><br>Drill stratigraphic test well, collect and analyze core<br><br>Baseline seismic surveys (2D and 3D) or other geophysical approach<br><br>Static and dynamic reservoir modeling<br><br>Storage development planning (FEED) | Corrective action on wells within Area of Review<br><br>Platform fabrication and installation<br><br>Install offshore structures<br><br>Drill, test, and complete injection and monitoring wells<br><br>Build pipeline to offshore transfer point and run power cables<br><br>Public outreach campaign | Inject $CO_2$<br><br>Safety and environmental monitoring<br><br>Pressure monitoring and analysis<br><br>$CO_2$ plume monitoring and analysis<br><br>Seismic event monitoring<br><br>$CO_2$ pipeline monitoring<br><br>Well integrity testing<br><br>Static and dynamic modeling<br><br>Area of Review reevaluation<br><br>Public outreach campaign<br><br>Produced water and treatment (optional) | Safety and environmental monitoring<br><br>Pressure monitoring<br><br>$CO_2$ plume monitoring<br><br>Decommissioning of site and pipeline | Not evaluated as part of modeling framework |
| Actions: Fiscal | Evaluate available lease offerings | Lease acquisition | Arrange for financial assurance and bonding<br><br>Submit fees to regulators | Maintain financial assurance and bonds<br><br>Submit fees to regulators | Maintain financial assurance and bonds<br><br>Submit fees to regulators | Maintain financial assurance and bonds<br><br>Submit fees to regulators | |
| Actions: Regulatory | Initial engagement with regulator stakeholders | Permits for exploration | Permit application development (multiple)<br><br>Permit revision and resubmittal<br><br>Develop project plans for site (delineation, testing, drilling, among others)<br><br>Develop reports (multiple) for site | Secure permits to install pipeline and topside structures<br><br>Secure permit to drill injection and monitoring wells<br><br>Update project plans for site | Periodic reporting to BOEM / BSEE (multi-frequency) | Periodic reporting to regulators (multi-frequency)<br><br>Preparation and submission of decommission application(s) for site and pipelines<br><br>Final reporting to regulators | |
| Cash Flow Trajectory | Negative | | | | Positive | Negative | |

***Exhibit 1-2. $CO_2$_S_COM_Offshore $CO_2$ saline storage project concept diagram***




In general, the model is designed to support $CO_2$ storage project site-screening and is capable of exploring the cost implications for potential offshore $CO_2$ storage project(s) by enabling the user to change several project operational and financial attribute configurations. As a result, CO2_S_COM_Offshore provides users the capability to conduct different types of technoeconomic analyses [1]. These may include supply curve analysis (from localized region to the GOA basin-level), customizable project-specific cost evaluation(s) that utilize user-defined input reflective of planned $CO_2$ storage site(s), onshore $CO_2$ source to offshore sink cost analysis, and scenario analysis to evaluate policy, financial, or technological factors.

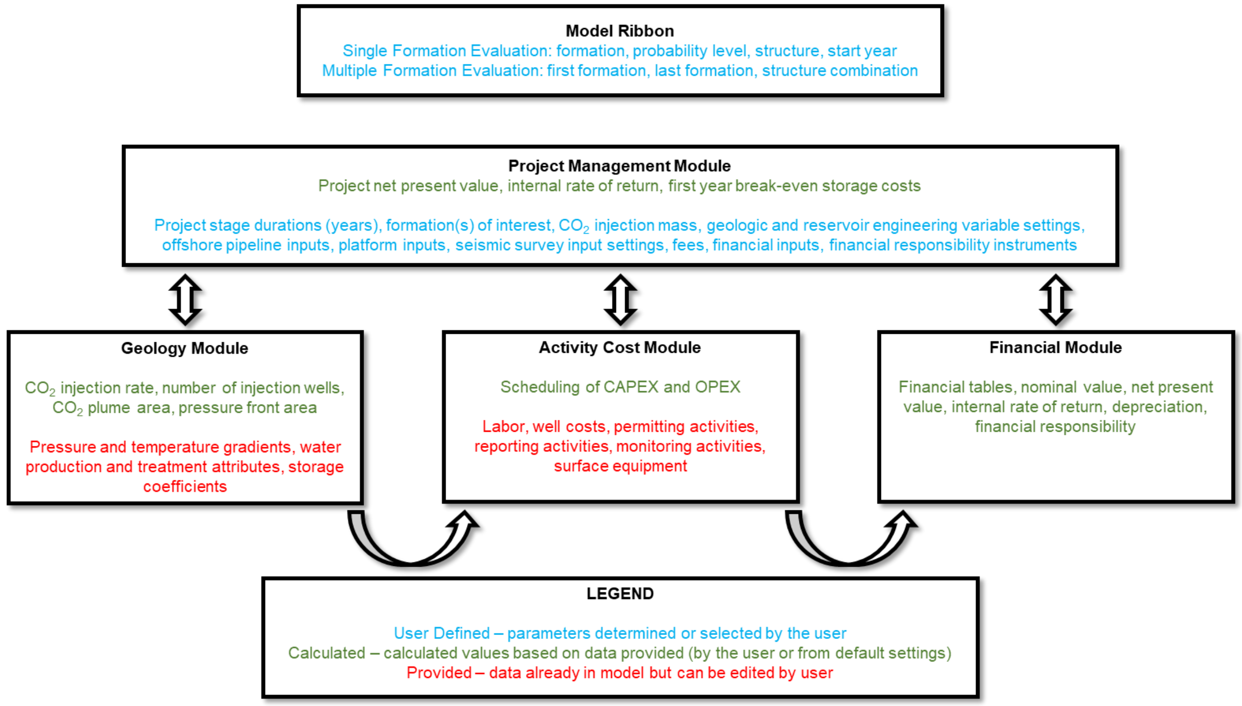
Offshore saline reservoirs provide a significant and accessible resource for geologic carbon storage [6, 7]. Furthermore, offshore $CO_2$ geologic storage is a promising technology due to several key advantages: (1) provides additional $CO_2$ storage potential that can supplement existing onshore storage resources in the United States; (2) storage operations would be located away from heavily populated, onshore areas; (3) OCS submerged lands are owned solely by the U.S. Department of the Interior [DOI] (i.e., single-owner); (4) provides storage options nearby populated areas along U.S. coastlines; and (5) reduces potential risk to underground sources of drinking water. Despite these benefits, conducting geologic $CO_2$ storage in the offshore environment will pose distinct challenges pertaining to site selection, operations, infrastructure use, and monitoring compared to operating onshore. As the prospect for deploying geologic $CO_2$ storage in the offshore GOA continues to mature, robust analysis and decision-support capabilities are needed that will assist stakeholders evaluate the technical, logistical, and cost-related implications associated with future project planning and design efforts. CO2_S_COM_Offshore accounts for these unique distinctions by incorporating multiple facets of offshore $CO_2$ storage project design, permitting, operations, monitoring, financing, closure, and decommissioning [8, 9, 10, 11, 12, 13, 14]. Consequently, CO2_S_COM_Offshore offers a significant and inimitable analytical resource for evaluating geologic storage in offshore settings.

Version 1 of CO2_S_COM_Offshore prioritizes modeling around the development of stand-alone $CO_2$ storage projects specifically decoupled from other ancillary offshore operations (e.g., offshore natural gas production and separation, tertiary enhanced oil recovery, or mineral extraction). Additionally, CO2_S_COM_Offshore considers the required physical infrastructure designed for operating in shallow marine environments as well as the distinctive geologic conditions of the GOA OCS that influence both storage viability and operational logistics. The model is positioned ahead of the anticipated release of new draft regulations from the U.S. Department of the Interior concerning geological $CO_2$ storage on the offshore continental shelf [15, 16]. However, Version 1 of CO2_S_COM_Offshore is built on a framework that considers the due diligence inherent in the regulations laid out within Title 30 of the Code of Federal Regulations (CFR), namely Chapter II managed by the Bureau of Safety and Environmental Enforcement (BSEE), and Part V under the Bureau of Ocean Energy Management (BOEM) [17]. By integrating operational, financial, monitoring, and reporting activities aligned to these regulatory considerations, the model provides an operational blueprint for stakeholders tasked with implementing geologic $CO_2$ storage in offshore contexts. By emphasizing these priorities, Version 1 of CO2_S_COM_Offshore aims to provide stakeholders with a comprehensive understanding of the cost implications specific to the unique challenges and opportunities offered in the GOA's shallow shelf. Future versions on the model may be consider additional features or functionalities beyond what Version 1 entails in order to enhance its analytical capabilities and enable improved assessment of offshore $CO_2$ storage resources in U.S. state and federal waters.

## 1.1 MODULES

The CO2_S_COM_Offshore model consists of four modules as shown in Exhibit 1-3. The functions of each of the four modules are distributed across one or more tabs within the Excel workbook, allowing users to run analyses on default parameters or modify them as they see fit. It is important to note that there are extensive linkages between tabs within and across modules. As a result, should the user adjust input data, the changes will propagate throughout other tabs within the model.

***Exhibit 1-3. FECM/NETL Offshore $CO_2$ Saline Storage cost model structure***




Outside of the modules themselves is a 'READ ME FIRST' tab, which provides useful information with respect to color and font conventions along with fundamental model assumptions that a user is not able to edit. A summary of each module and tabs within is presented below:

- **Project Management Module:** Module specific for project inputs that define the overall scope of the storage project and modeled outputs. The user can conduct multiple storage cost analyses from this module, modifying key inputs without entering the other modules. This module consist of 10 worksheets. The first worksheet, 'Key_Inputs,' contains the vast majority of user inputs that are most important. For ease of access, key project decisions in this module, such as start year and formation, are also located in the 'CO2_S_COM_Offshore' ribbon located at the top of the Excel screen. The second worksheet, 'Offshore_Eq', contains inputs related to offshore equipment, including the offshore pipeline, primary offshore structure, offshore satellite structures, offshore pressure boosting pump. The third worksheet, 'Fin_Res_Inputs,' contains user inputs for the financial responsibility instrument, including the selection of the instrument, and parameters for each instrument. On the next worksheet, 'Summ_Output,' the user can find a summary of many important outputs of the model. This worksheet is used as a report out of key results and only for informational purposes for the user. The fifth worksheet, 'Cost Breakdown 1,' uses data throughout the model to sum costs across different categories. These sums are used in some of the output the model produces. The last five worksheets, labeled 'Res_[…]1' and described further in Section 3.1 below, are updated after running the 'Evaluate Multiple Formations' macro as described later in Section 2.3.

- **Financial Module:** Tabs in this module generate project financial statements and provides the project management worksheet with the ability to solve for key outputs, the $CO_2$ storage first-year breakeven price (FYBE), and net present value (NPV) of the project (see Section 3.2). Calculation of financial responsibility cost and cost of instruments to satisfy financial responsibility requirements are done within this module. The Financial Module contains three worksheets. 'FinMod_Main' is the core worksheet of the Financial Module, and it includes the financial calculations for the project. 'FinMod FR Details' is the worksheet with all the specifics for the financial responsibility instruments. 'FR_Lookups' contains the look-up tables for the 'FinMod FR Details' worksheet.
- **Geology Module:** Includes tabs that provide geo-engineering equations, storage coefficients, and geologic database; calculates $CO_2$ injectivity, number of $CO_2$ injection wells, and plume area for $CO_2$. This module also calculates water withdrawal from $CO_2$ storage reservoir as well as subsequent treatment and disposal. The Geology Module consists of six worksheets. 'Geol Sal' contains the calculations related to the storage reservoirs. 'Geol DB Sal' is the worksheet with the geologic database. The sources for the database are in the worksheet 'Geol DB Sources.' The worksheet 'Water' contains calculations for the water methodology. 'Plume&Well Schedule' uses timelines to track the plume growth and well counts throughout the project. Finally, 'Geo-Activity Interaction' is used to readily identify the information passed from the Geology Module to the Activity Cost Module for cost calculations.
- **Activity Cost Module:** Tabs in this module are used to inform a collection of costs, when they occur, and how often they occur for all technology and labor used in a project. This module also works to generate annual costs per technology/labor applied over life of storage project. The Activity Cost Module contains four worksheets. 'Activity_Inputs' contains tables of inputs that define parameters of costs related the project. 'Surf Eq Cost' is a worksheet for surface equipment/facility cost calculations. 'Back-End_Cost Items' is the worksheet that gathers information about all costs and displays the costs on a project timeline. 'Drilling Costs' is used specifically for calculating well drilling (injection, monitoring, water production/injection) costs.

Section 3 below provides a more detailed summary of each module as a supplement to the overview provided here.

## 1.2 KEY OUTPUTS

The cost of designing, permitting, constructing, operating and closing a $CO_2$ saline storage project of any kind is of vital importance to the developers of such a project. The objective of the CO2_S_COM_Offshore is to ultimately offer quantitative cost-related insights to support project developers by calculating the revenues, costs, and financial performance of a candidate $CO_2$ saline storage project from the perspective of the storage operator based on a multitude of user-defined activity cost and financially-related inputs. Model output includes detailed summaries of total capital, operating, and financing costs. It also summarizes project revenues and earnings, taxes, and costs associated with financial responsibility instruments implemented.

Many of these cost calculations can be found within model's 'Summ_Output' tab (for the current formation being evaluated) and all of the result tabs including 'Res_Bas1', 'Res_CatP1,' 'Res_CatV1,' 'Res_SUStg1,' and 'Res_FRWat1' (when multiple formations are evaluated).

Additionally, the output sheet includes estimates of critical cost metrics like NPV and the FYBE (in $/tonne). NPV is the value of all future cash flows (positive and negative) over the entire life of an investment, discounted to the present using the minimum desired internal rate of return on equity. The FYBE is the price to store one metric ton of $CO_2$ that just barely makes the storage project financially viable ("break-even"), assuming sufficient revenues are generated to cover all project costs with the aspirational rate of return achieved (set via the "Cost of Equity" input in the 'Key_Inputs' tab). The FYBE is estimated via iteration on the $/metric ton storage price to achieve an NPV of $0 or as close to $0 as possible within the model. These metrics are reported under Section 1.0 of the Key_Inputs' tab.

Key technical attribute outputs related to the $CO_2$ injection volumes are also provided by the model to give context to the calculated storage costs. These include the estimated plume size at the end of injection that is determined using the DOE's volumetric equation [18] and uncertainty multiplier, as well the associated pressure front / area of review (AOR) calculated using a user defined pressure plume multiplier. The total potential prospective storage resource [19] for the selected reservoir is also provided based on volumetric calculations. These cost breakdowns are readily available in Section 11.0 of the 'Key_Inputs' tab and are summarized throughout the "Geology" columns in the 'Res_Bas1' tab. Costs associated with all phases of the project (i.e., capital expenditures [CAPEX] and operating expenses [OPEX]), as well as projected revenues and taxes, are output to discrete categories for a thorough understanding of modeled project financials. These cost breakdowns are readily available in the 'Summ_Output' tab.

# 2 Model Orientation and Use

The subsections below summarize important components and conventions within the model in order to help users best interact with and use CO2_S_COM_Offshore.

## 2.1 Tab Layout and Color Convention

CO2_S_COM_Offshore is organized across 24 worksheet tabs. These tabs are located near the bottom of the user's Excel window. Clicking on any tab will enable the user to view and interact with the contents within that given tab. The first tab in the model is a READ_ME_FIRST tab, which summarizes the contents and structure of CO2_S_COM_Offshore and provides contact information should users require any additional information about the model. The other tabs provide some form of technical functionality for CO2_S_COM_Offshore, which may include allowing the user to adjust inputs, performing calculations, or showing output results. The tabs organized on the bottom of the user's Excel window are colored via a convention aligning the specific CO2_S_COM_Offshore module described earlier in Section **Error! Reference source not found.** (Exhibit 2-1).

***Exhibit 2-1. Tab coloration conventions specific to the modules within CO2_S_COM_Offshore***

| Worksheet Color Conventions |
| --- |
| Project Management Module |
| Geology Module |
| Financial Module |
| Activity Cost Module |

The user can interact with inputs as well as observe calculated output under many of cells within the tabs. Section 2.2 below outlines color conventions which are intended to guide user interaction with workbook cells within CO2_S_COM_Offshore.

## 2.2 Workbook Cell Conventions

Workbook color and font conventions have been put in place to provide immediate visual indicators of the purpose of certain cells. A comprehensive list of these color and font conventions is available in Exhibit 2-2, as well as the READ_ME_FIRST worksheet of the model. The most important convention, the light orange input cell color, is listed first. The user can change values in any light orange cell to reflect the design of the project. In order to change a value, macros must first be enabled after opening the model.

***Exhibit 2-2. Color (top) and font (bottom) conventions for CO2_S_COM_Offshore***

| Cell Color Conventions |
| --- |
| Inputs specified in this cell (Type in this cell) |
| Not a data input cell |
| Title or heading rows |
| Overview or Instruction sections |
| Cells using values from other tabs |
| Schedules referenced in the 'Back-End_Cost Items' sheet |
| Outputs used in other sheets or intermediate calculations |
| Geological parameters from geology database |
| Inactive cell |

**Font Conventions**

| | |
|---|---|
| Used only for 'Back-End_Cost Items' binary switch: | hard-value, reference switch |
| Base font | Calibri 10 |
| Hyperlinks to places within the document | Hyperlink Text |

It is important to note that many cells contain important calculations or links to other cells within CO2_S_COM_Offshore, particularly the light blue and green colored cells. The user must take caution to not overwrite or delete the logic in place or else the model may fail to work as expected.

## 2.3 Generating Results and Output

To begin using the model, the user should first navigate to the 'Key_Input' tab under the Project Management Module. This tab provides the main interface to the CO2_S_COM_Offshore by providing a number of key inputs the user can modify to their liking. The sheet also summarizes key results. Key inputs of interest include the selected formation to evaluate (cell C17), the duration of each project stage (D43 – D47), the project start year (A47), the average $CO_2$ injection rate intended (F51), offshore structural settings (Section 8.0 on the 'Key_Inputs' tab), and financial parameter settings (Section 12.0 on the 'Key_Inputs' tab). The user should review and update all inputs in this tab, as well as in other tabs of interest, to set CO2_S_COM_Offshore settings to their liking.

Once user inputs are entered in CO2_S_COM_Offshore, the model can be used for single or multiple storage formation evaluating, in which numerous project related outputs will be generated for context with cost output. These include geologic formation data, $CO_2$ injection mass and associated size metrics pertaining to injection operations, project financials, and well counts by type. In the 'Key_Inputs' tab, the user has the option to manually adjust the "First Year Price of $CO_2$" (under Base year in cell C10), which is essentially the $/tonne of $CO_2$ the operator would charge a third-party entity to store captured $CO_2$ in dollars commensurate with the 1st year of the project. By doing so, NPV and IRR in cells D13 and D14 will adjust in real time. Cash flows will also change throughout the model as the price in cell C10 is varied by the user.

CO2_S_COM_Offshore includes two Excel® macros for obtaining result metrics related to FYBE price of $CO_2$ storage. The macro "NPV_Zero" determines the FYBE price of $CO_2$ that makes the net present value of the project owner equal zero and the IRR for the project equivalent to the user-specified cost of equity. When the "Breakeven Price Analysis: Single Formation" button is pushed on the 'Key_Inputs' tab (see Exhibit 2-3), the "NPV_Zero" macro will activate and results will reflect the single formation selected for evaluation on this tab. Additionally, the "First Year Price of $CO_2$" data by year will adjust in cells C10, D10, and E10. At this point, the user is able to review result summary data under the tabs in each module to for the single formation evaluated.

The second macro called "Eval_Form" loops through all the possible injection formations of interest in the 'Geol DB Sal' tab specified by the user and calculates the FYBE price of $CO_2$ for each, along with several other supporting output data. The user specifies formations of interest by picking a range withing 'Geol DB Sal' using cells C25 (first formation of interest) and C26 (last formation of interest) in the 'Key_Inputs' tab (Exhibit 2-3). The ribbon can also be used to set this formation range. The results for each formation are summarized in the five sheets: 'Res_Bas1,' 'Res_CatP1,' 'Res_CatV1,' 'Res_SUStg1', and 'Res_FRWat1.'

***Exhibit 2-3. Section 1.0, 2.0, and 3.0 of 'Key_Inputs' showing Single and Multiple Formation Evaluation Inputs***

| Row | | | | | | |
|---|---|---|---|---|---|---|
| 7 | **1.0 Model Run for One Storage Formation and One Structure** | | | | | |
| 8 | Breakeven Price Analysis: Single Formation | **Item** | **Base year** | **Proj start** | **Inj start** | **Unit** |
| 9 | | Year | 2008 | 2024 | 2029 | year |
| 10 | | First Year Price of CO2 | 32.19 | 77.76 | 77.76 | $/tonne |
| 11 | | | Change base year per cost data information | | | |
| 12 | | | | | | |
| 13 | | Net Present Value (NPV) of project | | 0 | 2024 | discounted $ |
| 14 | | Internal rate of return (IRR) for project | | 10.8% | | percent |
| 15 | | | | | | |
| 16 | **Select Storage Formation, Probability Level for Storage Coefficient, and Structure (Inputs to Geology Module)** | | | | | |
| 17–18 | Selected formation | | 1 | 1241_1 | PL_A1 | Chandeleur Area |
| 19 | Selected probability for storage coefficient | | P50 | Options: P10, P50, P90 | | |
| 20 | Geologic formation thickness setting | | Gross Thickness | 2 | 410 | formation thickness in feet |
| 21 | Select structure | | Reg_dip | Options: General, Anticline, Dome, Incline_10deg, Incline_5deg, Flat, Reg_dip | | |
| 22 | | | | | | |
| 23 | **2.0 Model Run for Multiple Formations and One or More Structures** | | | | | |
| 24 | Breakeven Price Analysis: Multiple Formations | Run Title: | New_Case_Run | | | |
| 25 | | First formation number: | 2 | 1241_2 | PL_A1 | Ship Shoal Area |
| 26 | | Last formation number: | 35 | 1761_6 | MLU_P1 | Ship Shoal Area |
| 27 | | Select Formation Structures | 4 | | | |
| 28 | | | Options for structures to be evaluated for each formation: | | | |
| 29 | | | Set = 0 for dome, anticline, and regional dip | | | |
| 30 | | | Set = 1 for general structure | | | |
| 31 | | | Set = 2 for dome, anticline, 5 degree incline, 10 degree incline and flat | | | |
| 32 | | | Set = 3 for dome, anticline, and flat | | | |
| 33 | | | Set = 4 for regional dip | | | |
| 34 | | | This control variable affects the percentage of the formation with each structure. | | | |
| 35 | | | See the data in Section 4.4 regarding percentages of each structure in the formation. | | | |
| 36 | | Name of workbook to store result sheets | Output_Cases_2024.xlsm | | | |
| 37 | | | | | | |
| 38 | **3.0 Operational Variables** | | | | | |
| 39 | | | | | | |
| 40 | **3.1 Project Timeline: Enter the duration of each stage of the project to define the project timeline.** | | | | | |
| 41 | | | | | | |
| 42 | Selected Project Start Year: | **Project Stage** | **Duration (Yrs)** | **Begin Year** | **End Year** | **Calendar Years:** |
| 43 | | Site Screening | 1 | 1 | 1 | 2024 - 2024 |
| 44 | | Site Selection & Site Characterization | 2 | 2 | 3 | 2025 - 2026 |
| 45 | | Permitting & Construction | 2 | 4 | 5 | 2027 - 2028 |
| 46 | | Operations | 30 | 6 | 35 | 2029 - 2058 |
| 47 | 2024 | PISC and Site Closure | 50 | 36 | 85 | 2059 - 2108 |
| 48 | | | | | | |
| 49 | **3.2 CO2 injection rate: Enter the average annual rate of CO2 injection for the project and the capacity factor** | | | | | |
| 50 | | | | | | |
| 51 | Nominal average tonnes of CO2 injected per year | | | | 2,000,000 | tonne/year |
| 52 | Capacity factor | | | | 85% | percent |
| 53 | Multiplier for annual to maximum daily rate of CO2 injection (1/capacity factor) | | | | 1.18 | multiplier |
| 54 | Maximum rate of CO2 injected on annual basis | | | | 2,352,941 | tonne/year |
| 55 | Total mass of CO2 injection over period of operations | | | | 60,000,000 | tonnes |
| 56 | Tonnes of CO2 Injected per day on average | | | | 5,479 | tonnes/day |
| 57 | | | | | | |
| 58 | **3.3 Set variable that controls the type of injection project** | | | | | |
| 59 | | | | | | |
| 60 | Control variable for type of injection project | | 0 | Set to 0 for injecting specified mass of CO2 (default) | | |
| 61 | | | | Set to 1 for injecting CO2 to fill max. possible plume area | | |

When the "Breakeven Price Analysis: Multiple Formations" button is clicked by the user (Exhibit 2-3), the model will prompt the "Eval_Form" macro into action. The multiple formation evaluation functionality also allows the user to automatically save results into an Excel® output file workbook. The name of that workbook can be specified by the user in cell C36. The file name for this separate worksheet and the file name posted on the 'Key_Inputs' worksheet in cell C36 have to be identical. This separate worksheet also has to be saved in the same folder as the model or it will not be seen by the model. Two important items worth note:

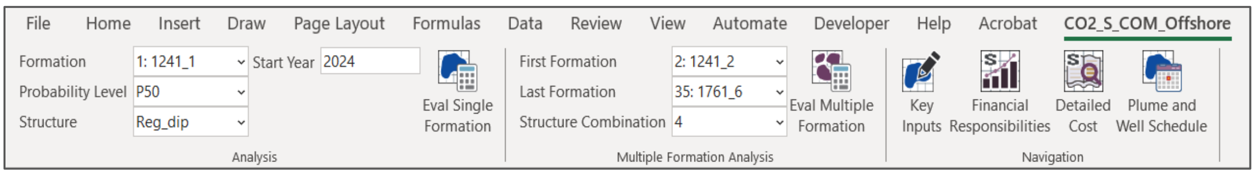
1. It is best to use a blank Excel® workbook for the purpose of saving results the first time the model is used in the multiple formation evaluation application.

2. If the user wishes to run the multiple formation evaluation several times and use the same, single workbook to save results, the model will add additional results tabs to the workbook to preserve results from initial runs (it will not overwrite existing results).

## 2.4 CO2_S_COM_Offshore Ribbon

The model includes a custom ribbon, as shown in Exhibit 2-4, which can be found by clicking the far-right tab entitled 'CO2_S_COM_Offshore.' This ribbon offers access to a variety of key project parameters, including formation selection for single and multi-formation analysis, probability level, geologic structure selection, and project start year. Additionally, the ribbon contains navigation buttons for quick access to sheets of interest such as Key_Inputs, Fin_Resp_Inputs, Back-End_Cost Items (entitled 'Detailed Cost'), and Plume&Well Schedule.

***Exhibit 2-4. CO2_S_COM_Offshore custom ribbon in Excel***




Ribbon parameters are linked to the appropriate input cell in the 'Key_Inputs' tab, allowing users to observe the effects of ribbon parameter changes throughout the model without having to refer back to the Key_Inputs sheet to make changes. Please note that changing the value in the ribbon will update the cell value in the 'Key_Inputs' tab, but changing the 'Key_Inputs' value will not update the ribbon value. This difference does not impact model functionality as the model refers only to the cells within the 'Key_Inputs' sheet.

# 3 CO2_S_COM_OFFSHORE MODULES

This section provides an in-depth description of the various modules that make up CO2_S_COM_Offshore. It is important for users to note that the many of the tabs under each module contain default settings that can be modified by user input as shown in Exhibit 1-3.

## 3.1 PROJECT MANAGEMENT MODULE

The Project Management Module consists of ten worksheets. The first worksheet, 'Key_Inputs,' contains the user inputs that are most important. The second worksheet, 'Offshore Eq', contains additional inputs for offshore equipment, including offshore primary structure, offshore satellite structure, offshore pressure boosting pump, and offshore power cost. This worksheet specifies the capital and annual operating and maintenance costs for offshore equipment. Default model settings assume that all infrastructure (i.e., pipelines and platforms) would be new. If the user wishes to assume an existing platform would be repurposed for use in the $CO_2$ storage project, Section 2.0 of this worksheet provides options for modification cost assumptions for refurbishment based on user-specific settings. The third worksheet, 'Fin_Res_Inputs,' contains user inputs for the financial responsibility instrument, including the selection of the instrument and parameters for each instrument. On the next worksheet, 'Summ_Output,' the user can find a summary of many important outputs of the model. This worksheet is used only for informational purposes for the user. The fourth worksheet, 'Cost Breakdown 1,' uses data throughout the model to sum costs across different categories. These sums are used in some of the output that the model produces. The last five worksheets, labeled 'Res_[…]1' and described further in this section, are updated after running the 'Multiple Formation Evaluation' macro as described in Section 2.3.

Key management decisions are entered in the 'Key_Inputs' tab of this module including annual volume of $CO_2$ injected, years of injection, time span for other stages of a storage project, injection well type, offshore equipment and pipeline configuration, 3-D seismic parameters, and financial parameters defining the business scenario to be modeled.  If a breakeven price analysis for a single formation is being modeled (cell A8 or the CO2_S_COM_Offshore ribbon), that formation is displayed in this tab.

A considerable amount of output information is posted in this module, on the worksheets 'Key_Inputs,' 'Fin_Resp_Inputs,' and 'Summ_Output,' which facilitates a ready comparison of different model parameters applied to a single formation. The user can stay in this module while performing numerous model-runs on a single formation.

Model output is presented in ten worksheets, five of which are hidden. Hidden worksheets are 'Res_Bas,' 'Res_SUStg,' 'Res_FRWat,' 'Res_CatV,' and 'Res_CatP'. Each contain formulas to calculate or reference the values for model output. In order for the formulas on these hidden worksheets to not change with each change in formula and structure, their output values are pasted into the unhidden worksheets, 'Res_Bas1,' 'Res_SUStg1,' 'Res_FRWat1,' 'Res_CatV1,' and 'Res_CatP1.' The user makes no changes to any of these worksheets. Any parameter changed in the 'Key_Inputs' or 'Fin_Resp_Inputs' tabs of the Project Management Module, or in the ribbon, is not reflected in the unhidden output worksheets until the Multiple Formation Evaluation macro is run, which updates all of the tables. This macro also saves the data output in a separate Excel® workbook. The name of that workbook can be specified by the user in cell C36. The file name for this separate worksheet and the file name posted on the 'Key_Inputs' worksheet in cell C36 have to be identical. This separate worksheet also has to be saved in the same folder as the model or it will not be seen by the model.

## 3.2 Financial Module

This module provides for a financial evaluation of a business scenario for a specific storage project from an NPV perspective using the financial parameters posted in the 'Key Inputs' worksheet of the Project Management Module and the schedule of investments and expenses made in the 'Back-End Cost Items' worksheet of the Activity Cost Module. The key outputs, discussed in Section 1.2, use a break-even analysis calculated in the 'FinMod Main' worksheet of the Financial Module to provide results.

## 3.3 Activity Cost Module

This module provides a cost database for all activity costs related to an offshore $CO_2$ storage project. It gives the user the opportunity to enter individualized cost data and change the timing for an activity (i.e., the year(s) over which the activity will occur or in which storage project stage(s) it will occur). The Activity Cost Module is comprised of four worksheets: 'Activity_Inputs,' 'Surf Eq Cost,' 'Back-End_Cost Items,' and 'Drilling Costs. Costs data provided in these worksheets were aggregated utilizing S&P Global's QUE$TOR™ cost estimation software and open-source scientific literature.

### 3.3.1 Financial Module Main (FinMod_Main) Worksheet

This worksheet pulls information from the Project Management, Geology, and Activity Cost modules to calculate the values posted in several tables. These tables organize cost data over the years the project occurs. For instance, this tab compiles cost data including escalation and discounting factors over time, revenues generated, operating and capital expenses, depreciation schedule for capital costs, financial responsibility-related costs, debts, taxes, and cash flow to project owners. Each table may summarize cost in real, escalated, and present value dollars.

### 3.3.2 FinMod FR (Financial Responsibility) Details Worksheet

This worksheet lays out the details behind the calculation of the cost of the financial instruments selected by the modeler. This model assumes that offshore storage projects will use similar financial instruments for risk mitigation or to meet future regulatory requirements.

### 3.3.3 FR Lookups Worksheet

Calculation of costs associated with the available financial instruments depends on the values selected from the drop-down options by the modeler in the 'Fin_Resp_Inputs' worksheet in the Project Management Module. These selected values are posted to their respective cells in the

'FinMod FR Details' worksheet. The lookup tables of these values are posted in the 'FR Lookups Worksheet.'

## 3.4 ACTIVITY_INPUTS WORKSHEET

The first part of the module, the 'Activity_Inputs' worksheet, contains four tables of cost and duration data that can be manipulated to the user's liking. They are grouped by cost type and named: Parameters Consistent Across All Activities (e.g., labor rates by laborer specialty for the duration of the project), Activity-Specific Parameters (e.g., site screening and characterization data acquisition, reservoir modeling, regulatory compliance and permitting), Parameters Used in Activities Across Multiple Stages (e.g., regulatory reporting, monitoring techniques, and data analysis), and Well-Drilling Costs (well drilling, geophysical logging, downhole equipment, and mechanical integrity testing), split by Primary Offshore Structure and Offshore Satellite Structure. All information in this worksheet, in conjunction with data entered in the 'Key_Inputs' worksheet, calculates and outputs cost data to the 'Back-End_Cost Items' worksheet.

### 3.4.1 Surf Eq Cost Worksheet

The 'Surf Eq Cost' worksheet specifies capital costs and annual operating and maintenance (O&M) costs for onshore surface equipment (e.g., capital and O&M costs for booster pumps, office building, access road to building), the offshore pipeline (e.g., capital and O&M costs for pipeline, right-of-way leasing, pipeline decommissioning), and other structures (distribution pipeline header capital and O&M costs, control system capital and O&M costs). These costs are also used in the 'Back-End Cost Items' Sheet.

### 3.4.2 Drilling Costs Worksheet

'Drilling Costs' is the third worksheet of the Activity Cost Module. This worksheet is used to calculate drilling and completing costs for new well, as well as costs for converting stratigraphic test wells for use as $CO_2$ injectors. Cost algorithms are based on analysis of cost data for offshore wells in the GOA generated by the QUE$TOR™ cost estimation tool. There are no user inputs or decisions on this sheet. However, there is an option on the 'Key_Inputs' tab for the user to select mobile or fixed drilling rig for wells drilled on a new jacket primary structure. Wells drilled on a caisson primary structure, retrofitted jacket primary structure, and satellite structures are costed using a mobile drill rig.

### 3.4.3 Back-End_Cost Items Worksheet

In the 'Back-End_Cost Items' worksheet, each activity cost is listed by the stage in which it may be used, thus creating multiple listings for each activity. These costs are listed this way to provide an auditable one-line record of each value in the cost calculation. Costs occurring in each year are summed, and this information is utilized by the Financial Module. A depreciation schedule is calculated in the Financial Module based on information from this worksheet. Presently, certain costs are labeled either Capital or Expense; however, the user can change these labels. Capital costs are added to a depreciation schedule where a simple straight-line depreciation calculation is applied.

All cells on this worksheet reference inputs elsewhere, and no values should be typed directly onto this sheet. It should also be noted that most of the costs presented are real costs, and for the most part, escalation and discounting of these costs is done on aggregated cash flows (such as capital costs or expenses) to keep the size of the spreadsheet more manageable.

## 3.5 GEOLOGY MODULE

This module includes the geologic database, storage coefficients, and geo-engineering equations. It calculates $CO_2$ injectivity, number of $CO_2$ injection wells, $CO_2$ plume area, water withdrawal (production) from the $CO_2$ storage reservoir, subsequent treatment and disposal. The Geologic Module has a flexible structure that allows the use of either model-provided data or proprietary data. The user should use proprietary data if the model does not include the formation required by the user for evaluation or if the user has better information than the model does on the specifics of the formation under review. The geologic information contained in this model is generalized at the formation level. This module consists of six worksheets: 'Geol Sal,' 'Geol DB Sal,' 'Geol DB Sources,' 'Water,' 'Plume&Well Schedule,' and 'Geo-Activity Interaction.' Below is a description of the function of each of the worksheets in the Geologic Module.

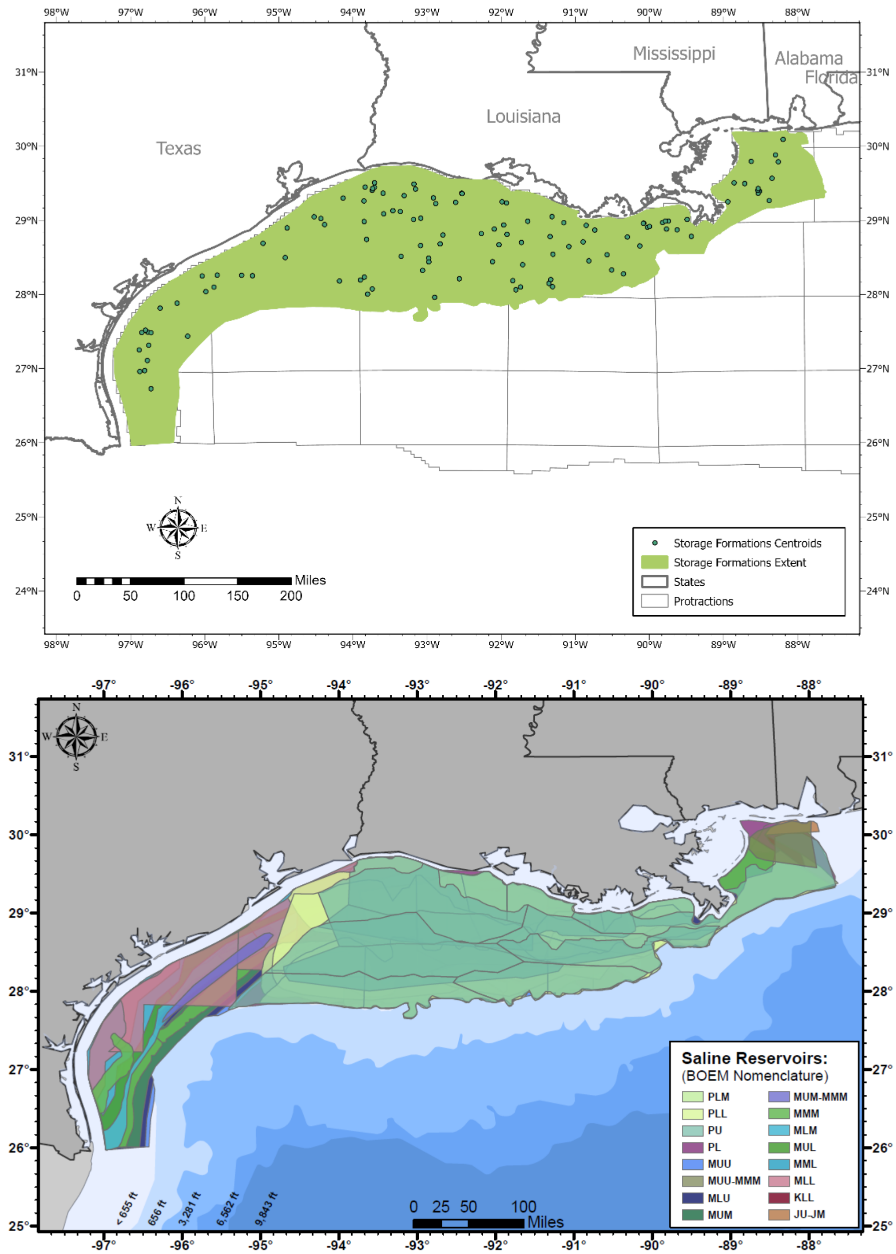
### 3.5.1 Geol Sal Worksheet

The 'Geol Sal' worksheet contains geology-related inputs and details on the Geologic Module methodology. It specifies geologic properties of the injection formation, determines a $CO_2$ storage coefficient for a specified fraction of the injection formation, calculates the area of the $CO_2$ plume for this storage coefficient and calculates the total mass of $CO_2$ that can be stored in the fraction of the injection formation where this storage coefficient is applicable. It also calculates the number of injection wells needed to inject the maximum daily mass of $CO_2$ to be injected.

### 3.5.2 Geol DB Sal

Specific attributes for 117 geologic formations are located on the 'Geol DB Sal' worksheet, the model's geologic database. Identifiers, location related information (e.g., closest state, latitudes and longitudes, protraction), area, depth, thickness, pressure, temperature, porosity and permeability, and other details are provided. Two shapefiles visually representing the boundaries of these formations, with associated attributes, are also available to aid in the user's modeling. One provides the polygons of individual formations with the other being the formation's centroids (Exhibit 1-1).

***Exhibit 3-1. Storage formation centroids (top) with areal extent of formations (bottom) in database***




The geologic database information was derived using a variety of sources including the Atlas of Gulf of Mexico Gas and Oil Sands Data (BOEM sands database) for formation level properties, BOEM Borehole Data for well information, well logs for validating the thickness of a play, USGS Gulf Coast data for insight on formation thicknesses and structure, and GOA play boundary references from the BOEM for definition of play boundaries [20, 21, 22, 23]. Database formations were first defined using chronozones, which were then divided by depositional style. Finally, these plays were subdivided based on proximity and similar geologic attributes using cluster analysis. Thickness reported in the BOEM sands database are representative of the hydrocarbon producing interval instead of the entire sand interval which could be suitable for carbon storage. Given this distinction, well log analysis in conjunction with the USGS Gulf Coast data were used to scale the producing interval to a “net” (properties suitable for carbon storage) and “gross” (the entirety of the sand) interval.

### 3.5.3 Geol DB Sources

This worksheet provides sources and accompanying reference information used for the data in the ‘Geol DB Sal’ worksheet. It currently includes the BOEM Sands Data and BOEM Borehole Data discussed in section 3.5.2.

### 3.5.4 Water

The worksheet labeled ‘Water’ contains inputs and calculations related to the model method for including water production, treatment, and disposal. The calculations on this worksheet pull data from other parts of the geology module, use data that has been entered by the user, and use a data set from an outside source. The results of the calculations are then carried through the model via the activity module and cost line items, in the same manner as other costs. This model assumes that water production will only occur in the pressure front area, which means that modeling water production requires activation of a satellite structure in the ‘Key_Inputs’ sheet. Users wishing to incorporate water production must also enter a maximum number of wells to dedicate to water production. All other water-related items are controlled through the ‘Water' worksheet.

### 3.5.5 Plume&Well Schedule

This worksheet lists time-dependent geologic factors, such as well counts and plume growth, in a timeline. In this worksheet, the user can find all year-dependent factors, including plume area, area of review (AoR), and well counts. The inputs and assumptions relevant to these values are also posted here for reference by this worksheet. This worksheet shows how many wells are added in a given year as well as the plume area in a given year that would need to be covered if seismic data acquisition is required by the project manager.

The information going into this worksheet is coming from user inputs in the ‘Key_Inputs,’ ‘Activity_Inputs,’ and ‘Geo-Activity Interaction’ worksheets. After the plume and well calculations are done, the information is sent to several other worksheets. Many times, it is sent to the ‘Back-End Cost Items’ worksheet, where it is used to determine costs that are paid on the basis of well counts or plume size. Additionally, it is sent to the ‘Key_Inputs’ and ‘Summ_Output’ worksheets to display the results for the user.

### 3.5.6 Geo-Activity Interaction

The Geo-Activity Interaction worksheet provides information to the user on the geology values that are transferred from the Geology Module to the Activity Cost Module, specifically the ‘Activity_Inputs’ worksheet. This worksheet also has three user inputs: rathole depth, depth below the mudline to begin directional drilling, and additional depth for stratigraphic wells.

# 4 Supporting Documentation

The intent of this QuickStart guide was to provide an abbreviated set of instructions and understanding of key outputs and inputs relevant to operating the Offshore $CO_2$ Saline Storage Cost Model. Its aim was to quickly allow the user to get up and running with the model, to begin assessing the financial viability of potential offshore storage operations. To this end, many details of the model's inner workings, assumptions, and design were omitted. However, a forthcoming user manual will provide a comprehensive overview of all facets of the model and will be available at NETL's Energy Analysis when published.

For additional information on the model's capabilities, these resources are available and can be reviewed:

- Mark-Moser, M., Grant, T., Morgan, D., Marquis, M., Bello, K., Sheriff, A., Vikara, D., Liu, G., Cunha, L. (2024). Modeling Cost of Offshore Carbon Storage in Saline Reservoirs, AAPG-SEG-SPE CCUS 2024 Conference, Houston, Texas.
- Mark-Moser, M., Grant, T., Morgan, D., Marquis, M., Bello, K., Sheriff, A., Vikara, D., Vactor, T., Shih, C., Liu, G., Cunha, L. (2024). CO2_S_COM_Offshore: A Technoeconomic Analysis Tool for Offshore Saline Carbon Storage. FECM NETL Carbon Management Program Review Meeting 2024. Pittsburgh, Pennsylvania.
- Mark-Moser, M., Vikara, D., Shih, C., Liu, G., Morgan, D., Grant, T., Bello, K., Sheriff, A., Cunha, L. (2024). Carbon storage cost modeling for the offshore Gulf of Mexico. USAEE/IAEE 41st North American Conference, Baton Rouge, Louisiana.

NETL has conducted research for offshore energy and carbon storage over the last two decades. Key relevant research on offshore energy and carbon storage includes the following:

- Rose, K. K., Bauer, J. R., & Mark-Moser, M. (2020). A systematic, science-driven approach for predicting subsurface properties. *Interpretation*, *8*(1), T167-T181.
- Romeo, L., Thomas, R., Mark-Moser, M., Bean, A., Bauer, J., & Rose, K. (2022). Data-driven offshore $CO_2$ saline storage assessment methodology. International Journal of Greenhouse Gas Control, 119. https://doi.org/10.1016/j.ijggc.2022.103736
- Wendt, A., Sheriff, A., Shih, C., Vikara, D., & Grant, T. (2022). A multi-criteria CCUS screening evaluation of the Gulf of Mexico, USA. International Journal of Greenhouse Gas Control, 118(May 2022). https://doi.org/10.1016/j.ijggc.2022.103688
- Mark-Moser, M., Romeo, L., Duran, R., Bauer, J. R., & Rose, K. (2024, April). Advanced Offshore Hazard Forecasting to Enable Resilient Offshore Operations. In *Offshore Technology Conference* (p. D021S017R008). OTC.

If technical assistance is required with the model, please reach out to the NETL point of contact with any inquiries - contact information is available on the author page.

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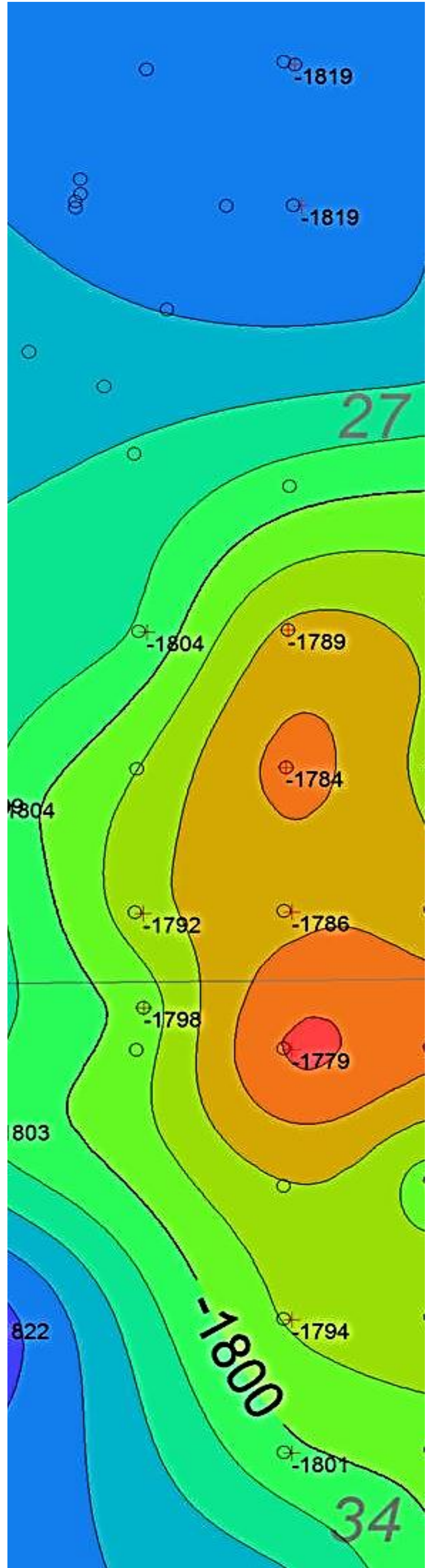


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