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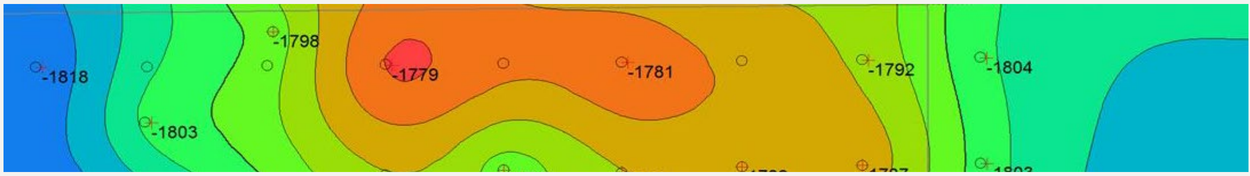

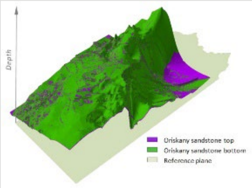


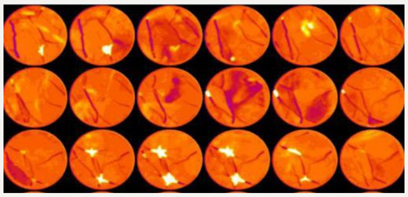


FECM/NETL CO_2 Saline Storage Cost Model (2024): User's Manual

December 24, 2024

DOE/NETL-2025/5316

U.S. Department of ENERGY

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LIST OF EXHIBITS

LIST OF EQUATIONS

ACRONYMS AND ABBREVIATIONS

2-D	Two dimensional
3-D	Three dimensional
AoR	Area of review
API	American Petroleum Institute
ARI	Advanced Resources International, Inc.
bbl	Barrel(s)
CAPM	Capital asset pricing model
CCSTP	Carbon Capture and Sequestration Technologies Program
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
cp	Centipoise
d	Day(s)
DOE	Department of Energy
EBIT	Earnings before interest and taxes
EPA	Environmental Protection Agency
ER	Enhanced oil and gas recovery
ERR	Emergency and remedial response
FECM	Fossil Energy and Carbon Management
FR	Financial responsibility
ft	Foot, feet
ID	Identification
IEA GHG	International Energy Agency Greenhouse Gas R&D Programme
in	Inch(es)
IOU	Investor-owned utility
IRR	Internal rate of return
JAS	Joint Association Survey
L	Liter(s)
LIDAR	Light detection and ranging
LoC	Letter of credit
m	Meter(s)
MBM	Modular borehole monitoring
mD	Millidarcy, millidarcies
mg	Milligram(s)
mi	Mile(s)
mi^2	Square mile(s)
MIT	Mechanical integrity test
Mtonne	Million tonnes
MVA	Monitoring, verification, and accounting
N/A, NA	Not applicable
NETL	National Energy Technology Laboratory
NPV	Net present value
O&M	Operation and maintenance
PISC	Post-injection site care
PNC	Pulsed neutron cased-hole
psia	Pound(s) per square inch absolute
PV	Present value
QGESS	Quality Guidelines for Energy System Studies
R&D	Research and development
T&S	Transport and storage
TDS	Total dissolved solids
tonne	Metric ton(s) (1,000 kilograms)
U.S.	United States
UIC	Underground Injection Control
USDW	Underground source(s) of drinking water
VBA	Visual Basic for Applications
VSP	Vertical seismic profile
WACC	Weighted average cost of capital
yr	Year(s)

1 MODEL INTRODUCTION AND ORIENTATION

The U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM), in collaboration with the National Energy Technology Laboratory (NETL), has developed the FECM/NETL CO_2 Saline Storage Cost Model (CO2_S_COM) (NETL, 2024a). This Excel-based tool provides a comprehensive framework for estimating the costs and breakeven prices associated with storing carbon dioxide (CO_2) in deep saline formations. Designed from the perspective of a CO_2 storage site owner, the CO2_S_COM incorporates four integrated modules—project management, financial analysis, activity cost estimation, and geological evaluation—to deliver fast, robust, and actionable insights for evaluating project finances. It is important to note that this model is not reservoir modeling software; instead, it focuses on the economic aspects of CO_2 storage projects.

The design of the CO2_S_COM incorporates the labor, equipment, technology, and financial instruments needed to meet the requirements of the U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) Class VI regulations (EPA, 2017a) and the monitoring and reporting requirements under Subpart RR of the Greenhouse Gas Reporting Rule (EPA, 2017b). The CO2_S_COM provides a flexible way to allow users to tailor the model to fit the requirements of each individual project by adjusting parameters in each stage (e.g., financial parameters or project lifetime). The storage project costs estimated by the model occur in one or more of the five stages of a storage project (see Exhibit 1-1): 1) site screening, 2) site selection and site characterization, 3) permitting and construction, 4) operations, and 5) post-injection site care (PISC) and site closure. Long-term stewardship is outside the scope of Class VI regulations and is not included in the model; however, a provision for collection of money for a long-term stewardship trust fund is provided. This provision should not be confused with the trust fund option for financial responsibility (FR).

The main objective of this model is to estimate the revenues, costs, and financial performance for a saline storage project. A key assumption in the CO2_S_COM is that the operator of the project (assumed to be the owner) is a profit-seeking entity that charges a source of CO_2 for storing the CO_2. More specifically, the operator sets a price for storing each metric ton (tonne) of CO_2. Given a price, the CO2_S_COM calculates revenues for storing CO_2 and the revenues along with the costs are incorporated into a financial model. Key outputs from the financial model are the net present value (NPV) of cash flow to the owners and the internal rate of return (IRR) of the project. If the NPV for the project exceeds zero then the price charged for storing CO_2 is high enough to cover all costs, including the costs of complying with the Class VI regulations, taxes, and financing costs.

A useful financial metric is the first-year breakeven CO_2 price, which is the price the operator would need to charge for storing CO_2 that makes the NPV for the project equal to zero. The first-year breakeven CO_2 price is the lowest price the operator can charge for injecting CO_2 and still have a viable project (just barely). The CO2_S_COM calculates the first-year breakeven CO_2 price. Within a worksheet in the model, an asterisk ("*") next to an item references a note or notes pertaining to that item further down in the sheet.

The purpose of this manual is to assist the modeler in understanding the CO2_S_COM, specifically major outputs, how the outputs are calculated, and how a modeler can edit the inputs to affect outputs for evaluating an onshore storage project. For further background knowledge, a description of the use of the model with a slightly different baseline scenario than the one provided in this manual is provided in NETL's "Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies" (QGESS T&S) (Warner, Vikara, Morgan, & Grant, July 2024).

Exhibit 1-1. Project stages for a CO_2 saline storage project

<table>
<tr><th rowspan="3">Site Screening</th><th>Site Selection and Site Characterization</th><th>Permitting and Construction</th><th>Operations</th><th>PISC and Site Closure</th><th>Long-Term Stewardship</th></tr>
<tr><th colspan="4">UIC Class VI Regulations</th><th rowspan="2">Developing State Regulations</th></tr>
<tr><td rowspan="2">2+ years</td><td rowspan="2">2+ years</td><th colspan="2">Class VI Permit</th></tr>
<tr><td>0.5 to 1 year</td><td>12 to 50 years</td><td>10 to 50+ years</td><td>Rest of civilization</td></tr>
<tr><td>Gather existing data
Develop several prospects</td><td>Select a prospective site; acquire new/additional data; acquire seismic data
Drill test well(s)
Prepare project plans for permitting
Arrange for FR</td><td>Submit plans for permit. Permit awarded; drill and test injection wells
Incorporate new well data in plans; get approval to begin injection</td><td>Inject CO_2
Drill monitoring wells and remediate old wells per plan
MVA per plan
Pay into fund for long-term stewardship</td><td>Monitor site and CO_2 plume per approved plan; establish non-endangerment
Close and restore site</td><td>Another entity (e.g., state) takes over</td></tr>
<tr><td colspan="2">Assemble acreage block; acquire pore space rights, surface access
Signing bonus, dollar per acre lease costs</td><td colspan="3">Demonstrate FR upon permit application
Maintain FR levels per changing costs</td><td></td></tr>
<tr><td></td><td>25% success rate on site characterization</td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="3">Negative cash flow</th><th>Positive cash flow</th><th>Negative cash flow</th><th>Covered by fee paid during operations</th></tr>
</table>

1.1 Model Orientation

The CO2_S_COM consists of 30 worksheets (or sheets) along with Visual Basic for Applications (VBA) macros and user-defined functions. The model has several features that simplify the computational process and increase functionality. These items include four fundamental modules and a custom tab on the ribbon where several VBA macros can be run. An overview of these items as well as the worksheets within the Excel file are described in the sub-sections below. Many worksheets within the model are divided into parts or sub-parts with the parts or sub-parts numbered. The numbering in each worksheet is independent of the numbering in other worksheets. The following sheets do not have parts or sub-parts that are numbered: 'READ_ME_FIRST,' 'Fin_Resp_Inputs,' 'Summ_Output,' five results sheets, 'Geol DB Sal,' 'Back-End_Cost Items,' and 'Drilling Costs'. Of the 30 worksheets within the model, four are key to the model's function, 19 provide useful information but are not critical to model performance, and seven are hidden and should not be modified.

1.1.1 'READ_ME_FIRST' Worksheet

A brief overview of the model and a brief description of the worksheets in the workbook are provided in this sheet. The 'READ_ME_FIRST' worksheet also provides information on color and font conventions along with fundamental model assumptions that a modeler is not able to modify. The color conventions (Exhibit 1-2) are specific colors used consistently throughout the workbook to provide immediate visual indicators of the purpose of certain cells. The most important convention, the light orange input cell color, is listed first. The modeler can change values in any light orange cell. To use the spreadsheet, the user must first enable macros after opening the spreadsheet file. The 'READ_ME_FIRST' sheet also has disclaimers and a BSD 1 open source software license.

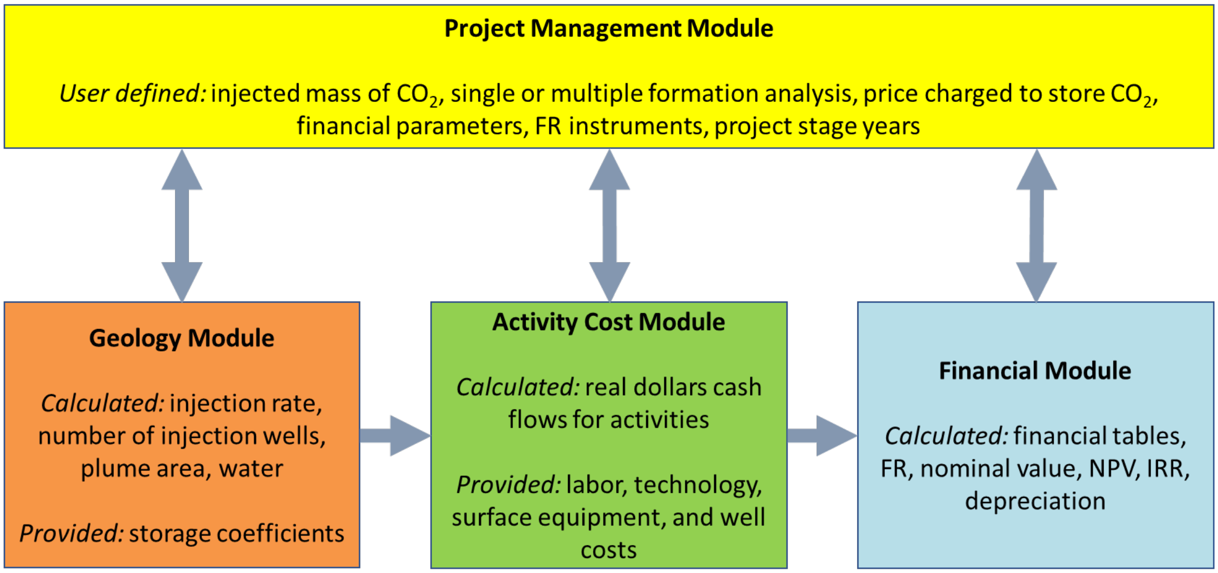
Exhibit 1-2. Model color conventions for text and cell color/style

Inputs specified in this cell (type in this cell)
Not a data input cell
Title or heading rows
Overview or instructions
Cells using values from other sheets
Schedules referenced in the 'Back-End_Cost Items' sheet
Outputs used in other sheets or intermediate calculations
Geological parameters from geology database

1.1.2 Four Fundamental Modules

The CO2_S_COM consists of four fundamental modules (project management, financial, activity cost, and geology), with the functions of each module distributed across one or more worksheets within the Excel workbook and comprising modeler inputs as well as intermediate outputs that build up the key outputs. Exhibit 1-3 shows the model's structure and lists some parameters within each module that are either user defined (parameters determined or selected by user), calculated (calculated values based on data provided), or provided (data already in model but can be edited by user). These items are discussed further in Section 1.2 and in the appropriate module sections (Section 2 for project management, Section 3 for financial, Section 4 for activity cost, and Section 5 for geology).

Exhibit 1-3. The CO2_S_COM structure



1.1.2.1 Project Management Module

This module has project inputs that define the overall scope of the storage project and generates selected outputs. The modeler can conduct a storage cost analysis from the project management module by modifying key inputs without entering the other modules. This module consists of nine worksheets, which are further discussed in Section 2:

1. **'Key_Inputs' worksheet**

   Key management decisions are entered in this sheet including annual volume of CO_2 injected, years of injection, time span for other stages of a storage project, some two dimensional (2-D) and three dimensional (3-D) seismic parameters, options for calculating the number of monitoring wells, and financial parameters defining the business scenario to be modeled. There are 14 parts in this worksheet: 1.0 Model Run for One Storage Formation and One Structure, 2.0 Model Run for Multiple Storage Formations and One or More Structural Settings, 3.0 Operational Variables, 4.0 Variables Related to Geology and Reservoir Engineering Calculations, 5.0 Site Screening and Characterization, 6.0 Corrective Action Inputs and Calculated Results, 7.0 Water Production, 8.0 Monitoring Wells: Numbers and Timing of Installation, 9.0 Atmospheric Monitoring, 10.0 Surface Equipment Inputs for Calculating Capital and O&M Costs, 11.0 3-D Seismic Inputs for Calculating Capital Costs, 12.0 Methodology for Calculating Well Drilling and Completion Costs, 13.0 Fees Paid by Storage Project Operator, and 14.0 Inputs and Calculations Related to Financial Module. The 'Key_Inputs' sheet also provides the user the ability to perform a single or multiple formation evaluation with results of the single formation being displayed in this sheet. A multiple formation evaluation will display results for the last formation evaluated. Output provided in this sheet includes the number of injection wells, number of monitoring wells, maximum CO_2 injection rate, total mass of CO_2 injected, CO_2 plume area, and formation and structure quantities. More information on this worksheet is provided in Section 2.1.

2. 'Fin_Resp_Inputs' worksheet

This sheet contains modeler inputs for the FR instruments including the selection of the instruments and financial parameters for each instrument. The 'Fin_Resp_Inputs' worksheet also includes output information pertaining to the costs of all components and instruments of FR with the results of the single formation being displayed in this sheet. A multiple formation evaluation will display results for the last formation evaluated. More information on this worksheet is provided in Section 2.2.

3. 'Summ_Output' worksheet

A summary of many important outputs of the model is within this sheet. This worksheet also includes output information from the project management, geology, and financial modules with the results of a single formation being displayed in this sheet. A multiple formation evaluation will display results for the last formation evaluated. The 'Summ_Output' worksheet is only used for informational purposes for the user. More information on this worksheet is provided in Section 2.3.1.

4. 'Cost Breakdown 1' worksheet

This sheet uses data throughout the model to sum costs across different categories. These sums are used in some of the output the model produces. More information on this worksheet is provided in Section 2.3.2.

5–9. 'Res_Bas1,' 'Res_CatV1,' 'Res_CatP1,' 'Res_SUStg1,' and 'Res_FRWat1' worksheets

These five sheets are populated with results after running the multiple formation evaluation macro. Model output is also presented in five hidden sheets: 'Res_Bas,' 'Res_CatV,' 'Res_CatP,' 'Res_SUStg,' and 'Res_FRWat.' These hidden worksheets contain formulas to calculate or reference the values for model output. For the formulas to not change with each change in formula and structure, their output values are pasted into the unhidden worksheets, 'Res_Bas1,' 'Res_CatV1,' 'Res_CatP1,' 'Res_SUStg1,' and 'Res_FRWat1.' The modeler makes no changes to any of these 10 worksheets. Any parameter changed in the 'Key_Inputs' or 'Fin_Resp_Inputs' sheets of the project management module, or in the "CO2_S_COM" ribbon tab (described in Section 1.2), is not reflected in the unhidden output worksheets until the multiple formation evaluation macro is run, which updates all the tables. This macro also saves the data output in a separate Excel workbook, "CO2_S_COM_Results.xlsm," which can be downloaded by the user on NETL's website or created as another Excel file with this name or another name chosen by the user (NETL, 2024b). The model and this separate workbook are programmed to recognize each other, so the file name for this separate workbook and the file name posted on the 'Key_Inputs' worksheet in Cell D35 have to be identical. This separate workbook also must be saved in the same folder as the model or it will not be identified by the model. When the multiple formation evaluation macro is run, five new worksheets will be inserted into this workbook with the same number. If other runs are performed, five new worksheets will populate with another number. For example, the first run will populate five worksheets with "1" at the end, while the second run will populate five with "2" at end. If the modeler chooses to use the Excel workbook from

NETL's website, there are example results sheets in the file that can be deleted. More information on these worksheets is provided in Section 2.3.3.

1.1.2.2 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 cash flows of capital investments and expenses made in the 'Back-End_Cost Items' worksheet of the activity cost module. Calculation of FR cost and cost of instruments to satisfy FR requirements are done within the financial module. This module also provides the 'Key_Inputs' sheet with the ability to solve for key outputs such as the breakeven price to store a tonne of CO_2. There are three worksheets within the financial module; they are further explained in Section 3:

1. **'FinMod_Main' worksheet**

   This worksheet is the core sheet of the financial module and has 10 parts: 1.0 Key Inputs and Outputs, 2.0 Escalation and Discounting Factors, 3.0 Revenues, 4.0 Outputs from 'Back-End_Cost Items' Sheet: Operating Expenses, Capital Costs, and Capital Costs by Depreciation Category, 5.0 Costs of Financial Responsibility Categories, 6.0 Financial Instrument Calculations for Financial Responsibility, 7.0 Debt (escalated $), 8.0 Taxes (escalated $), 9.0 Cash Flow Available to Owners (escalated and present value $), and 10.0 Miscellaneous Summary Cash Flow Information. It includes the financial calculations for the project and pulls information from the project management, activity cost, and geology modules to calculate the values posted in the parts. The macros executed in the 'Key_inputs' sheet find the CO_2 price in dollars per tonne of CO_2 injected that yield the NPV for the project of zero. This is the breakeven CO_2 price. The calculation of the NPV for the project is done in the 'FinMod_Main' worksheet. More information on this worksheet is provided in Section 3.1.

2. **'FinMod FR Details' worksheet**

   All the specifics for the FR instruments, including details behind the calculation of the cost of the selected financial instruments selected by the modeler to meet FR obligations under Class VI regulations, are within this sheet. There are 11 parts in this worksheet: 1.0 General Information Applicable to Most if Not All Financial Instruments, 2.0 Financial Instruments Selected by User, 3.0 Costs Associated with Different Financial Responsibility Categories, 4.0 Letter of Credit Calculations, 5.0 Trust Fund Calculations, 6.0 Escrow Account Calculations, 7.0 Surety Bond Method 1 Calculations, 8.0 Surety Bond Method 2 Calculations, 9.0 Insurance Method 1 Calculations, 10.0 Insurance Method 2 Calculations, and 11.0 Cash Flows for Financial Responsibility Instruments for Use in 'FinMod_Main' Sheet. More information on this worksheet is provided in Section 3.2.

3. **'FR_Lookups' worksheet**

   Calculation of costs associated with the available financial instruments depends on the values in the 'Fin_Resp_Inputs' worksheet of the project management module. These values are posted to their respective cells in the 'FinMod FR Details' sheet. Suggestions on these values are provided in the 'FR_Lookups' sheet through nine parts: 1.0 General Inputs, 2.0 Letter of Credit, 3.0 Trust Fund, 4.0 Escrow Account, 5.0 Surety Bond Method 1, 6.0 Surety Bond Method 2, 7.0 Insurance Method 1, 8.0 Insurance Method 2, and 9.0 Financial Instruments Used for Different Categories of Financial Responsibility. More information on this worksheet is provided in Section 3.3.

1.1.2.3 Activity Cost Module

This module provides a cost database for all activity costs related to a CO_2 storage project, presents the modeler the opportunity to enter individualized cost data, and allows the modeler to change the timing for an activity (i.e., the year[s] over which the activity will occur or in which storage project stage[s] will occur). Annual costs per technology/labor applied over the life of a storage project are generated within this sheet. Technology and labor are key variables comprising activity costs. High-cost activities include drilling wells and running seismic, whereas low-cost activities include taking samples, running tests, and writing reports. There are currently 490 different activities in this module. Some activities are unique to a storage project stage (e.g., drilling a strat well during site selection and site characterization), while others can occur in multiple project stages (e.g., formation water sampling or acquiring seismic data during site selection and site characterization, operations, and PISC and site closure). Information posted for each activity includes the unit cost of the activity item, the overall quantity of each activity (number of times performed), and the timing of the activity (the project stage and year in which the activity was performed). This module consists of four worksheets, which are further discussed in Section 4:

1. **'Activity_Inputs' worksheet**

   This worksheet contains four parts of modeler inputs that define costs of parameters related to the project: 1.0 Parameters Consistent Across all Activities, 2.0 Activity-Specific Parameters, 3.0 Parameters Used in Activities Across Multiple Stages, and 4.0 Well-Drilling Costs. Information provided in these parts include labor cost, project activity-specific cost items that are costed in a specific stage of the project, cost items for activities across multiple stages where incurred costs can be applied to all stages in the project's lifespan, and well drilling cost items for site characterization wells, injection wells, all types of monitoring wells, and water production/injection wells.

   The modeler can also use this worksheet to establish when specific costs are incurred and select and deselect which technologies will be used. The selection of various technologies is done differently depending on the part. If there is no entry for a technology for a project stage, then that technology will not be used. However, for all well-drilling costs (Part 4.0), to the right of each cost column is a column for turning the cost on or off, which is labeled 'ON/OFF' in each sub-part's appropriate timing table. The modeler should enter an 'x' in this column to turn on the cost or leave the cell blank to turn off the cost. More information on this worksheet is provided in Section 4.1.

2. **'Surf Eq Cost' worksheet**

Capital costs and annual operation and maintenance (O&M) costs for surface equipment/facility at a saline storage site are specified in this worksheet. Surface equipment includes a feeder pipeline; equipment/facility, roads, and buildings needed to operate the injection wells, and equipment and roads related to storage field operations. This sheet has one part: 1.0 Capital Costs and Annual Operating and Maintenance (O&M) Costs for 'Back-End_Cost Items' Sheet. More information on this worksheet is provided in Section 4.2.

3. **'Back-End_Cost Items' worksheet**

   This worksheet enables the modeler to fully audit and review the model calculations. It calculates the appropriate annual cost for each activity utilized in a storage project and posts this cost in the year(s) it is incurred. More information on this worksheet is provided in Section 4.3.

4. **'Drilling Costs' worksheet**

   This worksheet performs the calculations of drilling costs. More information on this worksheet is provided in Section 4.4.

1.1.2.4 Geology Module

This module includes the geologic database, storage coefficients, and geo-engineering equations and calculates CO_2 injectivity, number of CO_2 injection wells, and CO_2 plume area; the latter two are fundamental cost drivers for any CO_2 storage project. It also calculates water withdrawal (production) from the CO_2 storage reservoir as well as subsequent treatment and disposal (injection) of water not rendered potable. There are five worksheets within the geology module, and they are further explained in Section 5:

1. **'Geol Sal' worksheet**

   This worksheet contains geologic inputs for calculating CO_2 storage and the table of storage coefficients used in storage calculations. This sheet calculates the rate of injection for the storage formation modeled, the number of injection wells needed to inject the maximum daily mass of CO_2 to be injected, the total mass of CO_2 stored for each storage formation modeled based on any limitations selected by the modeler, the areal extent of the CO_2 plume, the plume uncertainty boundary, and the pressure front boundary. There are five parts in this worksheet: 1.0 Overview, 2.0 Outputs, 3.0 Inputs, 4.0 Surface Area of CO_2 Plume and Maximum Mass of CO_2 Formation Can Theoretically Store, and 5.0 Rate of Injection of CO_2 in Each Injection Well and Number of Injection Wells. More information on this worksheet is provided in Section 5.1.

2. **'Geol DB Sal' worksheet**

   The geologic database is posted within this worksheet. More information on it can be found in Section 5.2.

3. **'Water' worksheet**

   Inputs and calculations related to the model's method for including water production, treatment, disposal, or sale are contained in this worksheet through nine parts: 1.0 Status of Water Management, 2.0 Formation Information, 3.0 Brine Properties, 4.0 Calculation of the Maximum Rate of Flow in a Single Injection or Production Well, 5.0 Calculation of the Water Produced, Treated, Sold, and Re-injected, 6.0 Determine Number of Production and Injection Wells, 7.0 Specify the Depth of Water Injection Wells, 8.0 Costs (Note: Part 8.0 is Compatible with Sub-stage 6 Labels in 'Back-End_Cost Items' Sheet), and 9.0 Price for Treated Water That is Sold (Used in 'FinMod_Main' Sheet as Supplemental Revenue for Project). The calculations on this sheet pull data from other parts of the geology module and use data that has been entered by the modeler or in a dataset from an outside source. The results of the calculations are then carried through the model via the activity cost module and cost line items, in the same manner as other costs. The revenue in the financial module is also directly related to the input within this worksheet. The 'ON/OFF' switch for the water method is in the 'Key_Inputs' sheet (Cell N27) of the project management module. All other water-related items are controlled through the 'Water' sheet. More information on this worksheet is provided in Section 5.3.

4. **'Plume&Well Schedule' worksheet**

   This worksheet lists time-dependent geologic factors, such as well counts and plume growth, in a timeline. This sheet contains four parts: 1.0 Stage Durations and Operations Start and End Years, 2.0 Start and End Times for Different Well Types, 3.0 CO_2 Plume and Various Area and Length Quantities, and 4.0 Well Data. The modeler can find all year-dependent factors within this sheet including plume area, area of review (AoR), and well counts. The inputs and assumptions relevant to these values are also posted for reference. This sheet 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. More information on this worksheet is provided in Section 5.4.

5. **'Geo-Activity Interaction' worksheet**

   Information to the modeler on the geology values that are transferred from the geology module to the activity cost module is provided in this worksheet as well as four modeler inputs through two parts: 1.0 Parameters Determined by Geology and 2.0 Values Determined by Geology and Universal Activity Assumptions. More information on this worksheet is provided in Section 5.5.

1.1.3 'Cases' Worksheet

The 'Cases' worksheet allows the user to choose input case variables (referred to as input case variables in this worksheet) that they wish to systematically modify and to select different input values for these input case variables. Each case provides one set of input values for the input case variables and generates results for each case. This feature allows the user to perform systematic sensitivity analysis to determine how changing specific input case variables, either individually or in groups, affects output variables of interest to the user.

This worksheet has three parts: 1.0 "Process_Cases" Macro: Overview, Inputs, Outputs, and Running the Macro, 2.0 Inputs to macro, and 3.0 Outputs from macro. Cases are defined by the user determining input variables to modify in a systematic manner and then choosing values for these input variables. There can be as many as 51 input case variables and 40 cases. It is important to note that the user must indicate to the macro that an input case variable should not be processed by either entering "NA" for the name of the sheet where the target cell is located or entering a blank value in the row for the name of the input case variable in the column after the last input case variable that is to be processed. Also, the user must enter "end" in Column A in the row after the last case to be processed to indicate to the macro to stop processing cases. The user selects the starting and ending numbers of storage formations to be processed. The user also determines the results or output variables that are to be generated for each case and each storage formation.

The "Run Process_Cases" VBA macro is run by clicking the "Run Process_Cases" button in the 'Cases' worksheet (Cell A33). This macro allows the user to investigate how changes to one or more input case variables alter a variety of output variables. The macro also saves the contents of the 'Cases' sheet in a separate Excel workbook, "CO2_S_COM_Cases_Res.xlsm," which can be downloaded by the user on NETL's website or created as another Excel file with this name or another name chosen by the user (NETL, 2024c). The model and this separate workbook are programmed to recognize each other, so the file name for this separate workbook and the file name posted on the 'Cases' sheet in Cell B50 have to be identical. This separate workbook also must be saved in the same folder as the model or it will not be identified by the model. When the "Process Cases" macro is run, a worksheet will be inserted into the separate workbook as "Cases_yyyy_m_d_hr_min" where "yyyy" is the year, "m" is the month, "d" is the day, "hr" is the hour, and "min" is the minute. Thus, as the 'Cases' sheet is run, each results worksheet will have a unique identifier. If the modeler chooses to use the Excel workbook from NETL's website that stores the results from running the "Process Cases" macro, there is an example result sheet in the file that can be deleted. More details, including how to perform a run with this sheet, are within the documentation in the 'Cases' sheet in the model.

1.1.4 Other Hidden Worksheets

In addition to the five results sheet previously described ('Res_Bas,' 'Res_CatV,' 'Res_CatP,' 'Res_SUStg,' and 'Res_FRWat'), there are two other hidden sheets within the model that should not be modified:

1. **'Parameters' worksheet**

   This sheet facilitates communication between the "CO2_S_COM" ribbon tab and the 'Key_Inputs' sheet. All information within this sheet is used internally by the model and should not be modified; therefore, the sheet is hidden.

2. **'Version' worksheet**

This sheet provides information used by the developers to track edits made within the model. All information within this sheet should not be modified and is not particularly useful to users; therefore, the sheet is hidden.

1.1.5 "CO2_S_COM" Ribbon Tab

The CO2_S_COM includes a custom ribbon tab labeled "CO2_S_COM." Located on the far right of the ribbon, this ribbon tab provides an alternative way to run the model and change key inputs. Ribbon parameters are linked to the appropriate input cell in the 'Key_Inputs' sheet, allowing users to observe the effects of ribbon parameter changes throughout the model without having to refer to the 'Key_Inputs' sheet to make modifications or run the model. Please note that changing the value in the ribbon will update the cell value in the 'Key_Inputs' sheet but changing the value within the 'Key_Inputs' sheet will not update the ribbon value until after the macro is run. This does not impact model functionality as the model refers only to the cells within the 'Key_Inputs' sheet. Additionally, the ribbon contains navigation buttons for quick access to sheets of interest: 'Key_Inputs,' 'Fin_Resp_Inputs' (entitled Financial Responsibilities), 'Back-End_Cost Items' (entitled Detailed Cost), and 'Plume&Well Schedule.' The use of the ribbon tab to run the macro is discussed in Section 1.2.

1.2 How the CO2_S_COM Works

The CO2_S_COM has two operating modes depending on whether the user decides to calculate the revenues, costs and financial performance for a single storage formation or multiple storage formations. The model has the ability to provide revenues and costs in real (i.e., constant) or nominal (i.e., escalated) dollars. A third operating mode is also provided in the model. This mode is performed in the 'Cases' sheet and allows the user to evaluate multiple cases consecutively. A discussion on how to run the 'Cases' sheet is not provided in this section; see Section 1.1.3 and the 'Cases' sheet within the model for details. This section provides a quick start on performing a run with the model using the single and multiple formation evaluation buttons in the 'Key_Inputs' sheet and the "CO2_S_COM" ribbon tab. It is important to note that the user must first enable macros after opening the model for it to function properly. More detail on inputs, outputs, and calculated values are provided in Section 2.

1.2.1 Setting Input Parameters

The CO2_S_COM is set with default values for all inputs as suggestions for the modeler; however, the modeler can change as many or as few defaults as they wish. The first step in using the model, whether analyzing a single storage formation or multiple storage formations, is setting the inputs to desired values specific to the scenario being analyzed. With over 3,000 user inputs, some are changed more often than others. Exhibit 1-4 highlights the main user inputs commonly changed by the average user to produce customized results.

Inputs within Exhibit 1-4 are organized by sheet. The default value provided in the model (for both real and nominal dollar analysis, if applicable), and the cell location in the model within the designated sheet is given. Whether or not the input should be changed for a single or multiple evaluation run is also noted as well as if the parameter can be modified in the "CO2_S_COM" ribbon tab. General notes are provided for more information.

Exhibit 1-4. Main input parameters for running the CO2_S_COM

Model Sheet	Input	Default Value in Model	Location in Model	Single or Multiple Evaluation Run	Note
'Key_Inputs'	Formation number for single evaluation run*	314	Cell A17	Single	Formation numbers provided in Column A in the 'Geol DB Sal' sheet See Part 1.0 discussion under Section 2.1
	Probability level for storage coefficients*	P50	Cell A19	Single and multiple	Options are P10, P50, or P90 See Part 1.0 discussion under Section 2.1
	Structure for determining storage coefficients*	Reg_dip	Cell A20	Single	Options are general, anticline, dome, incline_10deg, incline_5deg, flat, or reg_dip See Part 1.0 discussion under Section 2.1
	First formation number for multiple evaluation run*	1	Cell C24	Multiple	Formation numbers provided in Column A in the 'Geol DB Sal' sheet See Part 2.0 discussion under Section 2.1
	Last formation number for multiple evaluation run*	314	Cell C25	Multiple	Formation numbers provided in Column A in the 'Geol DB Sal' sheet See Part 2.0 discussion under Section 2.1
	Formation structures to evaluate*	4	Cell C26	Multiple	Options are 0 for dome, anticline, and regional dip; 1 for general structure; 2 for dome, anticline, 5 degree incline, 10 degree incline, and flat; 3 for dome, anticline, and flat; and 4 for regional dip See Part 2.0 discussion under Section 2.1
	Project start year (yr)*	2023	Cell AC8	Single and multiple	See Part 14.0 discussion under Section 2.1
	CO_2 mass flow rate for injection (tonnes/yr)	4,310,000	Cell F50	Single and multiple	Default value per QGESS T&S (Warner, Vikara, Morgan, & Grant, July 2024) See Part 3.0 discussion under Section 2.1
	Capacity factor (%)	85	Cell F51	Single and multiple	Default value per QGESS T&S (Warner, Vikara, Morgan, & Grant, July 2024)

Model Sheet	Input	Default Value in Model	Location in Model	Single or Multiple Evaluation Run	Note
					See Part 3.0 discussion under Section 2.1
	Water production and injections status	Off	Cell N27	Single and multiple	Select whether to turn water management (e.g., water production, treatment, and re-injection/disposal) costs on or off See Part 7.0 discussion under Section 2.1
	Variable determining inclusion of pressure interference in the calculation of prospective storage resource	1	Cell E128	Single and multiple	Select whether or not to include pressure inference in the calculation of prospective storage resource. Options are 0 to not include and 1 to include. See Part 4.0 discussion under Section 2.1
	Percent equity (%)	45%	Cell AC10	Single and multiple	Remainder is debt Per "Cost Estimation Methodology for NETL Assessments of power Plant Performance QGESS" (Theis, February 2021) See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Cost of equity or minimum desired IRR on equity (%/yr)	13.30	Cell AC11	Single and multiple	10.77% is default when calculating real dollars, while 13.30% is default when calculating nominal dollars See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Cost of debt or interest rate on debt (%/yr)	6.30	Cell AC12	Single and multiple	3.91% is default when calculating real dollars, while 6.30% is default when calculating nominal dollars See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Effective tax rate (%/yr)	25.74	Cell AC13	Single and multiple	21% federal corporate income tax and 6% state and local tax with effective tax rate reflecting deduction of state and local taxes from federal income taxes See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Variable indicating which escalation rate to use from base year to first year of project	0	Cell AC15	Single and multiple	Options are 0 for lower 48, 1 for regional, and 2 for user input See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1

Model Sheet	Input	Default Value in Model	Location in Model	Single or Multiple Evaluation Run	Note
	Variable indicating which set of escalation rates to use from base year to first year of project	2	Cell AC16	Single and multiple	Options are 1 for Handy Whitman cost indices from 2008 (overall) to 2018 (overall), 2 for Handy Whitman cost indices from 2008 (overall) to January 1, 2023, 3 for user input, and any other number for Handy Whitman cost indices from 2008 (overall) to January 1, 2023 See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Escalation rate input by user to use from base year to first year of project (%/yr)	3.0	Cell AC23	Single and multiple	See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
	Escalation rate from start of project onward (%/yr)	2.3	Cell AC24	Single and multiple	0% is default when calculating real dollars, while 2.3% is default when calculating nominal dollars See Appendix: Rationale Behind Key Financial Parameters and Part 14.0 discussion under Section 2.1
'Fin_Resp_Inputs'	Corrective action funding	Trust fund	Cell A3	Single and multiple	Financial instrument options to use for financial responsibility are letter of credit, trust fund, escrow account, surety bond method 1, surety bond method 2, insurance method 1, insurance method 2, and self-insurance See Section 2.2
	Injection well plugging funding	Trust fund	Cell A20	Single and multiple	Financial instrument options to use for financial responsibility are letter of credit, trust fund, escrow account, surety bond method 1, surety bond method 2, insurance method 1, insurance method 2, and self-insurance See Section 2.2
	PISC and site closure funding	Trust fund	Cell A37	Single and multiple	Financial instrument options to use for financial responsibility are trust fund, escrow account, and self-insurance See Section 2.2

*These main inputs can also be adjusted using the "CO2_S_COM" ribbon tab.

1.2.2 Performing a Run with the Model

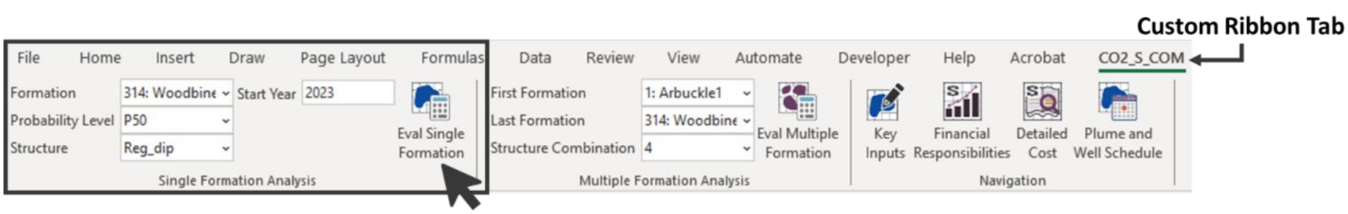
This section describes how to run the CO2_S_COM for both single and multiple formation evaluations using the appropriate buttons in the 'Key_Inputs' sheet and the functions of the "CO2_S_COM" ribbon tab in the Excel workbook.

1.2.2.1 Running the model for a single formation evaluation

To determine technical and economic values for a single formation in the model's geologic database:

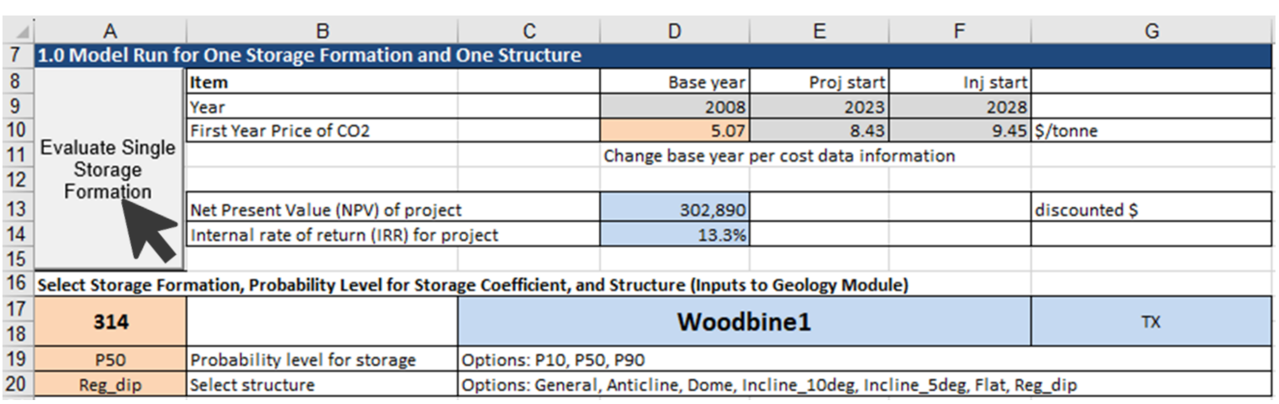
- Confirm macros are enabled within the model.
- Specify inputs (e.g., structure and project start year) in light orange cells (see Exhibit 1-4 for main inputs). Some of these inputs can also be adjusted within the "CO2_S_COM" ribbon tab (see gray box outlined in Exhibit 1-5).
- Run the model using the "CO2_S_COM" ribbon tab or the button within the 'Key_Inputs' sheet. When the macro is finished, a message box will pop up that says, "Macro Execution Complete! Run time of X minutes" where "X" denotes the number of minutes.
    - To run the model on the "CO2_S_COM" ribbon tab, go to the section labeled "Single Formation Analysis" (outlined with gray box in Exhibit 1-5) and click the button labeled "Eval Single Formation" (highlighted with an arrow in Exhibit 1-5).

Exhibit 1-5. Input drop-down menus and evaluation button for running single formation analysis in the "CO2_S_COM" ribbon tab



- To run the model on the 'Key_Inputs' sheet, go to Part 1.0 within that sheet and click the "Evaluate Single Formation" button in cells A8–A15 (highlighted with an arrow in Exhibit 1-6).

Exhibit 1-6. Running the CO2_S_COM for single formation analysis on the 'Key_Inputs' sheet



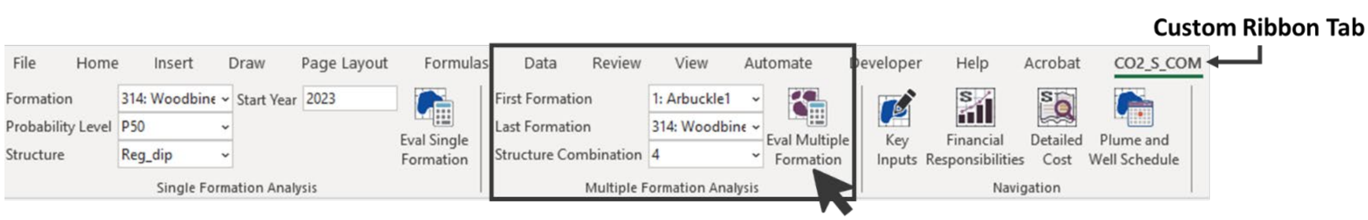
The model will now have results for the desired storage formation, which can be found in all sheets within the model, except the five results sheets and the 'Cases' sheet, based on project requirements input by the user.

1.2.2.2 Running the model for multiple formations evaluation

To determine technical and economic values for multiple formations in the model's geologic database:

- Confirm macros are enabled within the model.
- Save the supplementary results file "CO2_S_COM_Results.xlsm" from NETL's website or an Excel file with the same name or another name chosen by the user in the same folder as the model if wish to save results in a separate Excel file. Multiple model runs can be saved within this workbook. New sheets are added within this workbook for each model run, preserving results from previous runs.
- Specify inputs (e.g., structures to evaluate and mass of CO_2) in light orange cells (see Exhibit 1-4 for main inputs). Some of these inputs can also be adjusted within the "CO2_S_COM" ribbon tab (see gray box outlined in Exhibit 1-7).
- Run the model using the "CO2_S_COM" ribbon tab or the button within the 'Key_Inputs' sheet. If the modeler did not save the separate Excel file, the model will show an error message when running the macro; click "OK" to remove this error message. Results will still save in the model. When the macro is finished, a message box will pop up that says, "Macro Execution Complete! Run time of X minutes" where "X" denotes the number of minutes.
    - To run the model on the "CO2_S_COM" ribbon tab, go to the section labeled "Multiple Formation Analysis" (outlined with gray box in Exhibit 1-7) and click the button labeled "Eval Multiple Formation" (highlighted with an arrow in Exhibit 1-7).

Exhibit 1-7. Input drop-down menus and evaluation button for running multiple formation analysis in the "CO2_S_COM" ribbon tab



    - To run the model on the 'Key_Inputs' sheet, go to Part 2.0 within that sheet and click the "Evaluate Multiple Formations" button in cells A23–A31 (highlighted with an arrow in Exhibit 1-8).

Exhibit 1-8. Running the CO2_S_COM for multiple formation analysis on the 'Key_Inputs' sheet

	A	B	C	D	E	F	G
22	2.0 Model Run for Multiple Formations and One or More Structures						
23	Evaluate Multiple Formations	Run Title:	Baseline				
24		First formation number:	1	Arbuckle1			OK
25		Last formation number:	314	Woodbine1			TX
26		Control variable for structures	4				
27			Options for structures to be evaluated for each formation:				
28			Set = 0 for dome, anticline, and regional dip				
29			Set = 1 for general structure				
30			Set = 2 for dome, anticline, 5 degree incline, 10 degree incline, and flat				
31			Set = 3 for dome, anticline, and flat				
32			Set = 4 for regional dip				
33			This control variable affects the percentage of the formation with each structure.				
34			See the data in Sub-part 4.4 regarding percentages of each structure in the formation.				
35	Name of workbook to store result sheets			CO2_S_COM_Results.xlsm			

Model results for the desired storage formations based on project requirements input by the user can be found in the Res_Bas1,' 'Res_CatP1,' 'Res_CatV1,' 'Res_SUStg1,' and 'Res_FRWat1' sheets. These results will also be in the separate "CO2_S_COM_Results.xlsm" if the user decided to save this Excel workbook. Other sheets within the model, except the 'Cases' sheet, will just show results for the last storage formation evaluated.

1.3 Overview of This Manual

This manual has the following sections (for additional information on the CO2_S_COM not provided in this manual, please refer to notes and references in the model itself):

- Section 2: Describes the project management module
- Section 3: Discusses the financial module
- Section 4: Provides information in the activity cost module
- Section 5: Describes the geology module
- Section 6: Presents a list of references cited in the manual
- Appendix: Explains the rationale behind the financial parameters related to the financial module

2 PROJECT MANAGEMENT MODULE

This module has project inputs that define the overall scope of the storage project and modeled outputs. There are nine worksheets in this module, which are described in the subsequent sections below. Two of the worksheets contain inputs that define the overall scope (e.g., scheduling) and financial considerations of the storage project ('Key_Inputs' and 'Fin_Resp_Inputs'), which influence the key outputs. The remaining worksheets contain modeled outputs: 'Summ_Output,' 'Cost Breakdown 1,' and five results sheets (in the format of 'Res_[…]1').

2.1 'KEY_INPUTS' WORKSHEET

Consisting of 14 parts, the 'Key_Inputs' worksheet provides the modeler the ability to change parameters (in light orange color) related to project management. It also contains output cells (light blue cell color) that provide immediate feedback on variables that are calculated by the model. The worksheet includes buttons to run the single formation macro and multiple formations macro for obtaining results. Three output tables are provided within the sheet. Within the sheet, the asterisk ("*") next to an item references a note at the bottom of the sheet. The gray arrow within Column N and Column AN allows the modeler to easily move to the right and left sides of the 'Key_Inputs' sheet, respectively, without using the scroll function in the spreadsheet. Some parts of this worksheet are further broken down into sub-parts to provide more detail in the model. More information on high-level parts and sub-parts of the 'Key_Inputs' worksheet are discussed below:

Part 1.0: Model Run for One Storage Formation and One Structure. This part provides the user the ability to select a single storage formation for evaluation, choose the probability level and structural closure for the storage coefficient, and run a single formation analysis. Details on items within this part as well as the macro are discussed in this section, but information on how to run a single formation evaluation using the "CO2_S_COM" ribbon tab and 'Key_Inputs' worksheet can be found in Section 1.2.2.1.

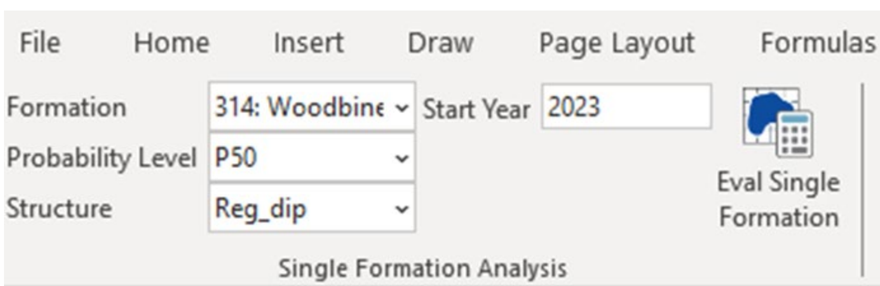
The number for the storage formation evaluated from the geologic database in a single formation model run is entered in Cell A17 and its corresponding name is shown in Cell C17 (see Exhibit 2-1). The number for the storage formation can be changed by selecting a formation from the "CO2_S_COM" ribbon tab drop-down menu (see Exhibit 2-2) or by updating the entry in Cell A17. For the purposes of this manual, 314 for Woodbine1 is posted in Cell A17 and the storage reservoir's name in Cell C17. In the geologic database ('Geol DB Sal' sheet), formation numbers (1–314) are listed in Column A and associated formation names are listed in Column B. The geologic database has data for 87 geologic formations in 36 basins or structural setting across 27 states.

Exhibit 2-1. Evaluate single formation in 'Key_Inputs' sheet

	A	B	C	D	E	F	G
7	1.0 Model Run for One Storage Formation and One Structure						
8	Evaluate Single Storage Formation	Item		Base year	Proj start	Inj start	
9		Year		2008	2023	2028	
10		First Year Price of CO2		5.07	8.43	9.45	$/tonne
11				Change base year per cost data information			
12							
13		Net Present Value (NPV) of project		302,890			discounted $
14		Internal rate of return (IRR) for project		13.3%			
15							
16	Select Storage Formation, Probability Level for Storage Coefficient, and Structure (Inputs to Geology Module)						
17–18	314		Woodbine1				TX
19	P50	Probability level for storage	Options: P10, P50, P90				
20	Reg_dip	Select structure	Options: General, Anticline, Dome, Incline_10deg, Incline_5deg, Flat, Reg_dip				

Below the storage formation selection, users may choose a probability level of the storage coefficient from the drop-down menu in Cell A19 of the 'Key_Inputs' sheet (see Exhibit 2-1) with options posted in in Cell C19. Storage coefficients are tied to structural style. These values are in Attachment A (Row 802) of the 'Geol Sal' worksheet. Storage coefficients are listed by depositional environment and each depositional environment has five structural settings. Also, each depositional environment/structural setting combination has three storage coefficient values representing a probability at P10, P50, and P90. The depositional environment for each storage formation is posted in the geologic database. A higher P-value (i.e., higher storage coefficient) provides for better storage, smaller CO_2 plume, and lower costs. The modeler can determine the range of storage costs for a particular storage formation by sequentially selecting each structural setting and probability of storage coefficient. This input can also be changed in the drop-down menu of the "CO2_S_COM" ribbon tab (see Exhibit 2-2).

Exhibit 2-2. Single formation analysis in "CO2_S_COM" ribbon tab



Below the probability level, users may select the structural settings to run (Cell A20, Exhibit 2-1) with options (general, anticline, dome, 10 degree incline, 5 degree incline, flat, and regional dip) listed in Cell C20. There is also a drop-down menu to select structure in the "CO2_S_COM" ribbon tab (see Exhibit 2-2). Each structural setting provides a different storage coefficient. Dome and anticline structural settings provide higher storage coefficients than the other structural settings since they are partially closed structures.

When the "Eval Single Formation" or "Evaluate Single Formation" macro is run within the "CO2_S_COM" ribbon tab or 'Key_Inputs' worksheet, respectively, the first-year breakeven price of CO_2 is determined by iteratively changing this price until the NPV for the project is zero. The displayed price is rounded up to the nearest penny, so the displayed NPV for the project is always slightly positive, but it is effectively zero for analytical purposes. The model will also show the IRR of the project breakeven. At the first-year breakeven CO_2 price, the IRR should be the same as the cost of equity. For example, a breakeven price analysis of the Woodbine 1 storage reservoir provides a breakeven CO_2 price of $8.43/tonne (Cell E10, Exhibit 2-1) in 2023 (project start year) with an NPV of $302,890 (Cell D13). This price is escalated from the value of $5.07 (Cell D10) for the base year, 2008. The project would return a negative NPV if the modeler charged $5.06 in 2008, providing an escalated 2023 price of $8.42 and an NPV of -$3,357. Therefore, the NPV of $302,890 at a CO_2 price of $8.43/tonne is effectively a zero value for NPV since it is only slightly positive.

If the modeler wants to know the NPV of a project for a price different from the breakeven price value, then the modeler should enter that price value in the light orange cell (Cell D10), which is the base year of the project. The resulting NPV and IRR will be posted in the blue cells (cells D13 andD14, respectively) below the base year, 2008 for purposes of this manual.

A value for the first-year price of CO_2 is posted in cells D10 (base year), E10 (project start year), and F10 (injection start year). Note the escalation in the price of CO_2 across these three cells. The costs in the model are all input relative to the base year of 2008. If the modeler has updated cost information, they can enter the associated base year in Cell AC7, which will be the year used to calculate engineering costs in other worksheets. It is important to note that if the base year is changed by the user, the modeler will need to make sure that all cost data in the model have been adjusted to this new base year. The first year of the project is set at 2023 to be consistent with other NETL technoeconomic models. Positive cash flow in the model occurs during operations based on the escalated storage price of CO_2. Earnings during operations covers all costs incurred from initial geologic evaluation to final site closure some 86 years later.

Part 2.0: Model Run for Multiple Storage Formations and One or More Structural Settings. This part provides the user the ability to select multiple storage formations and structures for evaluation and run a multiple formations analysis. Each multiple formation model run can be labeled; the name of the model run, or run title, can be entered in Cell D35 (see Exhibit 2-3). Details on items within this part as well as the macro are discussed in this section, but information on how to run a multiple formations evaluation using the "CO2_S_COM" ribbon tab and 'Key_Inputs' worksheet can be found in Section 1.2.2.2.

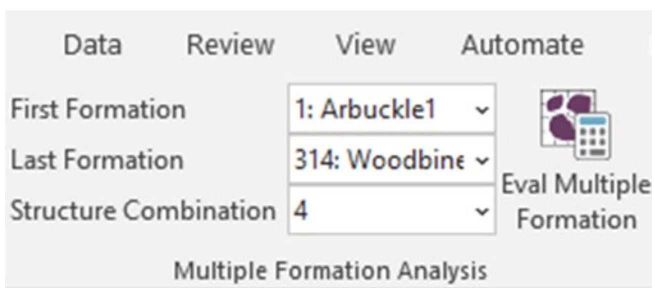
The number for the storage formations evaluated from the geologic database in a multiple formations model run is entered in cells C24 and C25 and their corresponding names are shown in cells D24 and D25 (see Exhibit 2-3). The numbers for the storage formations can be changed by selecting a formation from the "CO2_S_COM" ribbon tab drop-down menus (see Exhibit 2-4) or by updating the entry in cells C24 and C25. For the purposes of this manual, 1 for Arbuckle 1 and 314 for Woodbine 1 is posted in cells C24 and C25, respectively, and the storage formations' names in cells D24 and D25, respectively.

Exhibit 2-3. Evaluate multiple formations in 'Key_Inputs' sheet

	A	B	C	D	E	F	G
22	**2.0 Model Run for Multiple Formations and One or More Structures**						
23	Evaluate Multiple Formations	Run Title:	Baseline				
24		First formation number:	1	Arbuckle1			OK
25		Last formation number:	314	Woodbine1			TX
26		Control variable for structures	4				
27			Options for structures to be evaluated for each formation:				
28			Set = 0 for dome, anticline, and regional dip				
29			Set = 1 for general structure				
30			Set = 2 for dome, anticline, 5 degree incline, 10 degree incline, and flat				
31			Set = 3 for dome, anticline, and flat				
32			Set = 4 for regional dip				
33			This control variable affects the percentage of the formation with each structure.				
34			See the data in Sub-part 4.4 regarding percentages of each structure in the formation.				
35	Name of workbook to store result sheets			CO2_S_COM_Results.xlsm			

Another important modeling selection in this part is the structural setting in Cell C26, which is listed as "Structure Combination" in the "CO2_S_COM" ribbon tab (see Exhibit 2-4). Per the values listed in cells C28–C32 in the model, the modeler can select a suite of structural settings for costs to be generated for each storage formation in the geologic database. The model will evaluate each structural setting selected for each storage formation evaluated by the model. Selecting a value of "0" in the "CO2_S_COM" ribbon tab or in Cell C26 provides analysis of a dome, anticline, and regional dip structural setting; evaluation of 314 storage formations provides 942 results. The default for the structure control variable is regional dip, option "4" (see Exhibit 2-3).

Exhibit 2-4. Multiple formation analysis in "CO2_S_COM" ribbon tab



When the "Eval Multiple Formation" or "Evaluate Multiple Formations" macro is run within the "CO2_S_COM" ribbon tab or 'Key_Inputs' worksheet, respectively, the single formation cost analysis is replicated for each storage formation selected from the geologic database and read by the model, providing for multiple cost analysis. Output (run results) is saved to the five 'Res_[…]1' sheets within the model that are part of the project management module ('Res_Bas1,' 'Res_CatV1,' 'Res_CatP1,' 'Res_SUStg1,' and 'Res_FRWat1'). Data posted in these newly generated worksheets not only includes the results of the breakeven price analysis, but also real, escalated, and present value (PV) cost and revenue data for each storage formation, the total amount of CO_2 stored in the formation, rates of injection, and other descriptive detail about the formation for a modeler to review.

This macro also saves the results in a separate Excel workbook. The user can use the file "CO2_S_COM_Results.xlsm," which can be downloaded from NETL's website or the user can create another Excel file with a name chosen by the user (NETL, 2024b). The user will need to ensure the file name matches the file name posted in Cell D35 (for instance, "CO2_S_COM_Results.xlsm" in Exhibit 2-3), and then save it in the same folder as the model. The macro will automatically create a new worksheet with the modeling results in the workbook file listed in Cell D35, if such a file exists in the same folder as the model. If the modeler does not save a file with this name, the model will show an error message when running the macro; click 'OK' to remove this error message. The modeler can still access the results on the 'Res_ […]1' sheets within the model.

Part 3.0: Operational Variables. This part allows the user to provide inputs toward the storage project timeline, CO_2 injection rate, and injection type through three sub-parts (see Exhibit 2-5):

Sub-part 3.1: Project Timeline. This sub-part allows the user to enter duration of each stage of the project to define the project timeline, which sets the foundation of the overall project schedule. The default for the time duration of each stage of the project is posted in cells C42–C46, but these values can be changed per the modeled scenario. Begin year, end year, and calendar year values are calculated based on entered data. The total life of the project (or sum of the durations across all stages) cannot exceed 200 years.

The beginning calendar year of the project is entered in the "CO2_S_COM" ribbon tab (see Exhibit 2-2) or Cell AC8 in the 'Key_Inputs' sheet. The modeler must select a beginning year on or after 2008. This is the year in which site screening begins. The cost of storage is calculated for the year 2008. This cost is escalated, at user selected escalation rates, to the project start year and subsequent years.

Exhibit 2-5 discusses the importance of project time values. The operations stage is the only period when cash flow is positive. All costs are ultimately paid from revenues generated during operations. Reducing the periods for site selection and site characterization and permitting and construction provides for earlier revenue generation from operations. Reducing the time spent on PISC and site closure will significantly reduce costs and impacts on FR.

Exhibit 2-5. Importance of project time values

Project Stage	Location in 'Key_Inputs' Sheet	Note
Site screening (yr)	Cell C42	One year is considered sufficient time to evaluate the geology over a large enough area that, hopefully, will provide the opportunity for several prospective storage sites. All the work is done with existing data that can be acquired at some cost (see Exhibit 1-1).
Site selection and site characterization (yr)	Cell C43	There is a fair amount of risk in selecting a site that will be successfully characterized. One to two years is considered a minimum time to accomplish this, more time may be needed if the initial site(s) are unsuccessful. The default in the model is to characterize one site that is successful and presented for permitting over two years

Project Stage	Location in 'Key_Inputs' Sheet	Note
Permitting and construction (yr)	Cell C44	One to two years is a minimum period for permitting and construction. One year is needed for EPA or the regulatory authority to review and approve the application for permit. With permit approval, the injection wells are drilled, tested, and completed, and site facilities and equipment are constructed. Data from these wells are incorporated in the submitted "Plans" to confirm the data already presented. Updated plans are presented to EPA for final approval to begin injection.
Operations (yr)	Cell C45	The length of injection operations needs to match the project life of the source; 30 years is a typical time span. The plans submitted for application for the Class VI permit are acted on in this stage. Corrective action is either performed before injection begins or occurs during injection. The monitoring and testing plan is followed. An AoR review is performed at least every five years. FR costs are updated annually.
PISC and site closure (yr)	Cell C46	The default period is 50 years per Class VI regulations. Modeling a shorter time span will lower the breakeven CO_2 price by reducing the number of years costs are incurred for this particular project stage. There is also the possibility that more time may be required in this stage if non-endangerment cannot be established. The monitoring and testing plan for operations can be utilized or modified for PISC and site closure.
Long-term stewardship	N/A	This stage is outside the scope of the Class VI regulations, and it is not modeled. Its timeframe is unknown but could, theoretically, extend over a short interval of geologic time to provide for mineral trapping (NETL, 2014) and other geologic processes. The model provides for collection of money during operations for a long-term stewardship trust fund.

Sub-part 3.2: CO_2 Injection Rate. This sub-part provides the total annual injection rate for a storage project and capacity factor. The total annual injection rate for a storage project (or the nominal average tonnes of CO_2 injected per year) is entered in Cell F50. Revenue for a storage project depends on the total mass of CO_2 injected. There is an economies-of-scale benefit to injecting more tonnes of CO_2. Increasing the annual volume of CO_2 injected will lower the breakeven price but absolute costs will also go up because injecting more CO_2 results in an increased investment in monitoring activities, especially monitoring well drilling and seismic data acquisition. These are two areas where the modeler can model lower costs with fewer wells or different seismic programs. Economies of scale has limits depending on reservoir quality and depth.

The multiplier for annual to maximum daily rate of CO_2 injection (Cell F52) accounts for the capacity factor of the power plant or source and is the inverse of the capacity factor which is entered in Cell F51. When the plant is online, emissions are generated 24/7, which will exceed the average daily rate calculated by dividing the annual volume injected by 365. A plant with an 85 percent capacity factor has a multiplier of 1.18. The average daily injection rate over a year for the project posted is 11,808 tonnes of CO_2. The maximum daily rate is 13,892 tonnes for a plant capturing CO_2 24/7 (see Output table under Part 13.0 in the 'Key_Inputs' sheet). The maximum daily mass flow rate is used by the geology module to calculate the number of injection wells needed for the project.

The calculated total mass of CO_2 injected over the period of operations is posted (Cell F54) in the last line of this data series. This is a simple calculation of average annual mass of CO_2 injected times years of operations and does not reflect any restrictions in CO_2 plume area.

Sub-part 3.3: Set Variable That Controls the Type of Injection Project. This sub-part allows the modeler to select one of two options for the control variable for the injection project type. If the value is set to "0," the specified mass of CO_2 will be injected (this value is the default in the model). If "1" is selected, the mass of CO_2 to fill the maximum possible plume area will be injected. Inputting 1 can result in an unrealistically large mass of CO_2 being injected each year.

Part 4.0: Variables Related to Geology and Reservoir Engineering Calculations. This part allows the user to select several variables related to geologic and reservoir engineering calculations through six sub-parts:

Sub-part 4.1: Variables Used to Determine Basic Geologic Properties. This sub-part allows the modeler to select one of three options for the porosity (Cell E65) and permeability (Cell E71) values to use from the 'Geol DB Sal' worksheet. For both porosity and permeability, if the value is set to "1," the best estimate is used (this value is the default in the model for both parameters). If "2" or "3" is selected, the minimum value or maximum value, respectively, is used.

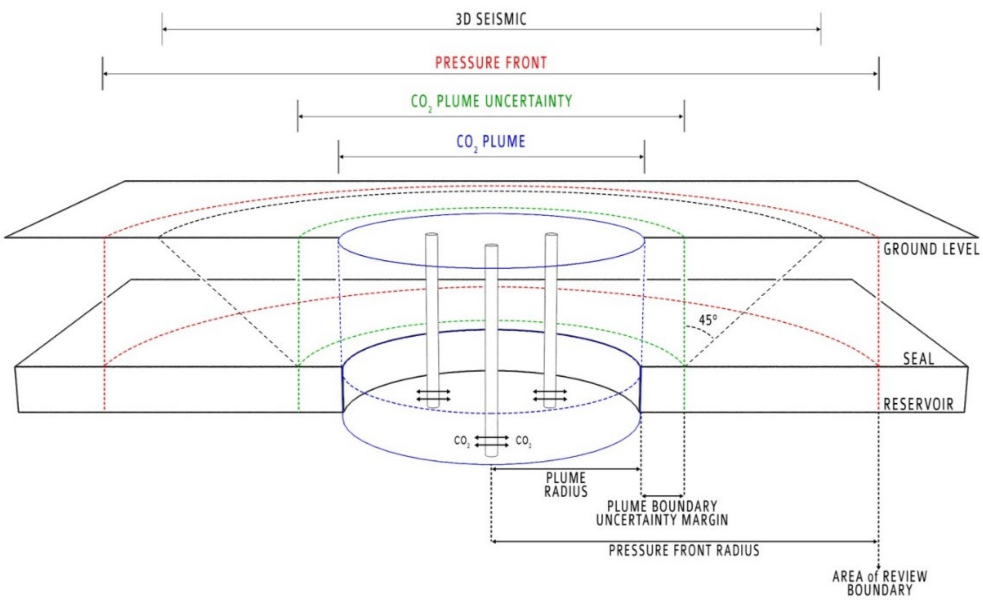
This sub-part also allows the user to provide the fraction of lithostatic pressure that determines the fracture pressure in Cell E77; 70 percent is the default in the model. Typical values are 60 percent on the low end and 80 percent on the high end. The higher this value, the greater the maximum injection pressure and, consequently, the storage formation can sustain higher CO_2 mass injection rates.

Sub-part 4.2: Variables Used to Calculate Relevant Areas and Lengths. Items for calculating CO_2 plume areas, 3-D seismic area, 3-D seismic and 2-D seismic line length, and nominal maximum surface area are provided in this sub-part. With respect to area related inputs, the model has a variable that controls how areas for CO_2 plume area, CO_2 plume uncertainty area, pressure front area, and 3-D seismic area are calculated (Cell E101). The user can select one of two options. If "0" is selected, the areas are based on the mass of CO_2 injected for the project (i.e., all injection wells). If "1" is selected, the areas are based on the mass of CO_2 injected into a single injection formation ("1" is the default value in the model), and the total area is found by multiplying the area for the injection well by the number of injection wells. The area control variable has a significant effect on the 3-D seismic area. The calculated 3-D seismic area based on the CO_2 plume uncertainty area for a single injection well multiplied by the number of injection wells gives a larger 3-D seismic area than the 3-D seismic area based on the CO_2 plume uncertainty area for the mass of CO_2 injected by all the injection wells.

The area is a relatively precise value for a subsurface situation with some level of uncertainty. The exact boundary of the CO_2 plume in the reservoir is unknown. This uncertainty is accounted for by the CO_2 plume uncertainty area multiplier value input by the modeler in Cell F82. This multiplier is applied to the CO_2 plume area.

The boundary defining the pressure front is also unknown and not specifically calculated by the model. The CO_2 pressure front AoR multiplier accounts for the pressure front, and this value is entered in Cell F83. This multiplier is applied to the CO_2 plume uncertainty area. The pressure front will most likely define the AoR per EPA Class VI regulations. This pressure boundary is defined where the elevated reservoir pressure due to injection of CO_2 is sufficient to displace storage formation waters into an overlying underground source of drinking water (USDW). These boundaries are illustrated in Exhibit 2-6.

Exhibit 2-6. Illustration of boundaries calculated by model



Angles that are needed for adequate resolution of 3-D and 2-D seismic images can also be modified by the user in this sub-part. There are three areas that are relevant to various costs (see Exhibit 2-6). The areal extent of the CO_2 plume is an analytical calculation that does not reflect geologic uncertainty. This analytical plume area is modified by an uncertainty factor establishing a CO_2 plume uncertainty area. This CO_2 plume uncertainty area is one of the major cost drivers impacting monitoring, verification, and accounting (MVA) costs, including 3-D seismic data acquisition. For seismic data to properly image the storage formation, its data acquisition occurs over an area extending beyond the estimated uncertainty limits of the CO_2 plume (see Exhibit 2-6). Calculation of the 3-D seismic area is based on the CO_2 plume uncertainty boundary and drives 3-D and 2-D seismic data acquisition cost. The pressure front, a multiple of the CO_2 plume uncertainty boundary, drives monitoring well costs for these wells drilled between the CO_2 plume uncertainty and pressure front boundaries. Depending on the multiplier for the pressure front, the 3-D seismic area may or may not encompass the pressure front. Both the angle from the CO_2 plume uncertainty edge to the surface needed for 3-D seismic (Cell F86) and the angle from the CO_2 plume uncertainty edge to the surface needed for 2-D seismic (Cell F87) are set at 45 degrees in the model. This line from the edge of the CO_2 plume uncertainty boundary within the reservoir is projected to the surface and defines the areal extent (3-D) or linear distance (2-D) needed to properly image the CO_2 plume in the reservoir. The angle of 45 degrees is a representative value that can be changed by the modeler.

To account for surface constraints that might limit the area that a project can cover, the modeler can enter a maximum surface area of the injection project. This value is entered in the 'Key_Inputs' worksheet in Cell F90. This constraint can be applied to one of three areal quantities and the value input in Cell E94 determines which of the three areas to use when applying the constraint. The three areas are: 1) the maximum extent of the CO_2 plume with uncertainty (enter "0" in Cell E94 to pick this option), 2) the maximum extent of the 3-D seismic area (enter "1" in Cell E94 to pick this option), or 3) either the maximum extent of the 3-D seismic area or the maximum extent of the pressure front, whichever is larger (enter "2" in Cell E94 to pick this option). This constraint is meant to account for political or cultural factors at the surface that could limit the size of the storage project rather than geologic constraints in the subsurface. As an example of political or cultural factors, it is likely that a storage project will not inject or have significant plumes under a heavily populated area. To illustrate how the constraint will work, suppose the user indicates the maximum extent of the CO_2 plume with uncertainty cannot exceed 1,000 mi^2. If the maximum extent of the CO_2 plume with uncertainty exceeds 1,000 mi^2, the model will reduce the average annual mass rate of CO_2 injection so that the maximum extent of the CO_2 plume with uncertainty is equal to 1,000 mi^2. This will also reduce the total mass of CO_2 injected. breakeven

Sub-part 4.3: Variables Controlling Which Storage Coefficient is Used and if the Storage Coefficient is Modified. This sub-part allows the user to select the method for calculating the storage coefficient and the multiplier. There are three options the user can select to calculate the storage coefficient. To use the value from the lookup table in Attachment A in the 'Geol Sal' worksheet, the user should select "1" (default in the model). To use a value specified by the user in Sub-part 3.5.2 in the 'Geol Sal' worksheet, the user should select "2." To use the value calculated in Sub-part 3.5.3 in the 'Geol Sal' worksheet, the user should input "3."

The modeler can select whether a multiplier will or will not be applied to the storage coefficient values used in this model and posted in Attachment A of the 'Geol Sal' worksheet. The multipliers for each structural setting are entered in Sub-part 3.5.4 of the 'Geol Sal' worksheet. Entering "0" in the 'Key_Inputs' worksheet Cell D120 means that these multipliers will not be applied. Entering "1" means that the multipliers posted will be applied in the cost analysis. If the multipliers exceed 1, the multipliers will increase the storage coefficient values, increasing the storage capacity for the storage reservoir modeled. This provides a methodology to model the impact of increasing storage capacity for CO_2, for example by water withdrawal.

Sub-part 4.4: Variables Controlling the Prospective Storage Resource Calculation for a Formation-Structure Combination. This sub-part allows the user to determine if pressure interference is included in the prospective storage resource calculation by choosing a "0" to not include pressure interference limitations or a "1" to include in Cell E128 (default in the model).

This sub-part also allows the modeler to adjust the percentage that a particular structural setting is present in a formation as well as the available storage potential per a particular structural setting for the storage formation modeled. Each structural setting represents a percentage of the total areal extent of each storage formation listed in the geologic database. The percentage of a structural setting in a storage formation can be edited by the modeler in cells C135, C136, and C141. Presently, dome and anticline (cells C135 and C136) each represent 1.25 percent of the areal extent for each storage formation listed in the geologic database, which is based on mapping of the Tensleep formation in the Wind River Basin done by the U.S. Geological Survey for their CO_2 storage potential assessment (Brennan, Furruss, Merrill, Freeman, & Ruppert, 2010).The 10 degree and 5 degree dip scenario represent up dip closure against a fault (IEA Greenhouse Gas R&D Programme, October 2009). The storage coefficients for these two structural settings differ little from the flat structural setting. The storage coefficient for a regional dip structural setting is an average of 10 degree incline, 5 degree incline, and flat structural settings. The values in cells C137 and C138 are determined by the values in cells C135 and C136. The values in cells C139 and C140 depends on the value selected for the control variable for structures in Cell C26 and the values in cells C135 to C138. If the user selects the general structural setting by setting the control variable for structures in cell C26 to "1," then the model assumes the storage coefficient for the general structural setting applies to 100 percent of the storage formation.

The modeler can restrict the volume of a storage formation available for storage in this sub-part by entering a percent available value in cells D135–D141. It is assumed that portions of each storage formation are unlikely to have storage projects implemented or have significant CO_2 plumes or pressure fronts under the surface. Examples are urbanized areas or any area which is densely populated. A value less than 100 percent for the percent of the area available for storage restricts the volume of prospective storage resource available for an injection project. The prospective storage resource calculated by this model represents a resource estimate that has yet to be proved. The prospective storage resource for any particular storge formation within a specific geologic formation will become actual storage capacity as storage projects are implemented and CO_2 is injected.

Sub-part 4.5: Method Used to Calculate Maximum Injection Rate for a Well That Storage Formation Can Sustain. One of seven methods for calculating the maximum injection rate for a well that the storage formation can sustain is selected by the user in this sub-part (Cell E151). The user's selection is pulled into Part 5.0 in the 'Geol Sal' sheet to calculate items. Selecting "1," "2," "3," "4," "5," "6", or "7" will implement methods of Law and Bachu, Advanced Resources International, Inc. (ARI), Cinar et al. (Cinar, Bukhteeva, Neal, Allinson, & Paterson, 2008), or Valluri et al. (Valluri, Mishra, & Ganesh, 2021). Both Law and Bachu and ARI are reported by the Carbon Capture and Sequestration Technologies Program (CCSTP) (CCSTP, 2009). The default in the model is "7" using the algorithms developed by Valluri et al. which are based on results from CO_2 injection projects. The algorithms in this sub-part calculate the maximum CO_2 injection rate for a single injection well that the geology of the storage formation can sustain without developing pressures that exceed 90 percent of the fracture pressure.

Sub-part 4.6: Maximum Injection Rate for a Well Based on Well Mechanics. The maximum mass rate of CO_2 injection in a single injection well that the well mechanics can sustain is set in this sub-part. The maximum flow based on well mechanics refers to the maximum flow in the well tube based on the pressure difference between the top and bottom of the well and the frictional losses in the tubing. The maximum CO_2 injection rate per well based on well mechanics is entered in Cell E163. This maximum daily rate of injection is multiplied by 365 days and accounts for 24/7 capture at the source discussed earlier; this value is posted in Cell E164 in million tonnes per year. The default maximum mass injection rate per well based on well mechanics is 3,660 tonnes/day.

The maximum mass injection rate per injection well is either 1) the maximum mass injection rate the formation can sustain or 2) the maximum mass injection rate per well based on well mechanics, whichever is smaller. The maximum mass injection rate per injection well and the maximum daily mass of CO_2 injected by the storage project are used to calculate the number of active injection wells needed. The number of injection wells needed for the storage formation modeled is posted in the Output table under Part 9.0.

Part 5.0: Site Screening and Characterization. This part provides inputs on aspects of site screening and characterization. Exhibit 2-7 provides descriptions of the input information included in this part.

Exhibit 2-7. Detail on inputs for site screening and characterization strat well and seismic aspects

Parameter	Location in 'Key_Inputs' Sheet	Note
Number of sites for intensive screening (sites)	Cell N5	This value illustrates some level of risk in selecting a successful CO_2 storage site. A default value of "1" means that over the period selected for site selection and site characterization, one site will be characterized at some level of geologic analysis. It is assumed in the model that each site initially receives equal analysis and that the last site characterized is successful. Each site characterized has one strat well drilled that provides an opportunity to gather fresh data with modern technology. In the model, this well is drilled 500 ft deeper than the injection well.
Number of 2-D seismic lines for intensive screening (lines)	Cell N6	A default value of "2" is provided in the model, so each site characterized will have a strat well drilled and acquisition of 2-D seismic data.
Number of strat wells on successful site (wells)	Cell N7	For the successfully characterized site, a default value of "1" means that one well is drilled. The strat well provides modern data on the stratigraphic section present in the area of the proposed CO_2 storage site. The successfully characterized site will also have 3-D seismic data acquired over its areal extent. Selection of 3-D seismic parameters can be done under Part 11.0 in the 'Key_Inputs' worksheet as well as in Part 3.7 in the 'Activity_Inputs' worksheet.

Parameter	Location in 'Key_Inputs' Sheet	Note
Strat wells converted to injection wells (wells)	Cell N10	Once drilled, the strat well must be plugged and abandoned unless it is converted for other use. The model allows the user to convert a strat well to a CO_2 injection well by entering the number of strat test wells to convert; a default of "0" is provided in the model.
Strat wells converted to deep above seal, in reservoir, or dual completed monitoring wells in CO_2 plume uncertainty area (wells)	Cells N11–N13	Once drilled, the strat well must be plugged and abandoned unless it is converted for other use. The model allows the user to convert a strat well to a monitoring well (either above seal, in reservoir, or dual completed) by entering the number of strat test wells to convert for each well within the CO_2 plume uncertainty area. A default of "0" is provided for all monitoring wells, except a default of "1" is provided for converting a strat test well to a dual completed monitoring well in the CO_2 plume uncertainty (Cell N13).

Part 6.0: Corrective Action Inputs and Calculated Results. This part allows the user to provide the density of deep legacy wells needing correction action (Cell N18), which is applied to the maximum extent of the pressure front area to determine the number of legacy wells requiring corrective action. Corrective action involves plugging and abandoning legacy wells that penetrate the caprock. These can either be wells that were not properly plugged and abandoned or wells with incomplete historical records regarding how they were plugged and abandoned. Corrective action is assumed to occur during operations and is assumed to begin in the first year of operations. The user can specify the percentage of the operations stage that is used for corrective action in Cell N19. If Cell N19 is set to "0" (i.e., 0 percent of operations), all corrective action occurs in the first year of operations. The total number of wells needing corrective action and the number of wells undergoing correction action annually are pulled in from Sub-part 2.13 in the 'Activity_Inputs' sheet and shown in Cell N20 and Cell N21, respectively.

Part 7.0: Water Production. The user selects if water management will be used in this part. If "ON" is selected, details are incorporated on the 'Water' worksheet. See Section 5.3 for further information.

Part 8.0: Monitoring Wells: Numbers and Timing of Installation. This part allows the user to select the method for calculating well counts in deep monitoring wells (above seal, in reservoir, dual completion), groundwater monitoring wells, and vadose zone monitoring wells, well spacing, and the timing of installation during construction and operations through three sub-parts which are discussed below. The majority of this part is inputs, but there are values pulled from the 'Plume&Well Schedule' sheet on the number of monitoring wells drilled for Sub-part 8.1.

Sub-part 8.1: Deep Monitoring Wells. This sub-part provides inputs for determining the well count and installation schedule for above seal, in reservoir, and dual completed monitoring wells in both the CO_2 plume uncertainty area and pressure front area outside of the CO_2 plume uncertainty area. Above seal monitoring wells are drilled to just above the seal or caprock formation, total depth based on the top of reservoir formation in the database (see 'Geo-Activity Interaction' sheet) less 200 ft thickness for the seal formation. In reservoir wells are drilled into and completed in the storage formation, providing direct sampling of conditions in the storage formation. In the model, in reservoir wells are drilled halfway through the storage formation. Dual completed monitoring wells are the same length as in reservoir monitoring wells. Dual completed monitoring wells are perforated in the storage formation and also in the formation above the seal or caprock. These monitoring wells monitor conditions in the formation above the seal and conditions within the storage formation. Monitoring well-related inputs can drive costs significantly, especially for lower quality reservoirs with large plume area. The more wells drilled (e.g., smaller well spacing), the higher the capital and O&M costs for deep monitoring wells. In their economic modeling analysis of the Class VI regulations, EPA identified the opportunity to use dual completed monitoring wells to reduce drilling costs (EPA, 2010).

For each type of deep monitoring well, the data needed to determine the number of wells and the schedule for their installation is the same for wells in the "In CO_2 Plume Uncertainty Area". Similarly, the data needed to determine the number of wells and the schedule for their installation is the same for wells in the "In Pressure Front Area outside CO_2 Plume Uncertainty Area". The schedule for the installation and operation of these wells is provided in the 'Plume&Well Schedule' worksheet. Because the data needed for each type of deep monitoring well is the same in the two different parts of the CO_2 plume uncertainty area, a discussion on each input is provided below using above seal monitoring wells as an example and can be seen in Exhibit 2-8.

In CO_2 Plume Uncertainty Area

Because the data needed for each type of deep monitoring well is the same in the portion of the reservoir labeled "In CO_2 Plume Uncertainty Area", the data needs are presented in this text for the deep above seal monitoring wells as an example, but the data needs are the same for the other two types of deep monitoring wells.

- Method used for well count (Cell N35): Four options are provided to determine the well count. If the user selects "1," it indicates the monitoring well count is proportional to the number of injection wells. Selecting "2" indicates the monitoring well count is proportional to the CO_2 plume uncertainty area. Selecting "3" indicates the monitoring well count is fixed. A "0" or any other number indicates no above seal monitoring wells are installed.
- Monitoring wells per injection well (well/injection well) (Cell N36): The user can provide the number of above seal monitoring wells per injection well. This value is used if Cell N35 is set to "1."
- Monitoring wells per unit CO_2 plume uncertainty area (well/mi^2) (Cell N37): The modeler can give the ratio of above seal monitoring wells to plume uncertainty area. This value is used if Cell N35 is set to "2."
- Fixed number of monitoring wells (Cell N38): This is the fixed number of monitoring wells used for all storage formations if Cell N35 is set to "3."

- Maximum number of monitoring wells (Cell N39): The modeler can place an upper bound on the number of above seal monitoring wells drilled. If the user does not wish to place a maximum value on the number of monitoring wells, a large number such as "9999," should be entered.
- Percent of monitoring wells installed in last year of construction (%) (Cell N40): If the user wishes some wells to be installed in the last year of construction and the remainder installed during operations, the user can specify the percent to be installed during the last year of construction. A value of 100 percent indicates that all the monitoring wells are installed during the last year of construction.
- Percent of operations stage used to install wells (%) (Cell N41): The value in Cell N41 is used if the user specifies a percentage less than 100 percentage in Cell N40. Cell N41 specifies the percentage of the operations stage used to install monitoring wells that were not installed in the last year of construction. A value of 50 percent indicates the first half of operations is used to install the remaining monitoring wells. A value of 0 percent indicates all the remaining monitoring wells are installed in the first year of operations.

In Pressure Front Area Outside CO_2 Plume Uncertainty Area

Because the data needed for each type of deep monitoring well is the same in the portion of the reservoir labeled "In Pressure Front Area outside CO_2 Plume Uncertainty Area", the data needs are presented in this text for the deep above seal monitoring wells as an example, but the data needs are the same for the other two types of deep monitoring wells.

There is one option for specifying the number of deep monitoring wells installed in the "Pressure Front Area outside CO_2 Plume Uncertainty Area." The user must specify a fixed number of wells which is applied to all the storage formations. This is typically a small number such as 0 or 1.

- Fixed number of monitoring wells (Cell N44): As noted above, this is the only option for specifying the number of deep above seal monitoring wells in the "Pressure Front Area outside CO_2 Plume Uncertainty Area." If the user enters "0," there are no deep above seal monitoring wells.
- Maximum number of monitoring wells (Cell N45): The modeler can place an upper bound on the number of above seal monitoring wells drilled. The value entered in this cell is only used if it is less than the fixed number of wells entered in Cell N44.
- Percent of monitoring wells installed in last year of construction (%) (Cell N46): If the user wishes some deep above seal wells to be installed in the last year of construction and the remainder installed during operations, the user can specify the percent to be installed during the last year of construction. A value of 100 percent indicates that all the monitoring wells are installed during the last year of construction.
- Percent of operations stage used to install wells (%) (Cell N47): The value in Cell N47 is used if the user specifies a percentage less than 100 percent in Cell N46. Cell N47

specifies the percentage of the operations stage used to install monitoring wells that were not installed in the last year of construction. A value of 50 percent indicates the first half of operations is used to install the remaining monitoring wells. A value of 0 percent indicates all the remaining monitoring wells are installed in the first year of operations.

Exhibit 2-8. Deep monitoring wells method, spacing, and installation

	J	K	L	M	N
30	**8.0 Monitoring Wells: Numbers and Timing of Installation**				
31	**8.1 Deep Monitoring Wells**				
32	**Item**			**Units**	**Value**
33	**Deep Above-Seal Monitoring Wells**				
34	**In CO2 Plume Uncertainty Area**				
35	Method used for well count (1, 2, 3, or 0, see note below for meaning)				0
36	Monitoring wells per injection well			well/inj well	0
37	Monitoring wells per unit CO2 plume uncertainty area			well/mi2	0.25
38	Fixed number of monitoring wells				0
39	Maximum number of monitoring wells				9999
40	Percent of monitoring wells installed in last year of construction				50.0%
41	Percent of operations stage used to install wells				50.0%
42	*Number of monitoring wells drilled*			# Drilled/Comp.	0
43	**In Pressure Front Area outside CO2 Plume Uncertainty Area**				
44	Fixed number of monitoring wells				0
45	Maximum number of monitoring wells				9999
46	Percent of monitoring wells installed in last year of construction				0.0%
47	Percent of operations stage used to install wells				50.0%
48	*Number of monitoring wells drilled*			# Drilled/Comp.	0
49	**Deep In-Reservoir Monitoring Wells**				
50	**In CO2 Plume Uncertainty Area**				
51	Method used for well count (1, 2, 3, or 0, see note below for meaning)				0
52	Monitoring wells per injection well			well/inj well	0
53	Monitoring wells per unit CO2 plume uncertainty area			well/mi2	0.25
54	Fixed number of monitoring wells				0
55	Maximum number of monitoring wells				9999
56	Percent of monitoring wells installed in last year of construction				50.0%
57	Percent of operations stage used to install wells				50.0%
58	*Number of monitoring wells drilled*			# Drilled/Comp.	0
59	**In Pressure Front Area outside CO2 Plume Uncertainty Area**				
60	Fixed number of monitoring wells				0
61	Maximum number of monitoring wells				9999
62	Percent of monitoring wells installed in last year of construction				0.0%
63	Percent of operations stage used to install wells				50.0%
64	*Number of monitoring wells drilled*			# Drilled/Comp.	0
65	**Deep Dual Completed Monitoring Wells**				
66	**In CO2 Plume Uncertainty Area**				
67	Method used for well count (1, 2, 3, or 0, see note below for meaning)				1
68	Monitoring wells per injection well			well/inj well	1
69	Monitoring wells per unit CO2 plume uncertainty area			well/mi2	0.25
70	Fixed number of monitoring wells				0
71	Maximum number of monitoring wells				20
72	Percent of monitoring wells installed in last year of construction				100.0%
73	Percent of operations stage used to install wells				0.0%
74	*Number of monitoring wells drilled*			# Drilled/Comp.	4
75	**In Pressure Front Area outside CO2 Plume Uncertainty Area**				
76	Fixed number of monitoring wells				0
77	Maximum number of monitoring wells				9999
78	Percent of monitoring wells installed in last year of construction				0.0%
79	Percent of operations stage used to install wells				50.0%
80	*Number of monitoring wells drilled*			# Drilled/Comp.	0
81	Note on "Method used for well count". There are 4 options as follows:				
82	1 indicates the monitoring well count is proportional to the number of injection wells				
83	2 indicates the monitoring well count is proportional to the CO2 Plume Uncertainty Area				
84	3 indicates the monitoring well count is a fixed number				
85	0 or anything other than 1, 2, or 3 indicates the monitoring well count is zero (no monitoring wells of this type)				

Sub-part 8.2: Groundwater Monitoring Wells. This sub-part provides inputs for determining the well count and installation schedule for groundwater monitoring wells. Groundwater monitoring wells are wells that monitor conditions in aquifers near the ground surface.

These are typically very low salinity aquifers that are most frequently used as actual sources of drinking water. In the model, these wells monitor conditions in the upper 500 ft although this number can be changed by the user. The schedule for the installation and operation of these wells is provided in the 'Plume&Well Schedule' worksheet. A discussion on each input is provided below and can be seen in Exhibit 2-9:

- Method used for well count (Cell N88): Three options are provided to determine well count. If the user selects "1," it indicates the monitoring well count is proportional to the number of injection wells. Selecting "2" indicates the monitoring well count is fixed. A "0" or any other number indicates no groundwater monitoring wells.
- Monitoring wells per injection well (well/injection well) (Cell N89): The user can provide the number of groundwater monitoring wells per injection well. This value is used if a "1" is entered in Cell N88.
- Fixed number of monitoring wells (Cell N90): The user can enter a fixed number of groundwater monitoring wells which is the same number in all storage formations. This value is used if a "2" is entered in Cell N88.
- Maximum number of monitoring wells (wells) (Cell N91): The modeler can place an upper bound on the number of groundwater monitoring wells drilled. If the user does not wish to place a maximum value on the number of monitoring wells, a large number such as "9999," should be entered.
- Percent of monitoring wells installed in last year of construction (%) (Cell N92): If the user wishes some groundwater wells to be installed in the last year of construction and the remainder installed during operations, the user can specify the percent to be installed during the last year of construction. A value of 100 percent indicates that all the monitoring wells are installed during the last year of construction.
- Percent of operations stage used to install wells (%) (Cell N93): The value in Cell N93 is used if the user specifies a percentage less than 100 percent in Cell N92. Cell N93 specifies the percentage of the operations stage used to install monitoring wells that were not installed in the last year of construction. A value of 50 percent indicates the first half of operations is used to install the remaining monitoring wells. A value of 0 percent indicates all the remaining monitoring wells are installed in the first year of operations.

Exhibit 2-9. Groundwater monitoring wells method, spacing, and installation

	I	J	K	L	M	N
86		**8.2 Groundwater Monitoring Wells**				
87		**Item**			**Units**	**Value**
88		Method used for well count (1, 2, or 0, see note below for meaning)				1
89		Monitoring wells per injection well			well/inj well	1
90		Fixed number of monitoring wells				10
91		Maximum number of monitoring wells				9999
92		Percent of monitoring wells installed in last year of construction				100.0%
93		Percent of operations stage used to install wells				0.0%
94		Note on "Method used for well count". There are 3 options as follows:				
95		1 indicates the monitoring well count is proportional to the number of injection wells				
96		2 indicates the monitoring well count is a fixed number				
97		0 or anything other than 1 or 2 indicates the monitoring well count is zero (no monitoring wells of this type)				

- ***Sub-part 8.3: Vadose Zone Monitoring Wells.*** Inputs for determining the well count and installation schedule for vadose zone monitoring wells is provided in this sub-part. Vadose zone wells are installed in the unsaturated zone and monitor conditions in soil gas. In the model, these wells monitor conditions in the upper 10 ft although this number can be changed by the user. The schedule for the installation and operation of these wells is provided in the 'Plume&Well Schedule' worksheet. The inputs for the vadose zone monitoring wells can be seen in Exhibit 2-10 and mirror the inputs for groundwater monitoring wells. Therefore, the inputs for the vadose zone monitoring wells are not discussed in detail. The user should review the discussion above for the inputs for the groundwater monitoring wells.

Exhibit 2-10. Vadose zone monitoring wells method, spacing, and installation

	I	J	K	L	M	N
98		**8.3 Vadose Zone Monitoring Wells**				
99		**Item**			**Units**	**Value**
100		Method used for well count (1, 2, or 0, see note below for meaning)				0
101		Monitoring wells per injection well			well/inj well	1
102		Fixed number of monitoring wells				0
103		Maximum number of monitoring wells				9999
104		Percent of monitoring wells installed in last year of construction				100.0%
105		Percent of operations stage used to install wells				0.0%
106		Note on "Method used for well count". There are 3 options as follows:				
107		1 indicates the monitoring well count is proportional to the number of injection wells				
108		2 indicates the monitoring well count is a fixed number				
109		0 or anything other than 1 or 2 indicates the monitoring well count is zero (no monitoring wells of this type)				

Part 9.0: Atmospheric Monitoring. User input for eddy covariance towers, which provide near-surface atmospheric monitoring, is provided in this part. Eddy covariance towers represent emerging technology and are expensive. The user can incorporate the number of eddy covariance towers to use in their storage project in Cell N113 (default is "0"). Further information on eddy covariance towers and other atmospheric monitoring technology available in this cost model can be found in Sub-part 3.12 in the 'Activity_Inputs' worksheet.

Output: Total Number of Wells Installed and Check on Well Spacing. This table provides a reference on the total number of wells installed for stratigraphic, injection, deep monitoring (above seal, in reservoir, dual completed), groundwater monitoring, vadose zone monitoring, water (brine) production wells, and water (brine) disposal wells. Stratigraphic test wells information is pulled from information within the 'Key_Inputs' sheet, while results for the injection, monitoring, and water production and disposal wells are pulled from either the 'Geo-Activity Interactions' or 'Plume&Well Schedule' sheets. The well spacing measure in this table provides a calculated value of the well spacing for monitoring wells based on the CO_2 plume uncertainty boundary.

Part 10.0: Surface Equipment Inputs for Calculating Capital and O&M Costs. This part includes data inputs for surface equipment. The storage site may include a feeder pipeline, which is a pipeline that begins either at a CO_2 source or at a trunkline and ends at the gate for the storage site. At the gate, it is assumed that the feeder pipeline connects to a high-quality flow meter that measures the mass rate of flow of CO_2 coming into the storage site. The CO_2 may subsequently flow through distribution pipelines to the injection wells. If there is one injection well, the meter may be located at the injection well and there may be no distribution pipeline. If there is more than one injection well, then the CO_2 will exit the meter to a header which distributes the mass of CO_2 to the different injection wells through distribution pipelines. A booster pump may be needed to boost the pressure of the CO_2 coming onto the site. The CO_2 is assumed to be delivered to the feeder pipeline and then the site as a liquid, so a booster pump rather than a compressor is used to increase the pressure of the CO_2 fluid.

There is one input for the feeder pipeline, whether or not the cost for a feeder pipeline should be included as part of the cost of the storage project. The user can include this cost by selecting "Yes" in Cell T5 or exclude this cost by selecting "No." Cell T6 provides the length of the feeder pipeline if the user chooses to include this pipeline in the cost of the storage project which is assumed to be equal to half the diameter of the calculated CO_2 plume area.

As noted above, a booster pump may be necessary for the storage site if the pressure of the CO_2 delivered to the storage site is not sufficient to transport the CO_2 to the injection wells and provide the pressure needed to inject the CO_2 into the storage formation. If the user wishes to include the cost of a booster pump, then the user should enter "yes" in Cell T9. Otherwise, the user should enter "no" in Cell T9. If the user enter "yes" in Cell T9, then the user should also enter the pressure at the inlet of the pump (Cell T10) and the outlet of the pump (Cell T11).

If there are distribution pipelines that transport the CO_2 from the header to injection wells, then the user needs to enter a multiplier in Cell T14. The multiplier is used with the radius of the CO_2 plume to calculate the length of each distribution pipeline. If there are no distribution pipelines, the user should enter "0" for the multiplier.

The data provided in this part is utilized in the 'Surf Eq Cost' worksheet, part of the activity cost module.

Part 11.0: 3-D Seismic Inputs for Calculating Capital Costs. This part provides inputs for estimating the cost and schedule of 3-D seismic data acquisition and processing, a significant expense for a CO_2 storage project. Updates made to this part (light orange cells) are automatically reflected in Sub-part 3.7 in the 'Activity_Inputs' worksheet.

Regarding 3-D seismic survey costs, this part includes a basic cost for a survey and an additional cost for processing field data. Cost may vary due to factors such as the adoption of different technology, improvements in existing technology, or enhanced field logistics such as favorable terrain in open prairie or farmland. The modeler can adjust these values if more accurate cost data becomes available. The additional cost for processing field data is expressed as a percentage of the acquisition cost to account for data processing expenses.

The modeler can also define 3-D seismic survey schedules for each project stage. Begin years, end years, and recurring intervals can be specified in the light orange cells to update the schedule and calculate the total occurrences per stage, displayed in the blue cells. If the default schedules are acceptable, the modeler can leave "0" in the light orange cells. The recurring period (every x years) cells represent the frequency within each stage. For instance, entering "2" specifies that a 3-D seismic survey should be conducted every two years. The model will calculate total occurrences per stage based on the specified begin and end years.

Part 12.0: Methodology for Calculating Well Drilling and Completion Costs. In this section, the modeler selects one of three methods for calculating well drilling and completion costs in the

'Drilling Cost' worksheet. Updates are reflected in the 'Activity_Inputs' sheet under Sub-part 4.2. Selecting "1" or "2" applies regression equations per American Petroleum Institute (API)-Joint Association Survey (JAS) 2006 data or API-JAS 2014 data, respectively (API, 2006) (API, 2014). If "3" is selected, the model uses a liner equation based on well length with parameters from industry. By default, the model uses Method "2." It is recommended to avoid using Method "1" as it tends to produce inconsistent cost estimates. For more details on the methodologies, refer to Section 4.4.

Part 13.0: Fees Paid by Storage Project Operator. This part outlines the various fees associated with CO_2 storage operations, as specified in the model.

- **Lease Bonus:** The lease bonus is applied to the 3-D seismic area during site characterization. In oil and gas leasing, this fee is the amount paid to secure a lease from the landowner holding mineral rights. In the model, securing a lease also includes obtaining pore space rights and surface access for drilling wells and installing associated equipment and facilities.
- **Injection Fee:** The injection fee is paid to a lessor for each tonne of captured CO_2 injected, similar to a royalty payment in oil and gas operations.
- **Long-Term Stewardship Trust Fund:** This fee is paid by per tonne of captured CO_2 injected to fund long-term stewardship activities. Several states have established long-term stewardship trust funds, with varying fee structures and, in some cases, maximum caps.
- **Operational Oversight Fund**: This fee, set at a default value of $0.01/tonne in the model, may be charged by states to cover the regulatory oversight costs for CO_2 injection activities.

Output: Rate of CO_2 Injection, CO_2 Plume Area, Other Areas, and Masses of CO_2 injected. This table displays calculated values for the average injection rate, CO_2 plume area, and related parameters. The values are organized into two columns: "Nominal" (based on user inputs and calculations without plume restrictions) and "Actual" (adjusted values applied in the cost model). If the "Actual" values match the "Nominal" values, it indicates that the plume uncertainty area, determined by the modeled CO_2 injection rate, falls within the "Nominal Maximum Surface Area for Injection Project," a parameter that can be adjusted by the modeler.

The table also contains lengths, ratios, and areas tied to the actual or nominal plume sizes. Its purpose is to offer a quick reference for evaluating how plume uncertainty area restrictions affect injection rates and associated costs for the storage project.

Additionally, the table provides both actual and nominal values for the CO_2 injection project:

- **Tonnes of CO_2 Injected per day on average:** Represents the average daily rate of injection based on the annual mass of CO_2 delivered to the storage site.
- **Maximum daily rate of CO_2 injection:** Accounts for continuous 24/7 CO_2 capture operations.

- **Total tonnes of CO_2 Injected**: If the plume uncertainty area is restricted, the total mass of CO_2 injected will be lower than the modeled total mass, reducing the daily injection rate accordingly.

Output: Calculated Quantities for Formation and Structure Where CO_2 is Injected. This part provides a snapshot of the calculated maximum prospective CO_2 source resource in formation-structure combination with and without availability constraint and other factors based on the maximum number of injection projects. The maximum number of projects that can be implemented in both these settings is also provided. Values are pulled from the 'Geol Sal' worksheet.

Part 14.0: Inputs and Calculations Related to Financial Module. This part allows the modeler to edit inputs related to the financial module (see Section 1.1.2.2 and Section 3), which takes tax, debt, and equity-required returns into consideration to calculate a breakeven price. This part is broken down into two sub-parts. Sub-part 14.1 provides the financial variables. It also allows the user to select base and project start years for costs (cells AC7 and AC8, respectively). Sub-part 14.2 contains a lookup table that provides a regional escalation rate based on the state where the storage formation is located if that option is chosen by the user in Cell AC15. A brief description for each entry in Sub-part 14.1 is given in Exhibit 2-11.

Exhibit 2-11. Financial inputs in 'Key_Inputs' sheet

Financial Parameter	Location in 'Key_Inputs' Sheet	Note
Percent equity (remainder is debt) (%)	Cell AC10	Debt/equity ratio will depend on the type of business operating the CO_2 storage facility. A 55/45 debt/equity ratio reflects a high-risk investor-owned utility (Theis, February 2021). An oil field service company, a pipeline company, or other large company may have different debt/equity ratios. See Appendix: Rationale Behind Key Financial Parameters
Cost of equity (%/yr)	Cell AC11	The default cost of equity in the model is 13.30% for a nominal dollar analysis or 10.77% for a real dollar analysis. A cost of equity of 13.30% (nominal dollar) or 10.77% (real dollar) reflects the average return on equity for natural gas storage and transportation companies per the CAPM method. The lower the use of equity to finance a CO_2 storage project, the lower the breakeven price as long as the cost of debt (interest rate of project debt) is lower than the cost of equity. See Appendix: Rationale Behind Key Financial Parameters
Cost of debt (%/yr)	Cell AC12	The 6.30% value entered reflects an investor-owned utility business scenario; this value is London Interbank Offered Rate plus a few percentage points. A 6.30% interest rate on debt is the default for a nominal dollar analysis, and a 3.91% value is the default for a real dollar analysis. See Appendix: Rationale Behind Key Financial Parameters
Tax rate (%/yr)	Cell AC13	The 25.74% value entered covers corporate federal and state tax rates. Research into any variation in state tax rates was not done. If the modeler knows of lower applicable tax rates, then the breakeven price of storage can be reduced some amount.

Financial Parameter	Location in 'Key_Inputs' Sheet	Note
		See Appendix: Rationale Behind Key Financial Parameters
Variable indicating which escalation rate to use from base year to first year of project	Cell AC15	The 0 value entered indicates that the escalation rate for lower 48 states is used (Cell AC21 in the 'Key_Inputs' sheet). Other options for escalation rate include 1 for region (state) or 2 for user input. See Appendix: Rationale Behind Key Financial Parameters
Variable indicating which set of escalation rates to use from base year to first year of project	Cell AC16	The 2 value indicates that the set of escalation rate to use is based on Handy Whitman cost indices from 2008 (overall) to January 1, 2023, which is determined from the lookup table in Sub-part 14.2. The escalation rate to use is posted in Cell AC22 in the 'Key_Inputs' sheet. Other options for escalation rate sets are 1 for Handy Whitman cost indices from 2008 (overall) to 2018 (overall), 3 for user input in the lookup table for Sub-part 14.2, and any other number for Handy Whitman cost indices from 2008 (overall) to January 1, 2023. See Appendix: Rationale Behind Key Financial Parameters
Escalation rate input by user to use from base year to first year of project (%/yr)	Cell AC23	The 3.0% value is the default in the model but can be changed by the user. This value is used if "2" is selected in Cell AC15 of the 'Key_Inputs' sheet. See Appendix: Rationale Behind Key Financial Parameters
Escalation (inflation) rate from start of project onward(%/yr)	Cell AC24	The 2.3% value entered applies to all costs posted in the 'Back-End_Cost Items' worksheet to calculate nominal values. This rate of escalation also applies to all revenues. The first-year breakeven price to store a tonne of CO_2 is escalated at this rate over the life of the project. A 0% value is entered as the default to calculate a real dollar analysis. See Appendix: Rationale Behind Key Financial Parameters
General and administrative factor (%)	Cell AC25	This value (20% default in the model) accounts for under estimation of general and administrative costs.
Site selection and site characterization failure contingency (%)	Cell AC26	This factor is included in EPA's economic analysis to account for risk associated with successfully selecting a potential storage site that will survive site characterization and be submitted for Class VI permit (EPA, 2010). Zero was entered because another method was adopted to model site characterization risk.
Process contingency factor (%)	Cell AC27	This value is to account for underestimation of the cost of installing the technology with subsequent successful trouble-free operation. This cost is assessed on all monitoring technology items. A 20% default is in the model.
Project contingency factor (%)	Cell AC28	This factor is to account for under estimation of costs to successfully complete the project. This cost is assessed on all capital costs. A 15% default is in the model.

2.2 'FIN_RESP_INPUTS' WORKSHEET

FR is a requirement in EPA's Class VI regulations [40 Code of Federal Regulations (CFR) §146.85]; therefore, owners or operators will need to demonstrate FR upon application for a Class VI permit [40 CFR §146.82(a) (14)]. The owner or operator of a Class VI injection project must provide assurance, through one or a combination of several financial instruments, that the costs of covered activities are provided for should the operator fail to complete these activities. These covered activities are corrective action, injection well plugging, emergency and remedial response (ERR), and PISC and site closure. Each covered area is the subject of a detailed plan submitted upon application for a Class VI permit [40 CFR 146.82]. The AoR and corrective action plan identifies defective old wellbores within the AoR that will require remediation to prevent leakage of CO_2. The number of old wells requiring corrective action is established by this plan; however, this does not rule out the possibility of an unknown well making its presence known once reservoir pressure is elevated due to injection. The PISC and site closure plan details what the operator will do post-injection to monitor the CO_2 plume and eventually establish non-endangerment upon which the site can be closed. When non-endangerment will be established post-injection can be modeled but is not fully known before injection begins. The injection well plugging plan is self-defined and the number of injections wells drilled is known. The ERR defines the areas of risk for a storage project, their probability of occurrence, and associated cost. ERR events are planned for in hopes that they will not occur; they are predictions.

Once approved, FR instruments are reviewed every year by the operator to assure EPA that sufficient funds will be available if the need arises. This review by the operator includes any adjustments made to the current dollar costs for corrective action, injection well plugging, ERR, and PISC and site closure as well as adjustments for inflation. Also, any adjustments made must be reported within 60 days [40 CFR §146.85]. Prior to approval of the FR instruments, the operator may be required to provide information related to the financial stability of the third-party institutions and their ability to back the financial instruments issued. All these requirements and activities are assumed to be successfully performed in the scenario modeled. With respect to FR and the covered activities, the scenario modeled assumes successful operations with no emergencies or failed efforts on the part of the operator.

Financial instruments recognized in the regulations for FR are self-insurance (corporate guarantee), trust fund, escrow account, insurance, surety bond, and letter of credit (LoC). These plans are used to establish the coverage needed for FR. The 'Fin_Resp_Inputs' worksheet is the primary sheet to model selection of FR instruments. To account for FR in the model, the 'FinMod FR Details' worksheet and parts of the 'FinMod_Main' worksheet, both in the financial module, include parts used to assess the impact of using the selected financial instrument, based on input from the 'Fin_Resp_Inputs' worksheet. These worksheets also have ties to the 'Back-End_Cost Items' worksheet.

For FR, the user must choose which instrument to use. On the 'Fin_Resp_Inputs' worksheet, the modeler can select the preferred instrument from a drop-down box in Cell A3, for corrective action and Cell A20 for injection well plugging. Both drop-down lists include all financial instrument options that are programmed into the model. The text next to the instrument selection provides some details of the instrument selected. For PISC and site closure, the instrument options are limited to trust fund, escrow account, and self-insurance because these are the instruments that are most likely to cover the risk associated with PISC and site closure due to number of years and magnitude of cost of this project stage. Selection of financial instrument for PISC and site closure is done in Cell A37.

Other modeler inputs refer to details related to the FR instruments and start in Column K of this worksheet. These are tied to the more detailed information in the financial module. The modeler only needs to make choices for the instrument or instruments selected, for which the input cells will be light orange. The 'FR_Lookups' sheet provides information on potential inputs to include for these options (see Section 3.3). The inputs within cells L5–L8 apply to all financial instruments, so they will be relevant regardless of which instrument is chosen. The project year in which the instrument is purchased is entered by the modeler in Cell L5, unless self-insurance is selected for all three activities then cells L5, L7, and L8 will be grayed out. The project year for which the instrument is purchased will be the first year of permitting and construction since FR is to be demonstrated upon application for a Class VI permit. This project year number is used along with the calendar start year from the 'Key_Inputs' sheet to calculate the calendar year posted in Cell L7 in which the financial instrument is purchased. The year in which the stream of engineering costs was estimated should match the dollar year of cost inputs. Cell L6 is linked to Cell AC7 in the 'Key_Inputs' sheet based on modeler input within that sheet for the base year. The annual inflation rate is also used regardless of which instrument is selected. This inflation value is also used to inflate the costs in the model, even in parts of the model not related to FR. The parameters that are relevant only to one instrument are also listed in this part of the 'Fin_Resp_Inputs' input sheet. These parameters are discussed in the sub-sections below. Additional details of each FR instrument are listed in the 'FinMod FR Details' worksheet.

ERR is covered by an insurance policy. The cost of this policy is calculated as a dollar per tonne value, which is modeler-defined in Cell L45 on the 'Fin_Resp_Inputs' worksheet. This cost represents a premium payment on a per tonne of CO_2 injected basis and is included in the model run, regardless of which instrument is chosen. The cost is applied during all years of the operations stage. The cost is linked to Cell E278 of the 'FinMod_Main' worksheet, and the cost then gets carried through the model calculations in that way. There is some additional discussion of ERR in Section 2.2.4.

In columns O–W on the 'Fin_Resp_Inputs' worksheet, tables provide the PV, nominal, and real costs, broken down by components and instrument of FR, while two graphs present PV costs for the components and instruments. These values reflect the formation selected for a single model run or the last formation evaluated in a multi-formation model run. However, this cost information can also be found in the output records when doing a model run using the "Evaluate Formations" macro (see the 'Res_FRWat1' worksheet).

2.2.1 Trust Fund

A trust fund can be established by the operator to provide funds should the operator fail, requiring a third party to be employed to complete a covered task. A trust fund is considered an actively managed account with a portfolio of financial instruments bearing a respectable rate of return. In the event of owner/operator failure, these financial instruments would have to be sold to fund completion of a covered task. A trust fund is a low-risk instrument where the money is in place and available when needed, a feature that the EPA favors (EPA, 2011). This type of instrument is well suited for PISC and site closure, which will occur over several decades after some 30 years of injection operations. For similar reasons, it is also suitable to cover corrective action and injection well plugging. However, the trust fund is not designed to respond to an ERR event due to the risk that the trust fund might not have sufficient funds to cover the response to and remediation of an emergency event.

The amount of money to be deposited in a trust fund is determined by estimating the current value of the activity or activities to be covered by the trust fund. In the CO2_S_COM, this estimation is done by escalating the real cost of each covered activity (2008 dollar costs) to the year in which the trust fund is established. Based on the defaults in the model, the trust fund is established in 2027. The sum of these annual expenses is the face value of the trust fund, and the PV of these annual expenses is the amount of money to be deposited in the trust fund. Discounting to calculate the PV for the trust fund is based on "…historical returns associated with a particular financial instrument" (NETL, 2011). In the model, PV is calculated on the real rate of return of the trust fund considering the annual rate of inflation and the expected nominal rate of return on the trust fund's portfolio. The trust fund will grow, per the input value of the modeler, at a nominal rate between 0.3 percent (based on a one-year treasury over five years) and 10.6 percent (return on S&P 500 over 30 years).

For each year of the trust fund's existence, an annual fee, taxes, and incurred expenses are deducted from the beginning year balance. Accrued interest earned by the portfolio will be added. The annual fee is a user input; the default is 0.82 percent. A range of potential values are provided for reference in Sub-part 3.2 in the 'FR_Lookups' sheet. While tax considerations for a trust fund may be complex, in the CO2_S_COM it is recommended to use the same tax rate used in Part 14.0 of the 'Key_Inputs' sheet. Incurred expenses are those for the covered activity: corrective action, injection well plugging, or PISC and site closure. Once a covered activity is completed, it no longer needs FR coverage, and the face value of the financial instrument can be adjusted accordingly. With a lower face value for either a trust fund or escrow account, the balance can be reduced per the current cost of the covered activity completed. In the CO2_S_COM, the covered expense is paid directly by the trust fund (or escrow account). When the last expense is paid, the trust fund has a balance of zero.

In the model, trust fund is an option to cover corrective action, injection well plugging, and PISC and site closure costs. The modeler can choose trust fund by using the drop-down boxes in Column A of the 'Fin_Resp_Inputs' worksheet. In the same worksheet, the financial parameters of the trust fund are specified to the right in cells L16–L20. These cells will be light orange when the trust fund option is selected. A range of potential values for the expected nominal rate of return on investment are provided for reference in Sub-part 3.1 in the 'FR_Lookups' sheet. The annual tax rate is recommended to be the same as what the user inputs in Part 14.0 of the 'Key_Inputs' sheet. Finally, the modeler can select the pay-in period for the trust fund. The pay-in period can be one year, two years, three years, the length of operations, or an alternative user defined pay-in period; pay-in begins in the year in which the financial instrument is purchased. Note that the length of operations option discussed does not mean the pay-in period exactly equals the operation period. Pay-in period still starts the year the financial instrument is purchased as the modeler specified and ends when operation ends. In other word, this option means the pay-in period will include the operation period where pay-in period may start earlier based on the setting. Payment into a trust fund over the period of operations is not recognized by EPA in their Class VI regulations or guidance documents. However, EPA listed a category for "Any other instrument(s) satisfactory to the Director" [40 CFR 146.85(a)(1)(vii)] in the regulations providing for new ideas for financial instruments.

Additional information about the trust fund method can be found on the 'FinMod FR Details' worksheet. The information that the modeler selected on the 'Fin_Resp_Inputs' worksheet is in rows 92–103 in the 'FinMod FR Details' sheet. References for inputs related to the trust fund can be found in Part 3.0 on the 'FR_Lookups' worksheet or by clicking "Trust Fund" in Cell K15 on the 'Fin_Resp_Inputs' sheet to be navigated there automatically.

2.2.2 Escrow Account

An escrow account is very similar in many respects to a trust fund. Although institutional differences between these two financial instruments can be significant, they are outside the scope of the CO2_S_COM. An escrow account is not as actively managed as a trust fund and is considered more liquid than a trust fund, thereby earning a lower rate of return. From EPA's perspective, the funds from an escrow account are more readily available when needed (EPA, 2011).

In the model, escrow account is an option to cover corrective action, injection well plugging, and PISC and site closure costs. The modeler can choose escrow account by using the drop-down boxes in Column A of the 'Fin_Resp_Inputs' worksheet. To the right in the same worksheet, more details of the escrow account can be specified in cells L23–L27. These cells will be light orange when the escrow account option is selected. A range of potential values for expected nominal rate of return on investment and annual administrative fee are provided for reference in Sub-part 4.1 and Sub-part 4.2, respectively, in the 'FR_Lookups' sheet. The annual tax rate is recommended to be the same as what the user inputs in Part 14.0 of the 'Key_Inputs' sheet. Finally, the modeler can select the pay-in period for the escrow account. The pay-in period for the escrow account works similarly to the trust fund, so the pay-in period can be one year, two years, three years, the length of operations, or an alternative user defined pay-in period; pay-in begins in the year in which the financial instrument is purchased.

Additional information about the escrow account method can be found on the 'FinMod FR Details' worksheet. The information that the modeler selected on the 'Fin_Resp_Inputs' worksheet is in rows 137–148 in the 'FinMod FR Details' sheet. References for inputs related to the escrow account can be found in Part 4.0 on the 'FR_Lookups' worksheet or by clicking "Escrow Account" in Cell K22 on the 'Fin_Resp_Inputs' sheet to be navigated there automatically.

2.2.3 Surety Bond

In its guidance document on FR, EPA noted that a surety bond is well suited for injection well plugging or corrective action. The number of injection wells is known, and the associated risks are obvious. With respect to corrective action, while there is some potential for an old unknown well requiring corrective action to be discovered during operations, the effort done in preparing the AoR and corrective action plan has greatly reduced this risk. A surety bond is not well suited for PISC and site closure or ERR where events can occur over long periods and/or uncertainty is considerable (EPA, 2011). The primary risk most likely lies with the operators and their ability to perform the required tasks.

A surety bond can be either a performance bond or a financial guarantee (payment) bond. As with self-insurance, EPA has concerns about instrument failure associated with a performance bond. EPA would prefer having access to the money with the ability to arrange for a third-party contractor to perform the work. Should the operator fail to perform and the surety bond is paid out, the financial institution that issues the bond has the right to pursue reimbursement.

The cost of a surety bond is based on the estimated current dollar cost of the covered activities and is calculated in the same manner as described above for a trust fund. If the surety bond requires an annual premium payment, then this annual premium is a percentage of the face value of the instrument.

In the model, there are two surety bond options for FR. The first surety bond option, "Surety Bond Method 1," is valued simply as an annual premium based on the face value of the surety bond. The second type of surety bond, "Surety Bond Method 2," is based on a pay-in period and the surety company's weighted average cost of capital (WACC). Surety bond is an option to cover corrective action and injection well plugging. The modeler can choose surety bond by using the drop-down boxes in column A of the 'Fin_Resp_Inputs' worksheet. To the right in the same worksheet more details of the surety can be specified in cells L30 and L33–L34.

In the model, a range of potential values for premium rates are provided for reference in Sub-part 5.1 in the 'FR_Lookups' sheet. The level of risk is based on whether the operators are deemed reliable and the likelihood with which they will fulfill their obligations. Premiums are paid until the sum of the premium payments equal the face value of the instrument or until the surety bond is released because the covered activities are completed. How long premiums are paid depends on the premium charged and the time span of the covered activity.

For the second method, the face value of the surety bond is discounted to a PV. The discount rate is the WACC for the surety, or an average WACC for the surety industry. This PV is paid in by the operator over one of four multi-year periods depending on the level of risk associated with the operator. In the model, a high-risk operator is allowed a three-year pay-in period, a medium-high-risk operator a five-year pay-in period, a medium-low-risk operator is allowed a seven-year pay-in period, and a low-risk operator an annual pay-in period per project length. The surety will invest the premium it has collected believing that it will earn returns at its WACC or better. This invested fund will grow in value to meet potential liabilities should the operator fail to perform the covered tasks. Under both methods of surety bonds in the CO2_S_COM, the operator will only pay the premium for the surety while the covered activities are ongoing. Even if a longer pay-in period is selected, the operator will not continue to make payments if all covered activities are completed.

Additional information about the surety bond methods can be found on the 'FinMod FR Details' worksheet. The surety bond information that the modeler selected on the 'Fin_Resp_Inputs' worksheet are in rows 182–184 and 203–207 in the 'FinMod FR Details' sheet. References for inputs related to the surety bond methods can be found in parts 5.0 and 6.0 on the 'FR_Lookups' worksheet or by clicking "Surety Bond Method 1" in Cell K29 or "Surety Bond Method 2" in Cell K32 on the 'Fin_Resp_Inputs' sheet to be navigated there automatically.

2.2.4 Insurance

In the CO2_S_COM, insurance is the only financial instrument used for ERR. The model is not capable of estimating the probability of occurrence for any particular event covered by an ERR plan nor is it able to assess the potential costs associated with the response to and remediation of an emergency event. It is far simpler to model ERR costs as a fixed cost per tonne of CO_2 injected, modeled as an insurance premium. Presently, the model uses a value of $0.75 per tonne of CO_2 injected, which is based on data submitted by the FutureGen Alliance upon application for their Class VI permit. (FutureGen Industrial Alliance, Inc., 2013). The fee is in 2008 dollars (the base year) and escalates each year at the general rate of escalation input by the modeler. The ERR insurance premium is assumed to be paid during operations (i.e., when CO_2 is injected). A modeling assumption is that coverage begins the first day of operations and extends until the site is closed at the end of PISC.

In its FR guidance, EPA noted that insurance might be suitable for certain events such as injection well plugging or PISC and site closure (EPA, 2011). PISC and site closure is a known event that occurs far out in time and over several decades, making it difficult to underwrite with an insurance policy. Should an operator be offered the opportunity of an insurance policy to cover PISC and site closure, the underwriter might want the premium paid up front, in which case the operator would be better off with a trust fund or escrow account.

Like the surety bond, there are two methods of insurance in the model for FR. Insurance method 1 is an annual premium payment, based on a percentage of the face value of the insurance policy. In the model, a range of potential values for premium rates are provided for reference in Sub-part 7.1 in the 'FR_Lookups' sheet. The premium is paid until the sum of the premium payments equal the face value of the policy or the instrument expires. Insurance premiums are calculated with a higher percentage of the face value than applied for a surety bond and over a 30-year period of operations, the insurance policy will likely be paid in full for coverage of corrective action or injection well plugging.

The second type of insurance, insurance method 2, is an accelerated premium payment. The sequence of estimated current dollar cost of the covered activities is discounted to a PV. The discount rate is the WACC for the insurer, or an average WACC for the insurance industry. This PV is paid in by the operator over several years depending on the level of risk associated with the operator: three-year pay-in period (operator considered a high risk), five-year pay-in period (medium-high risk), 30-year pay-in period (medium-low risk), or annual pay-in period per project length (low risk). Like the surety bond method, the operator will only pay the premium for insurance while the covered activities are ongoing.

Insurance is an option to cover corrective action and injection well plugging. The modeler can choose insurance by using the drop-down boxes in Column A of the 'Fin_Resp_Inputs' worksheet. To the right in the same sheet more details of insurance can be specified in cells L37 and L40–L41.

Additional information about both insurance methods can be found on the 'FinMod FR Details' worksheet. The insurance information that the modeler selected on the 'Fin_Resp_Inputs' worksheet is in rows 227–229 and 248–253 in the 'FinMod FR Details' sheet. References for inputs related to the insurance methods can be found in parts 7.0 and 8.0 on the 'FR_Lookups' worksheet or by clicking "Insurance Method 1" in Cell K36 or "Insurance Method 2" in Cell K39 on the 'Fin_Resp_Inputs' sheet to be navigated there automatically.

2.2.5 Letter of Credit

As with a surety bond, a LoC is well suited for injection well plugging or corrective action since these events will occur with certainty and within a reasonable time span. As discussed earlier, PISC and site closure occur too far out in time and over several decades to be considered suitable for coverage by a LoC. ERR also presents too much uncertainty for coverage by an LoC as the event may exceed the credit limit of the LoC (EPA, 2011).

A unique feature of an LoC is that an initial collateral payment is required. The amount of collateral is a percentage of the face value of the LoC and reflects the level of risk associated with the operator and their ability to perform the covered task(s). Should the LoC be drawn down for use by a third party, the operator is legally obligated to repay the face amount of the LoC with interest.

In the CO2_S_COM, the cost of the LoC is based on the current dollar value of corrective action and/or injection well plugging costs. In the model, a range of potential values for the amount of collateral collected, rate of return on collateral, and annual fee are provided for reference in Sub-part 2.1, Sub-part 2.2, and Sub-part 2.3, respectively, in the 'FR_Lookups' sheet. The amount of collateral required will be related to the risk presented by any operator. This collateral earns a rate of return over the life of the LoC. An annual fee, calculated as a percentage of the remaining balance of the face value of the LoC instrument, is paid by the operator. The annual return on the collateral is also applied against the annual fee paid by the operator. When the LoC is released, the collateral is returned to the operator. Since the earnings on the collateral were applied against the annual fee, only the principle amount is returned upon release.

The LoC option in the model can be selected for corrective action and injection well plugging by using the drop-down boxes in column A of the 'Fin_Resp_Inputs' worksheet. To the right in cells L11–L13 of the same worksheet, the modeler can select the parameters relevant to LoC calculations. The modeler first selects the percentage of the face value of the LoC that will be required for collateral. The modeler then selects whether the fee should be assessed on a low-, medium-, or high-risk operation. Finally, the modeler selects the estimated nominal rate of return on the collateral account.

Additional information about the LoC method can be found on the 'FinMod FR Details' worksheet. The LoC information that the modeler selected is in rows 66–68 on the 'Fin_Resp_Inputs' worksheet. References for inputs related to the LoC can be found in Part 2.0

on the 'FR_Lookups' worksheet or by clicking "Letter of Credit" in Cell K10 on the 'Fin_Resp_Inputs' sheet to be navigated there automatically.

2.2.6 Self-Insurance

A storage operator or owner who demonstrates good financial health may use self-insurance, or a corporate guarantee of a parent company to meet their FR obligations. Use of self-insurance or corporate guarantee for meeting FR requirements under Class VI regulations requires the owner/operator to pass certain financial tests. First, tangible net worth and net working capital must be at least six times the current cost estimate for all covered FR activities and surpass a minimum value of $100 million. At least 90 percent of total assets must be in the United States or those assets within the United State must have a value of at least six times the current cost estimate for all covered FR activities [40 CFR §146.85(a)(6)(v)]. Second, the owner/operator must either satisfy five financial ratios: debt-equity <2.0, assets-liabilities >1.5, cash return on liabilities >0.10, liquidity >-0.10, and net profit >0, or have a bond rating greater than BBB or Baa [40 CFR §146.85(a)(6)(v)].

Selection of self-insurance to meet FR requirements impose a potential financial obligation on the balance worksheet of the operator's corporation. It is an expense that will require planning and will become apparent if the company discloses the expected value of FR on its books. Corrective action, the remediation of old poorly plugged wells identified in the AoR and corrective action plan, plugging injection wells, and PISC and site closure are all events that will occur throughout the lifetime of the CO_2 storage operation. These events are expected, and the operator will pay for them as they occur. The risk to the owner/operator is the occurrence of an unforeseen event requiring ERR action.

EPA has expressed its concerns regarding self-insurance and has suggested that it will avoid approving the use of self-insurance to cover PISC and site closure due to concerns about instrument failure (EPA, 2011). In the case of self-insurance, failure implies bankruptcy of the company, which would void its balance worksheet and deny funds to EPA for completion of PISC and site closure through employment of a third party.

In the CO2_S_COM, self-insurance is still an option to be modeled for FR and can be selected for corrective action, injection well plugging, and PISC and site closure. Although self-insurance can theoretically be used to cover all four items of FR, the CO2_S_COM assumes that third-party insurance is used to cover ERR. This assumption also provides simplicity in model programing. For each of these operations, the operator pays to complete the work as they occur; no funds are set aside for expected future events. Corrective action will be paid for as old wells bores are remediated during operations. Injection wells will be paid for when they are plugged and abandoned prior to the beginning of PISC and site closure. The owner pays for PISC and site closure for as long as necessary: 10, 25, or 50 years. In the model, these costs are more than 30 years in the future and highly discounted for PV calculations using the cost of equity as the discount rate since it is equity dollars covering these costs. The key assumption is that any equity dollars the owner will be using to cover these future costs will have had the benefit of earning a 12-percent-compounded annual return each year until the sums are required for payment.

Other instrument(s) satisfactory to the Director: In addition to these instruments, EPA anticipates that new instruments that may be tailored to meet geologic sequestration needs may emerge and may be determined appropriate for use by the Director for the purpose of FR demonstrations (EPA, 2011). Paying into a trust fund or escrow account over the period of operations, one of the options in this model, is an example.

2.3 MODEL OUTPUTS

As stated before, the project management module provides modeled outputs within seven worksheets. A description on each of these sheets is provided below.

2.3.1 'Summ_Output' Worksheet

This worksheet is only used for informational purposes for the user. A summary of many important outputs of the model, including number of injection wells and area of CO_2 plume and mass of CO_2 that can be stored, is within this sheet. This worksheet also includes output information from the project management, geology, and financial modules.

2.3.2 'Cost Breakdown 1' Worksheet

This sheet provides a detailed breakdown of the costs for different categories of saline storage such as surface equipment costs, fees and lease costs, and monitoring costs. Sums are used in some of the outputs the model produces. This sheet includes six parts with all broken down into additional sub-parts except parts 4 and 6: 1.0 Miscellaneous Data, 2.0 Cost Breakdown, 3.0 Summary of Costs by Stage, 4.0 Summary of Costs by Cost Category and by Stage, 5.0 Summary of Costs by Category, and 6.0 From 'Back-End_Cost Items' sheet.

2.3.3 Results Sheets

There are 10 sheets that are populated with results after running the "Multiple Formation Evaluation" macro. The hidden sheets ('Res_Bas,' 'Res_CatV,' 'Res_CatP,' 'Res_SUStg,' and 'Res_FRWat') contain formulas to calculate or reference the values for model output. For the formulas to not change with each change in formula and structure, their output values are pasted into the unhidden worksheets, 'Res_Bas1,' 'Res_CatV1,' 'Res_CatP1,' 'Res_SUStg1,' and 'Res_FRWat1.' These output sheets contain the following information:

- 'Res_Bas1' worksheet: Summary of key results and many physical inputs for each formation
- 'Res_CatV1' worksheet: Summary of key results and costs for different cost categories for each formation
- 'Res_CatP1' worksheet: Summary of key results and costs for different cost categories as a percent of total costs for each formation
- 'Res_SUStg1' worksheet: Summary of key results, sources, and uses of cash and costs by stage for each formation

- 'Res_FRWat1' worksheet: Summary of key results, FR costs, and water processing inputs and costs for each formation

3 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 and the schedule of investments and expenses made in the 'Back-End_Cost Items' worksheet. Calculation of FR cost and cost of instruments to satisfy FR requirements are also done within this module. There are three worksheets within the financial module, which are described in the subsequent sections below: 'FinMod_Main,' 'FinMod FR Details,' and 'FR_Lookups.'

3.1 'FINMOD_MAIN' WORKSHEET

This worksheet is the main sheet in the financial module. It contains the financial evaluation of a business scenario for a specific storage project. The worksheet is organized in 10 parts, which detail each component of the financial evaluation. Some parts of this worksheet are further broken down into sub-parts to provide more detail in the model. More information on high-level parts of the 'FinMod_Main' worksheet are discussed below.

Part 1.0: Key Inputs and Outputs. This part summarizes key inputs taken from the project management module including capitalization, cost of equity and debt, tax rate, and escalation rate. Other key inputs and outputs included in Part 1.0 include key calendar years, mass of CO_2 injected, financial outputs, and FR lookup values and financial instruments used for each financial responsibility category. The lookup values are used in logic throughout the model for programming purposes. During the period the modeled project runs, certain aspects of its activities are also defined.

Part 2.0: Escalation and Discounting Factors. The factor that a real sum needs to be modified to convert it into nominal (escalated) dollars and then discount it back to PV dollars is shown in this part.

Part 3.0: Revenues. This part calculates revenues, if any, in real base year dollars (2008 dollars in the model), real project start year dollars (2023 dollars in the model), and escalated dollars that are generated by the project in each year of the project's lifespan. The revenues are used in the income statement. This part also shows the amount of CO_2 injected and water produced, treated, and sold per calendar year and project year.

Part 4.0: Outputs from 'Back-End_Cost Items' Sheet: Operating Expenses, Capital Costs, and Capital Costs by Depreciation Category. Operating expenses, capital expenses, and depreciation and amortization are shown in this part. It displays costs in real base year dollars (2008 dollars in the model), project start year dollars (2023 dollars in the model), and escalated dollar sums in the years they are incurred.

Part 5.0: Costs of Financial Responsibility Categories. This part splits all the elements of FR and displays them as costs for real base year (2008 dollars in the model), real project start year (2023 dollars in the model), escalated, and PV. These elements are activities related to the project: ERR, corrective action, injection well plugging, and PISC and site closure costs not related to the four prior items. This part also shows the schedule of when these costs are incurred in the project.

Part 6.0: Financial Instrument Calculations for Financial Responsibility. All cash activity related to meeting FR requirements for real base year (2008 dollars in the model), real financial instrument purchase year (2027 dollars in model), escalated, and PV costs is provided in this part. If a trust fund or escrow account needs to be funded, this part shows the funding schedule as well as the draw down schedule to meet all FR-related payments of the trust fund or escrow account. Additionally, it shows non-trust fund/escrow account schedules and premiums paid for ERR in real base year (2008 dollars in model) and escalated dollars. See Section 2.2 for a full discussion of FR.

Part 7.0: Debt (escalated dollars). This part defines the debt position of the project. It calculates how much debt principal is borrowed, interest is accrued, and interest and/or principal is repaid in a given year. It also tracks the total amount of debt the project is carrying in a given year.

Part 8.0: Taxes (escalated dollars). The tax bill incurred by the project in a given year is calculated in this part. To derive this figure, it calculates the tax basis and taxable income in each year and applies the marginal tax rate of the project to all taxable income. The project accumulates net operating losses in the beginning of operations and uses these to lower taxable income when it begins to generate storage revenue from injection.

Part 9.0: Cash Flow Available to Owners (escalated and PV dollars). This part shows how much money an owner can take out of the project or needs to invest in the project for each year. The sum of the PVs, determined by applying the cost of equity as a discount rate, of this full schedule of cash flows is the NPV of the project.

Part 10.0: Miscellaneous Summary Cash Flow Information. Other financial information, including revenue for storing CO_2 and debt proceeds in real base year (2008 dollars in model), real project start year (2023 dollars in model), escalated, and discounted (PV) dollars, is provided in this part.

3.2 'FINMOD FR DETAILS' WORKSHEET

This worksheet provides additional information and model transparency through 11 parts. Within this worksheet, some parts are further broken down into sub-parts to provide more detail in the model. In addition to the parts mentioned above for each method of FR, this worksheet contains the calculations for cash flows associated with each type of FR instrument. For additional information on the FR methods, assumptions, and limitations, please see the "Financial Responsibility Pricing Foundations White Paper" (NETL, 2014). The modeler does not need to access this worksheet to run the model. More information on high-level parts of the "FinMod FR Details' worksheet are discussed below:

Part 1.0: General Information Applicable to Most if Not All Financial Instruments. This part provides project and calendar years and escalation rates for different aspects of the project that is applicable to all the financial instruments. This information is either calculated or pulled from worksheets within the project management module.

Part 2.0: Financial Instruments Selected by User. Selected financial instruments for corrective action, injection well plugging, and PISC and site closure activities related to the project along with its associated number for cell references is given in this part.

Part 3.0: Costs Associated with Different Financial Responsibility Categories. This part uses information from Part 1.0 to calculate costs for three of the four FR categories (corrective action, injection well plugging, and PISC and site closure) in base year (2008 dollars in model), first year of project (2023 dollars in model), and financial instrument first year (2027 dollars in model) dollars. No changes should be made to these calculations. A schedule of when these costs are incurred in the calendar year, project year, and instrument year is also provided. Within the model, the default sequence of years begins with 2023, the first year of the project. Corrective action begins in the first year of operations, 2028, and costs are incurred every year, ending in 2043. Injection ends in 2057 with PISC and site closure starting in 2058 and ending in 2107. A total cost for the three FR categories is in Column D. ERR is not included since it is not covered by the instrument, but rather by the premium payment mentioned above.

Part 4.0: Letter of Credit Calculations, Part 5.0: Trust Fund Calculations, Part 6.0: Escrow Account Calculations, Part 7.0: Surety Bond Method 1 Calculations, Part 8.0: Surety Bond Method 2 Calculations, Part 9.0: Insurance Method 1 Calculations, and Part 10.0: Insurance Method 2 Calculations. These parts provide details and notes on each financial instrument and a 200-year timeline with cash flows and cost calculations related to the FR instrument option(s) selected. The modeler should not make any changes to these calculations except for cells D98 and D143, which allow the user to enter an overpayment percentage to ensure funds exist to cover costs at the end of operations for the trust fund and escrow account, respectively. Total (or maximum) cash flows for the financial instrument are in Column D and each cash flow or time dependent variable is noted with a unique identifier under each part. To emphasize these cash flow calculations, items related to the trust fund (Part 5.0) will be explained. The unique identifiers for the cash flow or time dependent variables take the form "TF#". The investment required to fully fund a trust fund (TF5), the interest earned (TF7), fees (TF8), and taxes incurred on interest minus fees (TF9) are posted in rows 114–118. The cost of corrective action as a potential out flow from the trust fund is posted in Row 110. This cost is also posted as an expense in Row 120.

Within these parts, a schedule of when these costs are incurred in the calendar year, project year, and instrument year is also provided. Within the model, the default sequence of years begins with 2023, the first year of the project. Costs for the selected financial instruments(s) start in the year the instrument was purchased, 2027.

Part 11.0: Cash Flows for Financial Responsibility Instruments for Use in 'FinMod_Main' Sheet. Cash flows for financial responsibility instruments from parts 4.0–10.0 of this worksheet that are used in Part 6.0 of the 'FinMod_Main' sheet are provided in this part. A schedule of when these costs are incurred in the calendar year, project year, and instrument year is also provided. Within the model, the default sequence of years begins with 2023, the first year of the project. Costs for the selected financial instruments(s) start in the year the instrument was purchased—2027—and are in real 2027 dollars.

3.3 'FR_LOOKUPS' WORKSHEET

This worksheet contains nine parts that provide references for additional user input options for the various financial instruments and a lookup table for the financial instrument cell reference and description. Within this worksheet, some parts are further broken down into sub-parts to provide more detail in the model. More information on high-level parts of the 'FR_Lookups' sheet are discussed below.

Part 1.0: General Inputs. Historical inflation rates to use as a reference to provide an escalation rate for the financial instruments in Cell L8 of the 'Fin_Resp_Inputs' sheet is given in this part.

Part 2.0: Letter of Credit, Part 3.0: Trust Fund, Part 4.0: Escrow Account, Part 5.0: Surety Bond Method 1, Part 6.0: Surety Bond Method 2, Part 7.0: Insurance Method 1, and Part 8.0: Insurance Method 2. These parts provide a reference for input options of the financial instruments with colors used to highlight the parts associated with each financial instrument. These inputs are entered by the user on the 'Fin_Resp_Inputs' sheet. These additional input options can be easily viewed by the modeler by clicking the financial instrument title in Column K on the 'Fin_Resp_Inputs' worksheet. To quickly navigate back to the 'Fin_Resp_Inputs' worksheet, the modeler can click on the "Financial Responsibilities" button located in the "CO2_S_COM" ribbon tab or scroll through the bottom menu of the workbook and click on the worksheet.

Part 9.0: Financial Instruments Used for Different Categories of Financial Responsibility. A lookup table for the financial instrument cell reference and description is given in this part. These items are used in other sheets throughout the model.

4 ACTIVITY COST MODULE

This module provides a cost database for all activity costs related to a CO_2 storage project, provides the modeler the opportunity to enter individualized cost data, and allows the modeler to 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). Annual costs per technology/labor applied over the life of a storage project are generated within this sheet. Many of the costs posted in the parts within this worksheet are sourced from EPA's economic modeling efforts (EPA, 2010). The activity cost module contains four worksheets, which are described in the subsequent sections below: 'Activity_Inputs,' 'Surf Eq Cost,' 'Back-End_Cost Items,' and 'Drilling Costs.'

4.1 'ACTIVITY_INPUTS' WORKSHEET

This worksheet is the point of entry for cost data utilized by the model. There are four parts within this sheet: 1.0: Parameters Consistent Across all Activities, 2.0: Activity-Specific Parameters, 3.0: Parameters Used in Activities Across Multiple Stages, and 4.0: Well-Drilling Costs. These parts are further broken down into additional sub-parts to provide more detail in the model. All information in this worksheet, in conjunction with data posted in the 'Key_Inputs' worksheet, are used to calculate and post cost data in the 'Back-End_Cost Items' worksheet. It is better for a cell within this sheet to reference a value posted here than another worksheet. Within the sheet, the asterisk ("*") next to an item references a note(s) at the bottom of the appropriate parts pertaining to that item.

A modeler can use this worksheet to change the costs applied by the model by inputting a unit cost as labeled in each sub-part for each light orange cell. These tables are populated with publicly available data (EPA, 2010) or calculated values based on purchased data (API, 2006) (API, 2014). If the modeler wishes to change a cost for an analysis or has better data available, new data can be entered in the light orange cells. More information on high-level parts and sub-parts of the 'Activity_Inputs' worksheet are provided below.

Part 1.0: Parameters Consistent Across All Activities. This part provides information on labor rates, total tonnes of CO_2 injected, conversions, and storage project timing through four sub-parts (most of the values in this part are pulled from the 'Key_Inputs' sheet):

> ***Sub-part 1.1: Labor Rates.*** The four categories for labor rates within this sub-part are geologist, engineer, landman, and field (i.e., field hand, a pumper in the oil patch). These rates get carried through to any activities that require labor hours. They are applied to each activity based on the type of labor selected by the modeler. If the modeler has better data for hourly rates, it can be incorporated in cells D9–D12.
>
> ***Sub-part 1.2: Total Tonnes Injected.*** The tonnes of CO_2 injected affect all costs dependent on the tonnes injected per year, as well as any costs dependent on the total tonnes injected. The value posted in this sub-part is used in the 'Back-End_Cost Items' worksheet. The modeler can change the management decision for tonnes injected in the 'Key_Inputs' worksheet.

Sub-part 1.3: Conversions. This sub-part provides CO_2 plume area in units of acres per square miles. Posting this conversion factor in this sub-part facilitates cell programing. Other conversion factors could be incorporated by the modeler to expand this sub-part.

Sub-part 1.4: Default Stage Timeline. This sub-part is connected to Part 3.0 in the 'Key_Inputs' worksheet. Posting this information in this sub-part facilitates cell programing in determining length of time for project stages and occurrence of costs or specific costs posted in the sub-parts of this worksheet. Any changes the modeler makes to the duration of each stage in Part 3.0 of the 'Key_Inputs' worksheet will change the default timing information in this sub-part.

***Part 2.0*: Activity-Specific Parameters.** This part contains costs and labor hours for activities that get performed one or more times during the time span of a specific stage in the project; there are no unique activities in this part for the PISC and site closure stage This part is organized into 13 sub-parts with the stage labeled in blue on the left side of each sub-part (Column H). The activity's timing and a modeler's ability to edit them is a critical benefit of the model. Each one of these activities is assigned a begin year and an end year within its project stage. The modeler can use the model's default values (gray cells) or override them by inputting their own values in the light orange cells under the header "Begin Year" and "End Year" (columns U and V for most sub-parts). These cells define the timeframe over which the specific activity can be performed. To determine frequency, the modeler can adjust the value under the header labeled "Periodic" (Column U for most parts). A value of "1" means this activity will be performed every year over its eligible timeframe, while a value of "5" means the activity will happen every five years over this period. The modeler can select any level of frequency desired. If the cost is desired to be a one-time cost, the modeler should select identical begin and end years for "User Input Selection" and enter a "1" into the "Periodic" cell. Below is a description of each of the 13 sub-parts within their appropriate stage for this portion of the activity cost module.

<u>Site Screening Stage</u>

Sub-part 2.1: Purchase/Acquire/Analysis. This sub-part contains unit costs and labor hours associated with acquiring and analyzing data and software to conduct a site screening for selecting a site for site characterization and eventually permitting. Initial costs for the project are posted in this sub-part. None of the work is required by Class VI permit regulations, but it is critical to the success of the project. The modeler may want to adjust the number of labor hours estimated for these activities to the extent in which the activity is more or less labor intensive than the baseline.

<u>Site Selection and Site Characterization Stage</u>

Sub-part 2.2 Purchase/Acquire and Analyze (Data/Software Not Acquired Earlier). Unit costs and labor hours associated with acquiring and analyzing data and software for site characterization, which has not been previously acquired, is contained in this sub-part. Like Sub-part 2.1, these costs address regulatory needs. This work, along with other data gathered from other activities in other sub-parts, is presented in the numerous plans (see

Sub-part 2.7) required for a Class VI permit application mentioned in the regulations. The modeler may want to adjust the number of labor hours estimated for these activities.

Sub-part 2.3: Prepare. This sub-part lists all items required in the Class VI regulations. Posted labor hours are associated with completing this work. Clicking on each item's cell provides a fuller title of each piece that must be prepared. The modeler may want to adjust the number of labor hours estimated for these activities.

Sub-part 2.4: Modeling (labor hours/site). Labor hours associated with modeling CO_2 plume migration in the reservoir over a 100- and 10,000-year period is posted in this sub-part. Modeling associated with tying well control to seismic data is also added. Reservoir modeling is included, and any improvements in modeling time or methods would be reflected in this sub-part. The modeler may want to change which type of modeling is done or how many hours are spent modeling. Changes will be made within this sub-part.

Sub-part 2.5: Corrective Action Planning (labor hours/site). Any labor hours used for corrective action planning are listed in this sub-part. Data gathered is included in the AoR and corrective action plan (see Sub-part 2.7) submitted for permit application. The modeler can use this sub-part to change labor hours required or add a unit cost associated with corrective action planning.

Sub-part 2.6: Front-End Engineering and Design (labor hours/site). This sub-part contains labor hours to complete front-end engineering and design for three areas: injection wells, monitoring wells, and surface facilities/intra-field pipelines. The modeler may choose to change the cost per well, field-wide cost, or the labor hours for each of these items.

Sub-part 2.7: Preparation of Plans for Class VI Permit (labor hours/site). This sub-part contains field-wide cost and labor hours for preparation of the five plans required for submittal when applying for a Class VI permit: AoR and corrective action, testing and monitoring, injection well plugging, PISC and site closure, and ERR. Also, prepared and secured during site selection and site characterization are the financial instruments that will meet the FR requirement. The modeler may choose to change the field-wide cost or the labor hours for any of the costs associated with Class VI application.

Sub-part 2.8: Land Leasing (labor hours/site). This sub-part covers labor and costs associated with securing pore space rights for the storage reservoir: labor hours for securing leases, value of bonuses (dollars per acre) paid for leases, and cost for public outreach program. The lease bonus value posted is from Part 13.0 in the 'Key_Inputs' sheet. The modeler may change the cost per acre or labor hours for these items if the modeler has better information or wants to consider analysis with specific data.

Permitting and Construction Stage

Sub-part 2.9: Permits (labor hours/site). The cost of a Class VI permit is posted in this sub-part. The cost and hours posted are those used by EPA in its economic modeling. This sub-part also includes costs for various permits that may be required for well drilling or other activity depending on federal/state regulations. Both the cost per well and the labor hours associated with obtaining these permits can be posted in this sub-part. These costs are important as permits are a crucial part of complying with regulations. The modeler may change the cost per well or the labor hours required for a given permit. This change would be done as an update of information or to analyze the impact of a change in permit costs.

Sub-part 2.10: Injection Well Drilling (labor hours/site). Class VI permit approval is a two-stage process. Approval to drill the injection wells is granted. These wells are drilled and all the data gathered from these wells, wireline logging, cores, vertical seismic profile (VSP), etc., must be incorporated in the five plans submitted for permit application. The cost of updating these plans is posted in this sub-part including a field-wide unit cost as well as labor costs. The per-well costs, such as drilling and completing the injection wells, are in sub-parts 4.1–4.10. With agreement on the updated plans, approval to begin CO_2 injection is granted. The modeler may choose to change the field-wide costs or labor hours associated with injection well planning.

Sub-part 2.11: Subpart RR (Subpart UU for ER Projects) (labor hours/site). This sub-part consists of one cost item, which covers the field-wide cost and labor hours required for the MVA plan required for compliance with Subpart RR. The modeler may use this sub-part to adjust the reporting cost to comply with different regulations.

Operations Stage

Sub-part 2.12: Gathering Field Data. The labor costs for gathering data, both for Subpart RR reporting and for other monitoring activities, is covered in this sub-part. The modeler can adjust the recurring period of reporting and the number of labor hours required for these activities.

Sub-part 2.13: Corrective Action. This sub-part contains the costs for corrective action based on deep wells, those that penetrate the seal and deeper. Cost items posted include cleaning out and plugging the well. The density of old wells requiring corrective action is in Cell J151, which is pulled from Cell N18 in the 'Key_Inputs' sheet. Presently, one corrective action well occurs, on average, 0.1/mi^2. Old wells may occur in clusters (abandoned field) or by themselves (exploration well). The 0.1/mi^2 value used is an estimate of how many old wells, distributed across the area defined by the AoR, might require corrective action. Total number of wells requiring corrective action is posted in Part 6.0 of the 'Key_Inputs' worksheet (Cell N20). The number of wells requiring corrective action depends on the density of old wells requiring repair (Cell N18 in 'Key_Inputs' worksheet) and the areal extent of the AoR. The modeler can change the specified number of wells per square miles for corrective action in the 'Key_Inputs' worksheet. Cost to repair old wells, to clean out, log, and re-plug, can be modified in this sub-part.

Part 3.0: Parameters Used in Activities Across Multiple Stages. Consisting of 14 sub-parts, this part is for activities that can be performed across more than one of the project stages (site selection and site characterization, permitting and construction, operations, and PISC and site closure). Within each of the 14 sub-parts, there are two tables. One includes an area to incorporate a "Recurring Period (every x years)," which provides for the technologies to be applied in one or all four project stages, while the other provides begin and end years for the project. The modeler inputs the desired recurring period, which is typically one, five, or ten years. If these years are chosen, the activity will be performed every year, five years, or ten years during the default timeframe posted in the gray cells under the "Years that will be used" columns in the begin year and end year table. The default period is pulled in from Part 3.0 in the 'Key_Inputs' worksheet. The beginning and end years can be selected by the modeler by entering the project years desired in the light orange cells under "User Input Selection." This option allows the modeler to pick specific years within a project stage if needed. Otherwise, the default assumption will include the full-time span of the project stage in which the activity is performed.

To understand how to incorporate inputs within this part, Sub-part 3.6 Aerial/Satellite Survey is discussed as an example. Default technology costs are provided for most of the activities within this sub-part. The model default shows the cost of an aerial survey and air-magnetic survey occurring only during site selection and site characterization (cells AO72 and AO73), between project years two and three. To utilize these technologies or technologies in another sub-part, values representing a recurring period can also be posted in the other storage project stages (permitting and construction, operations, or PISC and site closure) in columns AP through AR. A value of "1" means the technology is used and costed annually, a value of "5" means the technology is used and costed every fifth year. Restricting the use of this technology to a single year is discussed below. If no value is entered, then the cost will not occur.

Utilizing the begin and end year table (columns AT–AW), the modeler has some options on when costs occur. Each of the four rows of this table represent one of the project stages in the table to the left. The gray cells ('Years that will be used') are the default values established in Part 3.0 of the 'Key_Inputs' worksheet of the project management module and are posted in Sub-part 1.4 on the 'Activity_Inputs' worksheet. To apply the default timeframe for a particular stage, leave "0" in the begin year and end year cells under "User Input Selection" (light orange cells). In the model, the default timeframe is applied to all four project stages and the technology is utilized at the recurring period (every two years) established in the table to the left. To override the default timeframe, the timing information must be entered in the light orange cells ("User Input Selection") for each project stage in which the technology will be applied other than the default timeframe. To apply the technology once, in a single year, enter the same project year in the begin year and end year cells. Enter two different project years within the default timeframe (the gray cells) and the technology will be applied only within that constrained timeframe, but this will replace the cell equations. Another way to turn off a cost is to enter a number larger than 200, such as "9999," into the begin year and end year cells under the "User Input Selection" columns. Below is a description of each of the 14 sub-parts for this portion of the activity cost module:

Sub-part 3.1: Fees per Tonne CO_2 (Other Expenses). This sub-part contains per tonne fees paid during operations: an injection fee to lease holders, a long-term stewardship trust fund fee for the state, and an operational oversight fund fee for the state. Only a few states have established a long-term stewardship trust fund and/or other fees to support their efforts to regulate CO_2 storage. These values are pulled in from Part 13.0 in the 'Key_Inputs' sheet of the project management module. For specific analysis, the modeler can update these values in Part 13.0 of the 'Key_Inputs' worksheet if better information is available or to see how a change in fees would impact a project.

Sub-part 3.2: Fees, One-Time (Other Expenses). Fees that are paid one-time in compensation due to well drilling or establishing a surface monitoring site are contained in this sub-part. Costs posted for public outreach are a continuation of public outreach efforts conducted during leasing (Sub-part 2.8 in the 'Activity_Inputs' worksheet). The modeler can update these values if better information is available, for specific analysis, or to see how a change in fees would impact a project.

Sub-part 3.3: Periodic Reports. This sub-part includes labor hours related to record keeping, modeling field data, and writing periodic reports. These reports include semi-annual/annual or other periodic reports required by Class VI or Subpart RR regulations. At a minimum of every five years, AoR review is required. Any change in this plan reflecting updated data interpretation must be reflected in all other plans tied to the permit, including FR. FR should be assessed annually to assure that sufficient funds will be available. This financial assessment is reported to the EPA Director. The modeler can change the labor hours for record keeping, modeling field data for reports, or report preparation if better data indicates a change. It is important to note that there is also a special timing table for the injection well plugging report in this sub-part (starting in Row 36).

Sub-part 3.4: Fluid Samples. The technology cost and frequency of collecting fluid samples in various types of wells is posted in this sub-part. Costs and sampling from this sub-part is for periodic AoR reporting and PISC plan sampling. Fluid samples are collected from wells when they are drilled (see Sub-part 4.5). Under the technology cost heading in the sub-part, the cost to collect these samples depends on the number of sampling occurrences per year (12, if sampled monthly; 4, if sampled every three months) and the number of samples taken during each occurrence of sampling. The cost to collect samples per occurrence of sampling includes labor, while the cost to analyze each sample is posted separately. Frequency of sampling allows the modeler to select in which stage of the project samples will be collected. Entering "1" for operations and PISC and site closure means sampling will occur annually. The modeler may decide to use these cells for several single reservoir model runs to look at the cost impact of changing the number of samples taken or how frequently they are taken.

Sub-part 3.5: Gas Samples. This sub-part lists costs for collecting gas samples from the vadose zone well or from flux accumulation chambers that gather a soil gas sample. The cost for vadose zone well samples depends on the number of sampling occurrences per year (12, if sampled monthly; 4, if sampled every three months) and the number of samples taken during each occurrence of sampling. The cost to collect samples per occurrence of sampling includes labor, while the cost to analyze each sample is posted separately. Soil gas sampling cost with the flux accumulation chamber is per survey for each injection well and the number of sampling points in a survey plus an analysis cost per sample. Soil gas samples are collected during site selection and site characterization to establish a baseline. They are also collected during operations and PISC and site closure. The modeler may decide to use these cells to look at the impact of changing the number of samples taken or how frequently they are taken. Also, the modeler can change the cost for analyzing samples if better data becomes available.

Sub-part 3.6: Aerial/Satellite Survey. This sub-part lists aerial survey, air-magnetic survey for old wells, synthetic aperture radar, color infrared transparency films, thermal hyperspectral imaging, and ecosystem stress monitoring technology. Costs posted include mobilization cost, cost per square mile that the survey covers, and cost for data processing. There is an option to add a percentage of the cost for data processing. The modeler may choose to edit the values posted to reflect change in coverage or unit costs. Additionally, if these costs are to be applied over an area larger than the AoR for 3-D seismic, the modeler can add a percentage margin to extend the survey.

Sub-part 3.7: 3-D Surface Seismic. The costs for acquiring 3-D seismic data are displayed in this sub-part. The input cells for this part are in parts 4.0 and 11.0 of the 'Key_Inputs' worksheet. The total cost of 3-D seismic is based on the cost per square mile over which 3-D data is acquired plus a processing fee expressed as a percentage of the per-square-mile acquisition cost. Description of the 3-D seismic area is described in the discussion on parts 4.0 and 11.0 under Section 2.1. The modeler can make any changes to 3-D seismic inputs in parts 4.0 and 11.0 of the 'Key_Inputs' worksheet. The modeler may choose to change any of the costs due to better available data or specific analysis.

Sub-part 3.8: 2-D Surface Seismic. This sub-part provides for 2-D seismic data cost inputs. The total cost of 2-D seismic is based on the cost per linear mile plus a processing fee expressed as a percentage of the per linear mile acquisition cost. Description of the 2-D line length is described in the discussion on Part 4.0 under Section 2.1. Seismic planning costs for data acquisition and quality assurance costs is also entered in this sub-part. These are one-time costs incurred during site selection and site characterization. Additionally, there is an option to add a percentage of the cost for data processing.

The modeler may choose to change any of these costs or to turn them on or off to reflect various monitoring scenarios. The baseline uses 2-D seismic for site selection and site characterization, but many alternatives have been considered by various projects, so the modeler may want to use 2-D during the entire project or not use it at all. 2-D seismic may be used to evaluate various sites, and then used to further characterize the chosen site. Therefore, the cost of 2-D seismic during site selection and site characterization will depend on the number of sites considered and the number of lines at each site. These values can be entered by the modeler on the 'Key_Inputs' worksheet in Part 5.0, and they are posted in cells AH89 and AH90 on the 'Activity_Inputs' worksheet. If the modeler wants to look at various sites during operations or PISC and site closure, cells AI89, AI90, AJ89, and AJ90 in the 'Activity_Inputs' sheet act as an on/off switch for running lines on multiple sites during these stages. If both are set at "1" for either stage, the cost will be applied during that stage; however, if one or both are set to "0," no cost will be applied during that stage.

Sub-part 3.9: Wellbore Seismic (for In Reservoir and Above Seal Wells). This sub-part covers seismic data acquisition from the wellbore for in reservoir and above seal wells. Crosswell seismic and microseismic are selected in this sub-part. Microseismic technology is a known quantity. Crosswell seismic requires the use of two wells, and it is still in the testing stage. Use of VSP technology is selected in Sub-part 4.7. Additionally, there is an option to add a percentage of the cost for data processing. The modeler may choose to change any of these costs due to better available data or specific analysis.

Sub-part 3.10: Electrical. The selection of several different electrical geophysical technologies is provided in this sub-part. Cost, when posted, is calculated using a cost per station and number of stations. Additionally, there is an option to add a percentage of the cost for data processing. The costs for the majority of these technologies are not currently known, but several are being tested by various regional partnerships. Some of the details for this sub-part may change upon learning more about the listed electrical technologies. The modeler may choose to change any of these costs or to select ""electrical" as a replacement for other monitoring techniques.

Sub-part 3.11: Other Geophysical. This sub-part provides for posting costs for a gravity survey or use of tiltmeters. Gravity costs are calculated using the number of stations and cost per station. Tiltmeters can be deployed at the surface or as a string in a well. A tiltmeter station would either be a single tiltmeter at the surface or a string in a well. Advanced geophysical technology is presently undefined. Additionally, there is an option to add a percentage of the cost for data processing. The modeler may choose to change any of these costs or to select other geophysical methods for analysis that makes use of these technologies.

Sub-part 3.12: Atmospheric. Cost items for atmospheric monitoring, CO_2 detectors, eddy covariance, advanced leak detection system, and laser systems and light detection and ranging (LIDAR) are covered in this sub-part. These costs are calculated using an annual cost, cost per square mile, equipment unit cost, and a percentage of the sum to be applied for data processing. The modeler may choose to change any of these costs or turn them on or off.

Sub-part 3.13: Injection Well Monitoring. This sub-part contains the pressure falloff test and the corrosion tests for injection well monitoring. Technology cost, labor cost, and recurring period of testing is posted in this sub-part. Corrosion testing involves testing samples of the well casing for corrosion and rate of corrosion. Per regulations, corrosion sampling is done quarterly. Costs in this sub-part are for four sampling occurrences per year with a collection cost of $100 per sampling occurrence. The number of samples per occurrence is four; the cost to analyze these samples is $200. Entering "1" under Operations for the corrosion tests means that this test will be annual. The pressure falloff test is a single event with a single test cost. If necessary, labor hours can be included in this part for both. Per regulations, this test is done every five years. Entering "5" under Operations for the pressure falloff test means that this test will be run every five years on all the injection wells. The modeler may choose to change any of these costs due to better available data or specific analysis.

Sub-part 3.14: Data Analysis and Modeling. Costs related to reservoir modeling, data analysis, and laboratory testing during site selection and site characterization are covered in this sub-part. This work is done for periodic compliance as well as for prudent operation of the storage project. The reservoir modeling and data analysis include an annual component and a periodic cost component. The modeler may choose to change any of these costs due to better available data or specific analysis. Also, the modeler may increase or decrease the recurring period of the periodic costs.

Part 4.0: Well-Drilling Costs. This part includes costs to drill, complete, test, operate and maintain, and plug and abandon several different types of wells. Types of wells costed are posted at the top of this part in the Well Properties table. Well depth and casing and tubing diameters are also posted in the Well Properties table. There are 17 sub-parts within this part. Costs in each of the sub-parts are summed and posted in the year that each cost occurs in the 'Back-End_Cost Items' worksheet.

Some cells in this part are blanked out with a dark gray color that indicates that the cost is not relevant for the given well type. Within each sub-part there is an "ON/OFF" column that allows the modeler to apply the costs (x = on, blank = off) where user input is indicated (light orange cells). A description of each sub-part for this portion of the activity cost module is provided below starting with Sub-part 4.1.

The 17 sub-parts within this part are grouped to accommodate timing of costs. There are five "timing" tables between some of these cost tables that provide an opportunity to adjust the project year when certain well costs occur. These timing tables define time or a time span when a well is drilled and completed, when O&M costs are applied, when tests are conducted in the well during its life, and when the well is plugged and abandoned. Within these timing tables, the modeler can enter specific values for "Begin Year" and "End Year" in the light orange cells. Values representing a particular project year are posted in the light gray cells and are pulled from Part 1.4 of the 'Activity_Inputs' worksheet. Posting a value in the light orange cell will override the values in the gray cells. The only exception to this is the timing for drilling strat test wells, which always default to the first year of site selection and site characterization; therefore, these cells are gray. The five timing tables in this part are as follows:

1. Timing Sub-parts 4.1–4.10 (starts in Row 12): A "Periodic" line is included in this timing table to allow the modeler to adjust the recurring period that will apply to costs within each of these sub-parts. The default values posted show that these costs occur annually.
2. Timing Sub-parts 4.11–4.13 (starts in Row 174): These sub-parts cover activities that may occur throughout the life of the well. The modeler adjusts the recurring period in a line directly above each sub-part instead of within the timing table.
3. Timing Sub-parts 4.14–4.15: (starts in Row 237): Costs posted in these sub-parts are associated with work done to improve storage efficiency and may occur annually or periodically. The modeler adjusts the recurring period in a line directly above the sub-part instead of within the timing table.
4. Timing Sub-part 4.16 (starts in Row 273): Costs posted in this sub-part are associated with adaptive reservoir management. Within the timing table, the modeler can offset in years from start year of operation (when efforts to optimize CO_2 flow begin) and offset in years from last year of operation (when efforts to optimize CO_2 flow stop). The modeler adjusts the recurring period in a line directly above the sub-part instead of within the timing table.

5. Timing Sub-part 4.17 (starts in Row 298): This timing table covers costs at the end of the life of a well. Costs in Sub-part 4.17 are applied when the well is plugged and abandoned, either at the end of site characterization for strat wells, end of operations for injection wells, or end of PISC for monitoring wells. A "Periodic" line is included in this timing table to adjust the recurring period that will apply to costs within this sub-part; however, the modeler can only adjust this period for water production and disposal wells. The default values posted show that these costs occur annually.

Strat wells are only drilled during the first year of site selection and site characterization. The number of strat wells drilled is posted in the 'Key_Inputs' worksheet. Currently, injection wells are only drilled during permitting and construction. Replacement/new injection wells drilled during operations may be provided in a future version of the model. The number of injection wells drilled is determined in the 'Geol Sal' worksheet and is based on the storage reservoir parameters of the storage reservoir modeled. All monitoring wells are drilled during operations. Not all in reservoir, above seal, or dual completed monitoring wells are drilled at the beginning of operations. An equal number of monitoring wells are drilled every five years with the initial group drilled in the first year of operations. The method to determine the number of monitoring wells and groundwater and vadose zone monitoring wells is entered in the 'Key_Inputs' sheet; these methods consist of well count proportional to the number of injections wells or CO_2 plume uncertainty area or a fixed number (see Part 8.0 in Section 2.1). Well spacing is considered for monitoring wells only, measured in square miles. For the purpose of this manual, groundwater and vadose zone monitoring wells are tied to the injection well; there is one groundwater monitoring well drilled for each injection well in the model and no vadose zone monitoring wells. Water production and water disposal wells are also costed in this sub-part. Modeling parameters regarding water production, treatment, and disposal are explained in the 'Water' worksheet. Aspects related to all monitoring wells, including well spacing, dual completions, and the number of groundwater and vadose zone wells, are management decisions posted in the 'Key_Inputs' worksheet of the project management module.

Sub-part 4.1: Permits. This sub-part includes costs for well drilling permits (other than Class VI), water discharge permits, and air emissions permits. Permits costs posted are for those permits tied to the well. A state permit to drill the CO_2 injection well is required. Class VI permit costs are posted in Sub-part 2.9 of the 'Activity_Inputs' sheet. The modeler can choose to turn permitting costs on or off. Also, the modeler may decide to change the cost data to better available data or to specific analysis of the cost's impact.

Sub-part 4.2: Drilling Costs. This sub-part posts the costs for drilling wells along with the method used to calculate costs. Costs are calculated in the 'Drilling Costs' worksheet by three methods that are dependent on the depth of the well. Well depth is calculated in the 'Geol Sal' worksheet utilizing depth to top of storage formation and storage formation thickness data in the 'Geol DB Sal' worksheet. Methods were developed using API-JAS well cost data (API, 2006) (API, 2014) and an EPA algorithm (EPA, 2010). For more information on the three methods see Section 4.4. Costs for groundwater and vadose zone wells are calculated on a fixed depth and cost basis. Depth for these two wells is entered in the 'Geo-Activity Interaction' worksheet, cells E36 and E37. Costs are posted in the 'Drilling Costs' worksheet, cells AE7 and AF7. The modeler can choose to turn drilling costs on or off. The cost values are calculated in the 'Drilling Costs' worksheet, so any changes to the methods should be made in that sheet.

Sub-part 4.3: Wireline (Geophysical). This sub-part allows the modeler to select wireline logging tools to use during well drilling. For each tool, a cost is given, if applicable. The modeler can choose to turn the wireline costs on or off for each well, changing the suite of logging tools used in any well. Also, the modeler may decide to change the cost data to better available data or to provide specific analysis of the cost's impact.

Sub-part 4.4: Core Recovery. Costs for core recovery are included in this sub-part. In addition to the costs per well for whole and sidewall, this sub-part also contains inputs for the feet of core cut and the number of sidewall cores taken. The modeler can choose to turn these recovery costs on or off, which determine whether whole core and/or sidewall are taken. Also, the modeler may decide to change the cost data based on better available data or the amount of core taken.

Sub-part 4.5: Fluid Recovery. This sub-part includes costs for fluid sample recovery. A pump test is conducted in groundwater wells while a repeat formation test wireline tool is used in deeper wells. The inputs for this sub-part consist of several samples per well for each well type and a unit cost for each sample. The sub-part also contains selection cells, with the ability to turn fluid recovery costs on or off, next to the samples per well cells. The modeler can choose to change the number of samples taken or the cost for each sample as well as turn fluid recovery costs on or off for each type of well.

Sub-part 4.6: Well Tests. Costs for a drillstem test, pressure falloff test, and pump test are covered in this sub-part. For each of these costs, the sub-part includes a unit cost in dollars per well. The modeler can choose to turn these costs on or off or change their values. The modeler may also decide to apply these tests to different types of wells.

Sub-part 4.7: Well Seismic. This sub-part specifies the use of the VSP tool in wells when they are drilled (not for groundwater or vadose zone wells). The VSP costs are for the acquisition of VSP data and processing. The modeler can choose to turn these costs on or off or change their values.

Sub-part 4.8: Analysis. This sub-part contains space for petrophysical analysis of well data. This analysis is a regulatory requirement for the injection wells when they are drilled, and this cost is posted in Sub-part 2.10 for this purpose. Also, costs for core analysis, geomechanical analysis, or geochemical analysis of a fluid sample can be entered in this sub-part. Costs posted in this sub-part can also be applied to other well types. Since there are no default cost information in this sub-part, the modeler may choose to add cost values and turn these costs on or off.

Sub-part 4.9: Completion. The items for completion of the well for injection, monitoring, or eventually production and disposal of water are contained in this sub-part. The equipment listed is used in EPA's economic analysis of its Class VI rules. Cost for the CO_2 injection well wellhead and control equipment is currently a flat cost (EPA's algorithm was not used in this cost), which also includes the continuous monitoring equipment. While there is a distinction between surface casing and long string casing for cementing, that is not the situation for casing itself. Casing and tubing cost posted are for corrosion resistant steel used in wells completed in the reservoir. Casing and tubing diameters from the Well Properties table above Sub-part 4.1 are used to calculate cost of corrosion resistant casing and tubing in this sub-part. These two values can be changed by the modeler as necessary. Well stimulation is listed but costs are currently not known. The modeler will need to apply these costs to relevant wells and can change the cost per well or per foot per well for additional analysis as well as turn the costs on or off. Also, the modeler may decide to change the diameter for casing or tubing.

Sub-part 4.10: Downhole Equipment for Wells. This sub-part posts costs for equipment installed in the well during completion. The pressure, temperature, and resistivity gauge is to monitor reservoir parameters, part of the testing and monitoring plan. The check valve is a safety device to prevent back-flow of injected CO_2 and is a regulatory option. The modeler can choose to turn these costs on or off. Also, the modeler may decide to change to better available cost data or to specific analysis of the cost's impact.

Sub-part 4.11: Operations and Maintenance. This sub-part contains the annual O&M costs for the wells, which are from EPA's economic analysis of Class VI rules. These costs have a fixed annual component and per foot of well depth component. The recurring period of O&M or other tests can be adjusted by posting a value in the "Periodic" line immediately above this sub-part (Row 185). The default value posted shows that these costs occur annually. The modeler may decide to change to better available cost data or to specific analysis of the cost's impact or turn the costs on or off.

Sub-part 4.12: Mechanical Integrity Tests. This sub-part contains costs for the annual mechanical integrity test (MIT) required by Class VI regulations. Available technology for this test includes pressure test, tracer survey, temperature log, noise log, and casing inspection log. For each of these items, the cost has a per-well component and a per-foot per-well component. The technology listed is per Class VI regulations, but the state may require periodic testing of the monitoring wells, drilled under a state permit. The modeler can select which technology to apply to the different types of wells depending on the chosen MVA plan by turning the costs on or off. Also, the modeler may alter the cost for these items given either better information or analysis goals and adjust the recurring period in the "Periodic" line immediately above this sub-part (Row 201). The recurring period default values posted show that these costs occur annually or every five years.

Sub-part 4.13: Periodic Monitoring. This sub-part provides technology applied periodically for monitoring purposes; compliance with the plans appended to the Class VI permit. Three technologies are listed: VSP, pulsed neutron cased-hole (PNC) log, and modular borehole monitoring (MBM) tool. The MBM tool provides for fluid sampling, pressure, temperature, and geophysical monitoring. Additional cost details for the MBM tool as well as deployment costs are being pursued. Costs posted are the same as applied in Sub-part 4.3 and Sub-part 4.7, where costs are applied to the well when it is drilled. The modeler may want to change costs if there is better or preferred data or turn the costs on or off. The modeler can also adjust the recurring period in the "Periodic" line immediately above this part (Row 223).

The recurring period default values posted show that these costs occur annually or every five years.

Sub-part 4.14: Monitoring for Conformance Control. Across the height of an injection interval, permeability will vary and the injected CO_2 will preferentially flow through the high permeable intervals, by-passing the low permeable intervals. Thus, pore space in low permeability intervals will be underutilized. This is referred to as a conformance problem and such problems can be detected by tests such as spinner surveys, which are included in this sub-part. The spinner survey is a wireline tool that can measure fluid velocity downhole in different intervals and can be used to identify intervals that are not receiving much fluid. Monitoring to detect conformance issues is presumably done more frequently than the implementation of conformance control measures. These costs are classified as expenses. The modeler may want to change costs if there is better data or preferred data or turn the costs on or off. Cost change may represent a suite of tools used. The modeler can also adjust the recurring period in the "Periodic" line immediately above this sub-part (Row 251). The recurring period default value posted shows that this cost occurs every two years.

Sub-part 4.15: Conformance Control Implementation. If conformance is an issue and the low permeability intervals are sufficiently distinct from the high permeability intervals and the two types of intervals are thick, then measures can be taken to improve conformance. This can involve additional coring and logging in newly drilled wells to better define the low and high permeability intervals. In existing CO_2 injection wells, the low permeability intervals can be fracked to increase their permeability. Conformance control can also include injecting cement or polymers into high permeability intervals to decrease their permeability and encourage the injected fluids to flow into the underutilized low permeability intervals. Well workovers can also be done to enhance the permeability of the low permeability intervals. All of these items are included in this sub-part. The category "Well workover and materials" is intended to cover the cost of cement or polymer, as well as the cost of well workovers. These costs are classified as capital costs. New CO_2 injection wells can be drilled, providing an opportunity to gather new cores and other data, but the model does not provide for additional CO_2 injection wells drilled after the permitting and construction stage. The modeler may want to change costs if there is better or preferred data or turn the costs on or off. The modeler can also adjust the recurring period in the "Periodic" line immediately above this sub-part (Row 261). The recurring period default value posted shows that these costs occur every five years.

Sub-part 4.16: Adaptive Reservoir Management. Adaptive reservoir management is the process of using site characterization data, geologic models, reservoir simulation models, injection data, and monitoring data to better manage the injection of CO_2. Before injection begins, the operator will use site characterization data to construct a geologic model and reservoir simulation model. The operator will use the reservoir simulation model to predict the evolution of the CO_2 plume. This information will be used to establish the AoR. After injection begins, the operator will collect additional data as monitoring wells are installed and seismic surveys (or other geophysical methods) are conducted, and this data can be used to improve the underlying geologic model and reservoir simulation model. The operator will also obtain information on the relationship between pressure and flow rates in injection wells and track the evolution of pressure propagation in monitoring wells. The evolution of the CO_2 plume will be tracked through seismic surveys (or other geophysical methods) and sampling from monitoring wells. The reservoir simulation model will be executed and the resulting CO_2 plume and pressure front compared to observed data. The model will be calibrated to better match observations. After calibration, the operator will be able to run scenarios where flows in one injection well may be increased and another decreased to better manage the CO_2 plume and better utilize available pore space for storing CO_2. This process is called adaptive reservoir management, and costs related to this process are included in this sub-part. It is assumed that there will be some additional costs each year for doing this analysis and for adjusting flow rates in injection wells. The operator will already be collecting and synthesizing much of this data for the periodic AoR review, so the modeling costs are primarily for using the reservoir simulation model to explore the implications of altering the flow rates in different injection wells. These costs are classified as expenses. The modeler may want to change costs if there is better or preferred data or turn the costs on or off. The modeler can also adjust the recurring period in the "Periodic" line immediately above this sub-part (Row 287). The recurring period default value posted shows that these costs occur annually.

Sub-part 4.17: Plug and Abandon. This sub-part is the only well part that is applied at the end of well use. It includes all costs that deal with plugging and abandoning the wells and site restoration, either at the end of operations for CO_2 injection wells (Begin/End Years = 36) or for the monitoring wells after PISC and site closure (Begin/End Years = 86). Items and costs are from EPA's economic analysis of Class VI regulations. The modeler may want to change costs if there is better or preferred data or turn the costs on or off.

4.2 'SURF EQ COST' WORKSHEET

The 'Surf Eq Cost' worksheet provides the capital and O&M costs for various kinds of surface equipment at a saline storage site. These costs are used in the 'Back-End_Cost Item' worksheet. The source for many of the costs posted in this worksheet is the 2014 NETL report "Acquisition and Development of Selected Cost Data for Saline Storage and Enhanced Oil Recovery (EOR) Operations" (NETL, 2014). This worksheet consists of one part; however, it is further broken down into additional sub-parts to provide more detail in the model. Within the sheet, the asterisk ("*") next to an item references a note at the bottom of the sheet. More information on the high-level part and sub-parts of the 'Surf Eq Cost' worksheet are discussed below.

Part 1.0: Capital Costs and Annual Operating and Maintenance (O&M) Costs for 'Back-End_Cost Items' Sheet. This part provides a summary of the subsequent sections. It is further broken down into additional sub-parts in the model to provide more detail:

Sub-part 1.1: Costs for Feeder Pipeline from Main CO_2 Pipeline to CO_2 Storage Site. This sub-part provides capital and O&M costs for a feeder pipeline. The feeder pipeline transports CO_2 from a main CO_2 pipeline to a distribution (header) point within the saline storage site. The length of pipeline (Cell D15) is sourced from the 'Key_Inputs' worksheet as are the other values in the blue cells, except Cell D16, which is from the 'Geo-Activity Interactions' worksheet.

Pipeline fixed capital costs is an estimation of the costs of intra-field CO_2 pipeline and other pipeline equipment (e.g., manifold) and installation (NETL, 2014). This value is entered in Cell D22 for a producing well. Pipeline variable capital costs (Cell D24) is based on the annual mass of CO_2 injected for the storage project. This cost occurs in the year when operations begin, which are set in the project management module ('Key_Inputs' worksheet) and posted in this part in the gray cells under "Years that will be used." For recuring period (Cell E28, the value of "1" means capital cost occur every year. For O&M costs (Cell E34), "1"means that O&M costs occur every year.

Sub-part 1.2: Costs for Equipment, Buildings, and Roads Needed to Operate Injection Wells and One-Time Cost for Custody Transfer Gauge. This sub-part provides the capital and O&M costs for equipment, buildings, and roads needed to operate injection wells. Capital and O&M costs for a pump that boosts the pressure of CO_2 entering the saline storage facility is shown in Sub-part 1.2.1. At some facilities, the pressure may not need to be boosted. However, the capital and O&M costs are presented in this sub-part in the event the pressure of the CO_2 needs to be increased before it is injected.

Capital and O&M costs for the distribution pipeline network are provided in Sub-part 1.2.2. This network consists of a header or manifold and pipes. The header connects to either the feeder pipeline or the exit of the boost pump and directs the CO_2 flow into smaller diameter pipes. These pipes then transport the CO_2 to the injection wells.

Capital and O&M costs for the building, control equipment, and access road to the building are provided in Sub-part 1.2.3, while capital and O&M costs for the gauge used to measure custody transfer of CO_2 from the source/pipeline to the storage site operator is provided in Sub-part 1.2.4.

4.3 'BACK-END COST ITEMS' WORKSHEET

Each activity cost is listed in this worksheet 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 picked-up 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 modeler can change these labels. Capital costs are added to a depreciation schedule where a simple straight-line depreciation calculation is applied.

Although it is not necessary for model output, the modeler may perform their own audit to confirm that an activity cost is properly calculated by the model and applied to each year intended by the modeler. To follow a cost calculation thoroughly, the modeler needs to trace the cost calculation sequence across many columns in this worksheet.

- First, the modeler must identify the cost of interest. This task can be done using columns A (Cost ID), B (Stage), C (Sub-stage), and D (Item).
- Descriptive information about the cost is found in the next eight columns, E (Well Type) through M (Categories for Detailed Cost Breakdown). These items are used for summing

costs across various criteria and shifting capital costs from first year of operations to last year of permitting.

- The category for generating reduced order costs is in Column N. Reduced order costs for macroeconomic modeling are provided in columns AW–BD.
- Columns O (Cost Component Name) to AM (the last of several columns for posting Multiplier Units) show the main components of the cost calculation. These columns are structured in a format meant to standardize all cost calculations: ax+by+cz.
- In addition to the main components, there are four factors by which the ax+by+cz value is multiplied. These four factors are in columns AN–AR. The first factor is a binary switch that turns on or off the cost item. The second factor is used for any costs that include a value by which the entire line calculation is multiplied. This factor is shown in two columns, one for the value and one for the unit. The third factor is the process contingency that is incurred on all costs for monitoring activities. The last factor is the project contingency that is incurred for all capital costs. Column AS calculates all cost components from the left in the worksheet to show the effective cost-per-year before any year-dependent factors.
- Columns AT–AV identify which, if any, year-dependent factors apply to the cost.
- The timing information for the cost—begin year, end year, and periodic value—is shown in columns BE–BG. The same three values are used to define a cost's timing regardless of whether the cost is an annual cost, a one-time cost, or a periodic cost.
- Total incurred cost values are in the next three columns, BH–BJ. These columns represent the sum of real, escalated, and PV dollars across the row.
- To see the real cost posted in each year of the project, in 2008 dollars (base year), the modeler should look at columns BK–JB. These columns show a schedule of costs over the life of a CO_2 storage project. A typical project may take 86 years. The model provides for a maximum project life of 200 years. Rows 3 and 4 show the escalation and discount factors for each year. The formulas in the cells from year 1 through year 200 use the begin year, end year, and periodic value to decide whether the cost should be posted in a given year. Also, any factors that are year dependent, such as well count or plume area, are multiplied by the other cost components in this worksheet. These year-dependent factors are held in the 'Plume&Well Schedule' worksheet.

4.4 'DRILLING COSTS' WORKSHEET

Well drilling and completion costs based on three methods are calculated in this worksheet. The costs depend on the lengths of wells as provided in the 'Activity_Inputs' sheet. The first method is based on the 2006 API-JAS of Well Drilling Costs (API, 2006). Tables within columns B–AZ are used in this method. The first table covers all equations used for drilling cost calculations and the states or regions utilizing those calculations (columns C–P). The next table (columns S–Z) contains the parameters and equations for all state or regions from the first table. Columns AA–AH show the well depths used for each well type, which are determined in the geology module.

These depths are then incorporated into equations to determine well costs, which are posted in columns AI–AP. Except for groundwater and vadose zone wells, these well costs need to be multiplied by 1,000 to get a per well cost and are based on 2006 dollars. Finally, in columns AS–AZ, the costs are converted to 2008 dollars and are given in dollars per well. For all wells other than groundwater and vadose zone wells, the algorithm requires the cost to be multiplied by 1,000, which is done in these cells. These algorithms are derived by plotting the cost information provided by the API-JAS report on drilling cost (API, 2006).

Columns BB–BX provide information on the second method for calculating well drilling and completion costs, which is based on the 2014 API-JAS of Well Drilling Costs (API, 2014). The first table provides an equation, and the coefficients used to calculate costs in 2014 dollars for different regions within the United States; a map highlighting these regions is provided (columns BB–BF). Well depths (i.e., well lengths) are incorporated into the equation to determine well costs, which are posted in columns BH–BO. All costs are in 2014 dollars per well, except for groundwater and vadose zone wells. These wells are calculated on a dollar per foot basis in 2006 dollars. In columns BQ–BX, the costs are converted or de-escalated to 2008 dollars and are given in dollars per well.

The third method is based on an algorithm from EPA that considers well length and cost per foot (columns BZ–CH) (EPA, 2010). Costs are provided in 2008 dollars. The last two sets of tables provide a summary of costs for the user. The table within columns CJ–CR provides well costs for each method of the current storage formation and costs using the method selected by the user in 2008 dollars per well. The table within columns CU–DF provides a comparison of well costs by depth for the three methods in their original cost years (2006 dollars, 2014 dollars, and 2008 dollars) and costs converted or de-escalated to 2008 dollars, if needed. For Method 1 and Method 2, costs are given for a general area (i.e., total onshore wells) and Northeast, respectively, for the comparison.

5 GEOLOGY MODULE

Geologic information contained in the geology module is generalized at the formation level. This module includes specific geologic properties of the storage formations, geo-engineering equations, a geologic database, and storage-related calculations such as CO_2 injectivity, number of CO_2 injection wells, CO_2 plume area, and water withdrawal (production) from the CO_2 storage formation and subsequent treatment and disposal (injection) of water not rendered potable. The geology module has a flexible structure that allows the use of either model-provided data or proprietary data. The modeler should use proprietary data if the model does not include the formation required by the modeler for evaluation or if the modeler has more relevant information on the specifics of the formation under review. This module consists of five worksheets, which are described in the subsequent sections below: 'Geol Sal,' 'Geol DB Sal,' 'Water,' 'Plume&Well Schedule,' and 'Geo-Activity Interaction.'

5.1 'GEOL SAL' WORKSHEET

Geology-related properties, calculations, inputs, and outputs based on the selected injection formation (from the 'Key_Inputs' sheet) as well as details on the geology module methodology are within this worksheet. The worksheet consists of five parts, and there is also an appendix (attachment) to this worksheet provided as a lookup table for site-specific CO_2 storage coefficients. Some parts of this worksheet are further broken down into sub-parts to provide more detail in the model. More information on high-level parts and sub-parts of the 'Geol Sal' worksheet are discussed below.

Part 1.0: Overview. This part provides an overview and explains the structure of the full worksheet (it also contains one sub-part with references):

Sub-part 1.1: References. A list of references for methodologies employed in this worksheet is provided in this sub-part.

Part 2.0: Outputs. Various outputs for the geology module are displayed in this part through four sub-parts, which are discussed below. All of these sub-parts, except Sub-part 2.2, are further broken down into additional sub-parts in the model to provide more detail:

Sub-part 2.1: Selected Geologic Properties of Injection Formation. This sub-part presents information on the properties for the injection formation selected such as reservoir properties, lithology, depositional environment, latitude and longitude at the centroid of the surface area representing the storage reservoir modeled, and lithostatic, fracture, and hydrostatic pressure gradients.

Sub-part 2.2: CO_2 to be Stored. This sub-part calculates items pertaining to CO_2 being stored such as years of injection of CO_2, total mass of CO_2 injected, and average daily rate of CO_2 injection.

Sub-part 2.3: Area of CO_2 Plume and Mass of CO_2 That Can Be Stored. The area of CO_2 plume and the mass of CO_2 that can be stored is calculated in this sub-part. This sub-part also presents information pertaining to the density of CO_2 to be stored, the type of structure used, and the diameter of the CO_2 plume area.

Sub-part 2.4: Rate of Injection of CO_2 in Each Injection Well and Number of Injection Wells. This sub-part gives the rate of injection of CO_2 in each injection well and number of injection wells for the selected methods of Law and Bachu or ARI, which are both reported by the CCSTP (CCSTP, 2009), Cinar et al. (Cinar, Bukhteeva, Neal, Allinson, & Paterson, 2008), or Valluri et al. (Valluri, Mishra, & Ganesh, 2021). The model has not been tested with either the ARI or Cinar et al. methods for calculating the rate of injection.

Part 3.0: Inputs. In this part, the modeler specifies inputs related to geologic properties and CO_2 storage coefficients and calculates the number of wells needed to inject the desired mass rate of CO_2 into the injection formation. There are six sub-parts within this part, which are discussed below. All of these sub-parts, except sub-parts 3.1, 3.2, and 3.6, are further broken down into additional sub-parts in the model to provide more detail:

Sub-part 3.1: Overview. This sub-part provides an explanation on the structure of each part or sub-part regarding inputs from other worksheets, general inputs related to geology, specifications of geologic parameters for injection formation, inputs related to CO_2 storage coefficients and calculating maximum CO_2 plume area, and inputs related to determining the number of injection wells.

Sub-part 3.2: Inputs from Other Sheets. Inputs specified on other worksheets that are needed to calculate the area of the CO_2 plume and the number of injection wells are reproduced in this sub-part. Specifically, these inputs all relate to the nominal mass injection rate for CO_2 and the duration of injection. The actual annual mass rate of CO_2 injection can be different from the nominal value. The modeler does not need to input any additional information in this sub-part.

Sub-part 3.3: General Inputs Related to Geology. This sub-part provides general inputs related to geology, such as temperature and pressure gradients, and information needed to estimate the fracture pressure.

Sub-part 3.4: Specification of Geologic Parameters for Injection Formation. This sub-part specifies the geologic properties and parameters that are used in the rest of the 'Geol Sal' worksheet and other worksheets. Within the 'Geol Sal' sheet, this data is used in Sub-part 3.4.1 to calculate a variety of parameters that are critical for estimating CO_2 storage costs. Some geologic properties within Sub-part 3.4.1 (i.e., temperature, lithostatic pressure, ambient hydrostatic pressure, fracture pressure, and vertical permeability) are calculated in Sub-part 3.4.2, and the results are displayed in Sub-part 3.4.1 under the column labeled "Calculated Value." These calculations are done because these parameters may not be specified in the 'Geol DB Sal' worksheet and parameter values can be estimated.

When the modeler selects an injection formation from the list of formations in the 'Geol DB Sal' worksheet, that value is pulled from the 'Key_Inputs' sheet and posted in Cell D234 of the 'Geol Sal' sheet. The geologic data for that formation are extracted from the 'Geol DB Sal' worksheet and displayed in the purple-shaded cells in the column labeled "Database" in Sub-part 3.4.1 of the 'Geol Sal' worksheet. The modeler has the option to choose between a "Database," "Calculated Value," or "From 'Key_Inputs' Sheet" value for some data within Sub-part 3.4.1 by entering a "1" or "2" in the light orange highlighted cells within the

"Selection Control" column (Column F) of the 'Geol Sal' worksheet. The options associated with these numbers are described in Column K (starting in Cell K261). It should be noted that for the temperature and hydrostatic pressure parameters, if the modeler indicates the "Database" value should be used and this value is "NA," then the "Calculated Value" is used. There are no database values for lithostatic pressure, fracture pressure, or vertical permeability, so the "Calculated Value" is used.

When the macro for generating cost-supply data is executed, the "Selection Control" is set to "1" for all parameters to force the model to use values in the database in the 'Geol DB Sal' worksheet. The modeler does not need to enter any data in Sub-part 3.4.2, only Sub-part 3.4.1 if there is a need to change posted values.

Sub-part 3.5: Inputs Related to CO_2 Storage Coefficients and Calculating Maximum CO_2 Plume Area. This sub-part allows the modeler to specify the CO_2 storage coefficient and the fraction of the injection formation for which this CO_2 storage coefficient is applicable. The CO_2 storage coefficient is used in Part 4.0 to calculate the areal extent of the CO_2 plume, and it can be determined by the following:

- Using the CO_2 storage coefficient in Sub-part 3.5.1 retrieved from the lookup table in Attachment A (starts in Cell B802). The storage coefficient depends on the lithology and depositional environment for the injection formation and the structure and probability level specified by the modeler. The CO_2 storage coefficients in Attachment A are from a report by the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) (IEA Greenhouse Gas R&D Programme, October 2009).
- Specifying a storage coefficient directly in Sub-part 3.5.2.
- Specifying values for the factors composing the CO_2 storage coefficient and calculating the CO_2 storage coefficient from the product of these factors in Sub-part 3.5.3. IEA GHG discusses these factors and provide site-specific values for different types of geology (IEA Greenhouse Gas R&D Programme, October 2009).

A multiplier reflecting the influence of research and development (R&D) on the storage coefficient is calculated in Sub-part 3.5.4 and used within Sub-part 3.5.5. The multiplier is "1" if there is no influence from R&D. The modeler determines which of the CO_2 storage coefficients (lookup table, specified, or calculated) will be used for the rest of the cost model in Sub-part 3.5.5 based on the number for the parameter "Storage coefficient control" (Cell D356, which is pulled from Cell D112 in the 'Key_Inputs' sheet). The options associated with the numbers for this parameter are described in Cell F356.

The specified values for the fraction of the injection formation that has the storage coefficient specified in Sub-part 3.5.5 and the fraction of the formation with the indicated structure available for storage is in Sub-part 3.5.6 and Sub-part 3.5.7, respectively. The value in Sub-part 3.5.6 mostly relates to the fraction of the injection formation that is assumed to have a particular kind of structure (such as dome versus anticline versus flat). The factor in Sub-part 3.5.7 is intended to reflect institutional constraints (high populations such as cities may overlay some of the formation with the structure) and the influence of pressure interference between injection projects that will limit how much of the formation can be used for storage.

When the macro for generating cost-supply data is executed, the "Storage coefficient control" is set to "1" to force the model to use lookup values based on the lithology data for injection formations in the database in the 'Geol DB Sal' worksheet.

Sub-part 3.6: Inputs Related to Determining the Number of Injection Wells. This sub-part allows the modeler to specify the method used to calculate the mass rate of CO_2 that can be injected into a single well (either vertical or horizontal). This mass rate is used to calculate the number of wells needed to inject the maximum mass of CO_2 that the project is designed to handle on any given day. The inputs needed to perform the calculations for each method are specified in this sub-part. The Valluri et al. method is the default method for calculating the CO_2 injection rate (Valluri, Mishra, & Ganesh, 2021). Other methods include the Law and Bachu method and ARI method (both as reported by CCSTP (CCSTP, 2009)) and Cinar et al. method (Cinar, Bukhteeva, Neal, Allinson, & Paterson, 2008).

Part 4.0: Surface Area of CO_2 Plume and Maximum Mass of CO_2 Formation Can Theoretically Store. This part calculates the maximum mass of CO_2 a formation can theoretically store and shows calculations pertaining to the surface area of CO_2 plume and the maximum mass of CO_2 the formation can theoretically store. There are four sub-parts within this part, which are discussed below. All of these sub-parts, except sub-parts 4.2 and 4.3, are further broken down into additional sub-parts in the model to provide more detail:

Sub-part 4.1: Surface Area of CO_2 Plume. This sub-part provides the total mass of CO_2 injected over the duration of the project, basic geologic parameters, density of CO_2 at the midpoint of the formation, CO_2 storage coefficient, and surface area of CO_2 plume.

Sub-part 4.2: Mass of CO_2 That Can be Stored in Formation-Structure Combination Without Considering Pressure Interference (Storage Capacity Estimate). The total mass of CO_2 that can be stored in the formation-structure combination (i.e., CO_2 storage capacity) is calculated in this sub-part. It is constrained by the fraction for the formation-structure combination that is available for storage, which is input by the user and intended to reflect constraints that limit where CO_2 can be stored. This total mass calculation does not include the potential for multiple injection projects simultaneously injecting CO_2 into the same formation to generate pressure interference that can limit the number of projects that can be implemented simultaneously.

Sub-part 4.3: Mass of CO_2 That Can be Stored in Formation-Structure Combination Considering CO_2 Plume Uncertainty Area and a Permeability-based Pressure Interference Factor from Teletzke et al. (2018) (Storage Capacity Estimate). This sub-part calculates the total mass of CO_2 that can be stored in the formation-structure combination (i.e., CO_2 storage capacity) considering the availability constraint and the potential for pressure interference to limit the number of storage projects that can be operated simultaneously in the formation-structure combination.

Sub-part 4.4: Total CO_2 That Can be Stored in Injection Formation With Different Structures. This sub-part provides the total CO_2 that can be injected in the storage formation in different structural settings: dome, anticline, 10 degree incline, 5 degree incline, flat, regional dip, or general (no specific structure). Regional dip is the combination of 10 degree incline, 5 degree incline, and flat structural settings.

Part 5.0: Rate of Injection of CO_2 in Each Injection Well and Number of Injection Wells. In this part, the number of injection wells needed to inject a maximum daily mass of CO_2 into an injection formation is calculated. Four methods, known by their authors, are provided for estimating the number of active and total injection wells. The first two are Law and Bachu and ARI, as reported by CCSTP (CCSTP, 2009). The third, Cinar et al. provides for vertical and horizontal wells either fractured stimulated or not (Cinar, Bukhteeva, Neal, Allinson, & Paterson, 2008). The fourth, Valluri et al., provides for vertical wells (Valluri, Mishra, & Ganesh, 2021). There are six sub-parts within this part, which are discussed below. All of the sub-parts, except Sub-part 5.1, are further broken down into additional sub-parts in the model to provide more detail:

Sub-part 5.1: Number of Injection Wells and Rate of Injection of CO_2 in Each Well for Selected Method. This sub-part presents the number of injection wells and rate of injection of CO_2 in each well for the selected method.

Sub-part 5.2: Input Values Common to More Than One Method. Several input parameters common to two or more of the four methods are provided in this sub-part.

Sub-part 5.3: Law and Bachu Methodology for Vertical Injection Wells. This sub-part calculates the number of vertical injection wells needed to inject the desired daily mass of CO_2 using the method developed by Law and Bachu as reported by CCSTP (CCSTP, 2009). No enhancement to permeability from hydraulic fracking is provided in this method.

Sub-part 5.4: ARI Methodology for Vertical Injection Wells. The method developed by ARI, as reported by CCSTP (CCSTP, 2009), is used to calculate the number of vertical injection wells needed to inject the desired daily mass of CO_2 in this sub-part. No enhancement to permeability from hydraulic fracking is provided in this method.

Sub-part 5.5: Cinar et al. Methodology for Vertical and Horizontal Injection Wells With and Without Hydraulic Fracking. This sub-part uses methods developed by Cinar et al. (Cinar, Bukhteeva, Neal, Allinson, & Paterson, 2008) for calculating the number of vertical injection wells without hydraulic fracking (Sub-part 5.5.2), number of vertical injection wells with hydraulic fracking (Sub-part 5.5.3), number of horizontal injection wells without hydraulic fracking (Sub-part 5.5.4), and number of horizontal injection wells with hydraulic fracking (Sub-part 5.5.5).

Sub-part 5.6: Valluri et al. Methodology for Vertical Injection Wells. The method developed by Valluri et al. (Valluri, Mishra, & Ganesh, 2021) is used to calculate the number of vertical injection wells needed to inject the maximum rate of CO_2 that a formation can sustain in this sub-part. No enhancement to permeability from hydraulic fracking is provided in this method.

Attachment A: Lookup Table for Site-Specific CO_2 Storage Coefficients Based on Lithology, Depositional Environment, and Structure. This attachment provides the lookup table for site-specific CO_2 storage coefficients based on lithology, depositional environment, and structural setting (dome, anticline, 10 degree incline, 5 degree incline, flat, and regional dip). The storage coefficient for regional dip is the average of the values for 10 degree incline, 5 degree incline, and flat. The CO_2 storage coefficients in this attachment were obtained from the report prepared by IEA GHG (IEA Greenhouse Gas R&D Programme, October 2009). The values in the first 21 rows are from Table 13 of the referenced report while the values in the remaining rows are from Appendix E of the referenced report.

5.2 'GEOL DB SAL' WORKSHEET

This worksheet contains a geologic database with 87 geologic formations partitioned into 314 potential storage formations scattered across 36 basins in 27 states. Most of the storage formations listed are subdivided into sub-units based on state boundaries or position within a particular basin. For example, the Mount Simon formation is present in five states and found in two basins and the arch area between them. The Mount Simon is divided into 11 storage formations (storage formation numbers 187–197 in 'Geol DB Sal' sheet). The Frio formation is confined to Texas and is divided into 19 storage formations (storage formation numbers 86–104 in 'Geol DB Sal' sheet). If known, each potential storage formation is characterized by geographical, geological, and water management data including longitude and latitude of the storage formations' centroid, surface area, thickness, treated water price, water disposal cost, and salinity. The storage formations were defined to accommodate many saline storage projects while considering that the geologic data is representative of the entire storage formation.

The modeler can edit the data within the geologic database as they see fit or create a new database. Storage formations 315–334 are placeholders where the user can enter up to 20 user-defined formations (rows 318–337). However, any edits entered to the geologic database must match the current format for the model to read the new data. Storage formations 315 to 317 repeat data for three existing storage formations to illustrate how new storage formations can be added to the sheet. These three storage formations are used to illustrate output from the macro in the Cases sheet.

If the user wishes to incorporate their own storage formations, they must be included before the dark blue line in Row 338 (labeled "zz-End" in Cell A338) for the macros to read the new storage formations. The user can insert more rows before Row 338 if they need more rows for new storage formations. The row after the last row with user defined storage formations must be the row with the label "zz-End" in the first column. The added storage formations need to be numbered consecutively between user defined storage formations for the macro to work properly.

5.3 'WATER' WORKSHEET

This worksheet, known as the water module, provides calculations related to water production (or withdrawal), treatment, and re-injection (or disposal). The nine parts within the 'Water' worksheet provide inputs, include cost information that is provided to the activity cost module, and have water price information that is supplied to the financial module. Several engineering calculations that depend on geology data are also included in this sheet, which is why it is part of the geology module. Some parts of this worksheet are further broken down into additional sub-parts to provide more detail in the model.

Parts 1.0–7.0 within this sheet have geology data or engineering calculations, while Part 8.0 calculates costs that are passed to the 'Back-End_Cost Items' worksheet (which is included in the activity cost module). Part 9.0 specifies the price obtained to treat water, which is provided to the 'FinMod_Main' worksheet to calculate revenues from the sale of treated water. Costs associated with the water production and disposal wells are found in Sub-parts 4.1–4.17 in the 'Activity_Inputs' worksheet. The modeler input costs for these wells as described in the well cost part of the activity cost module (Part 4.0 discussed in Section 4.1). More information on high-level parts and sub-parts of the 'Water' worksheet are discussed below.

Part 1.0: Status of Water Management. This part provides information on water management status by indicating whether water management calculations are turned on or off. This information is pulled from the 'Key_Inputs' worksheet where that decision is provided by the user.

Part 2.0: Formation Information. Information on the modeled storage formation related to formation name, formation number in the geologic database, structure modeled, and salinity are given in this part. All the values, except the salinity which is from the 'Summ_Output' sheet, are sourced from the 'Key_Inputs' worksheet and are dependent on user input.

Part 3.0: Brine Properties. Physical properties of the in situ brine in the storage formation reservoir are provided in this part. Data pulled from the geologic database (i.e., 'Geol DB Sal' sheet) and posted in the blue cells of columns F and H are used to calculate the temperature, pressure, and salinity of the brine in the storage formation (Column D). These values are then used to calculate the brine density and brine viscosity with Visual Basic modeler-defined functions. These Visual Basic functions were adapted from functions written in the Python programming language by Karl Bandilla. The Python program BrineProperties_1_0.py is part of a series of Python programs (Google Code, 2010). This Python program was released as free software under the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at the modeler's option) any later version of the license.

Part 4.0: Calculation of the Maximum Rate of Flow in a Single Injection or Production Well. This part provides the calculation of maximum flow rate for water producing (withdrawal) and water injection (disposal) wells. Calculations of these values based on a wellbore flow model or permeability, thickness, and viscosity are provided in four sub-parts within this part:

> ***Sub-part 4.1: Calculate Maximum Rate That Water Can be Produced in a Single Well Based on Permeability, Thickness, and Viscosity.*** This sub-part calculates the rate of water production (in barrels per day) based on physical properties of the reservoir (e.g., height and bottom hole pressure for injection well) that are either pulled in from the 'Geol Sal' worksheet or 'Geo-Activity Interaction' worksheet and posted in the blue cells or calculated. The water production equation is provided in Eq. 5-1 below and in Row 47 in the model with the value calculated in Cell D45. For production, the bottom-hole pressure (P_{wp}) of the well is less than the reservoir pressure. A simple assumption is that the bottom-hole pressure differential for production or injection is the same.

$$Q_{H_2O} = \frac{7.08 \cdot k \cdot h \cdot (P_e - P_{wp})}{\mu \cdot \ln\frac{r_e}{r_w}} \qquad \textbf{Eq. 5-1}$$

Where

k = permeability (darcies)

h = height of reservoir (ft)

P_e = ambient reservoir pressure at midpoint (psia)

P_{wp} = bottom hole pressure for production well (psia)

μ = viscosity of water at reservoir conditions (cp)

r_e = effective radius of injection in the reservoir (ft)

r_w = radius of wellbore (ft)

Sub-part 4.2: Calculate Flow Rate in a Single Production Well Based on Wellbore Flow Model. This sub-part allows the modeler to enter a value to limit the rate of production (Cell D53, 10,000 bbl/d is the default in the model), which will impact the well count for water production wells. The water production rate is also calculated in this part and considers the water production calculated in Sub-part 4.1.

Sub-part 4.3: Calculate Maximum Rate That Water Can be Injected in a Single Well Based on Permeability, Thickness, and Viscosity. The rate of water injection (in barrels per day) based on the physical properties of the reservoir provided in Sub-part 4.1 is provided in this sub-part. This value is calculated using Eq. 5-1 but substituting P_{wp} with P_{wi} (i.e., bottom hole pressure for injection well). For injection, bottom-hole pressure of the well is greater than the reservoir pressure. A simple assumption is that the bottom-hole pressure differential for injection is the same as production.

Sub-part 4.4: Calculate Flow Rate in a Single Injection Well Based on Wellbore Flow Model. This sub-part allows the modeler to enter a value to limit the rate of injection (Cell D61, 10,000 bbl/d is the model's default), which will impact the well count for water injection wells. The water injection rate is also calculated in this part and considers the water injection rate calculated in Sub-part 4.3.

Part 5.0: Calculation of the Water Produced, Treated, Sold, and Re-injected. This part provides several user inputs related to water management of the water withdrawn from the storage reservoir, calculations for the volume of CO_2 in the reservoir and the volume of water produced from the reservoir, and water flows for each water management option. Water withdrawn from the storage reservoir will be disposed of or some portion treated, rendered potable, and sold for anthropogenic use. Also, some modeling has suggested that only a portion of the reservoir saline water needs to be removed to control reservoir pressure and prevent endangerment of the seal. The aforementioned information is provided in four sub-parts within this part, which are discussed below. Sub-part 5.4 is the only sub-part further broken down into additional sub-parts in the model to provide more detail. An equation for water blending (Sub-part 5.5) is given as a supplement below Part 9.0 in the model and is also discussed below. Part 5.0 mostly contains calculations, but there are some values pulled from the 'Key_Inputs' and 'Geol Sal' worksheets.

Sub-part 5.1: Inputs. This sub-part allows the user to determine whether water pre-injection production (which starts a year before injection) will be included (Cell D67, "OFF" is the default in the model) and provides the percent of the calculated mass of water to be withdrawn from the storage reservoir (Cell D68, 20 percent is the model's default) and the percent of the withdrawn water that will be treated (Cell D69, 50 percent is the default in the model). The user only has the ability to choose 20 percent, 50 percent, or 100 percent for the percentage of water withdrawn from the storage reservoir. This part also gives the duration of production, which is pulled from the 'Key_Inputs' sheet, and correlates to the user's input for operations. The percent of treated water sold is based on the salinity and the overall recovery (percentage of produced water) of the chosen treatment technology provided in Sub-part 8.2 in the 'Water' worksheet.

Sub-part 5.2: Volume of CO_2 in Reservoir at Reservoir Temperature and Pressure. The volume or mass of CO_2 in the storage reservoir at reservoir temperature and pressure (Cell D81) is obtained in this sub-part using reservoir height, porosity, and storage coefficient values pulled from the 'Geol Sal' sheet and the calculated surface area of the CO_2 plume. The volume of CO_2 in the storage reservoir establishes the volume or mass of potential water withdrawal. The mass of CO_2 injected over operations (Cell D74) is from the 'Geol Sal' worksheet but also calculated in Cell T66 in the 'Key_Inputs' sheet. A volume check is also provided in this sub-part for validation.

Sub-part 5.3: Volume of Water Produced from Reservoir at Reservoir Temperature and Pressure. This sub-part provides the volume (Cell D86) and mass (Cell D89) of water produced (withdrawn) per the selection in Cell D68. The density of water at reservoir conditions is also provided per the calculation in Part 3.0 and is used in the mass of water produced calculation.

Sub-part 5.4: Water Flows. The calculated volume of water withdrawn, treated, sold, and re-injected/disposed is provided in this sub-part. There is also a water check calculation that should equal the water produced in Cell D95.

Sub-part 5.5: Equation for Water Blending. Since no commercially available technologies have the ability to treat brines with total dissolved solids (TDS) above 230,000 mg/L, and the geologic database in the model includes formations with brine waters higher than 230,000 mg/L, a dilution equation was developed and used to calculate the amount of treated water required for mixing with the brine to bring the total level of TDS down to a treatable concentration.

This sub-part, starting in Row 186, is a supplement to Part 5.0 and provides the overall recovery for water blend (and its components) that is used to determine the percent of treated water sold (Cell D70) in Sub-part 5.1.

***Part 6.0:* Determine Number of Production and Injection Wells.** This part calculates the number of production and injection wells in two sub-parts:

Sub-part 6.1: Number of Production Wells. The volume of water produced each day (in barrels per day) and the number of production wells is calculated in this sub-part. The number of water production wells is determined by the calculated flow rate for a producing water well taking into account any limitations set by the modeler (Part 4.0).

Sub-part 6.2: Number of Injection Wells. This sub-part calculates the volume of water injected each day (in barrels per day) and the number of water disposal (i.e., injection) wells. The number of injection wells are determined in a similar manner as production wells with additional consideration given to the volume of water treated, rendered potable, and sold (Part 5.0).

Part 7.0: Specify the Depth of Water Injection Wells. This part calculates the depth of the water injection or disposal well based on the modeler's input for the depth above or below the storage reservoir for disposal of water withdrawn from the storage reservoir (Cell D120, default is 0 ft in the model) as well as the depth to the top of the storage formation from the 'Geol Sal' sheet. Entering a negative value in Cell D120 places the water disposal horizon above the storage reservoir. This negative value should account for the thickness of the seal, which is assumed in the model to be 200 ft. Entering a positive value places the water disposal horizon below the storage reservoir. This positive value should account for the thickness of the storage formation of up to 1,000 ft. The modeler can check in the 'Geol DB Sal' worksheet for formation thickness (Column S or column number 19).

Part 8.0: Costs. This part provides pipeline costs for water production and injection wells and unit costs for water treatment, disposal costs, and production through four sub-parts which are discussed below. Sub-part 8.1 is further broken down into additional sub-parts in the model for more detail. Costs within Part 8.0 align with cost categories listed under Sub-stage 6 within the 'Back-End_Cost Items' sheet:

Sub-part 8.1: Pipeline Costs for Water Production and Injection Wells. This sub-part determines pipeline costs for water production and injections with a pipeline network based on how many miles of pipeline exist per producing well. This pipeline distance provides transportation to surface facilities and to the injection well. The number of miles per producing well or injection well is entered in Cell C128. This distance is factored in capital and operating costs, which are also posted in this sub-part. Pipeline fixed capital costs is an estimation of the costs of water pipeline and other pipeline equipment (e.g., manifold) and installation (NETL, 2014). This value is entered in Cell C131 for a producing well. Pipeline variable capital costs (Cell C132) for a producing well is based on the annual mass of water produced per well (Cell D55). These costs are also calculated for an injection well (cells C135 and C136). Water production-treatment-disposal is done only during injection operations. The period over which this occurs is set in the project management module ('Key_Inputs' worksheet) and posted in this sub-part in the gray cells. For recurring period (Cell E139), the default value of "1" means capital cost occur in the first year of the period, or years that this value represents. For O&M costs (Cell E145), the default "1" value means that O&M costs occur every year.

Sub-part 8.2: Unit Costs for Selected Treatment Options. This sub-part allows the modeler to select costs for water treatment options. Three water treatment processes (reverse osmosis with vapor compression evaporation, vapor compression evaporation with mid hybrid evaporator or crystallizer, and vapor compression evaporation with high hybrid evaporator or crystallizer) are listed with costs (Electric Power Research Institute, 2016). Minimum, maximum, and mid-point costs (in 2016 dollars) are provided and de-escalated to 2008 dollars (base year in model) using an escalation factor. The modeler can determine which option to use within the light orange cells in Column H. Based on the salinity of the storage formation (Cell C25), the appropriate treatment technology will be turned on or off. There are two placeholders where the modeler can add other treatment options and costs (in 2016 dollars, light orange cells) and turn the technology on or off.

Sub-part 8.3: Cost Ranges for Selected Disposal Options. This sub-part allows the user to select water disposal costs and turn them on or off. Four disposal options (onsite-re-injection, offsite re-injection, evaporation, and offsite third-party disposal) are listed with three cost options (minimum, maximum, and mid-point). The modeler can determine which cost option to use within the light orange cells in Column G and turn the costs on or off ("off" is default in the model) in the light orange cells in Column I. Offsite third-party disposal costs are based on the offsite commercial disposal costs for the oil and gas industry, estimated to be $2.50/bbl (Energy and Environmental Research Center, 2013). These costs are overall per barrel fees paid to a third-party operator to remove the brine from the CO_2 storage site and dispose of it.

Sub-part 8.4: Unit Cost for Water Production. This sub-part provides the modeler the ability to incorporate the unit cost (dollars per barrel) of water production, which is the cost of lifting the water from the reservoir to the surface. A cost of $0.25 is estimated for lifting and transportation. Transportation costs are posted in Sub-part 8.1; production costs should reflect lifting. Based on pump efficiency and lifting from a depth of 7,500 ft, a cost of $0.19 is estimated for lifting costs. Using a fixed cost in this sub-part is a simple method to represent this cost.

Part 9.0: Price for Treated Water That is Sold. The resale of treated water to existing industries with a high-water demand could add an additional revenue stream to a carbon storage project. Industries that consume vast quantities of water include power plants for thermoelectric cooling, the agricultural industry for irrigation, and oil and gas companies for drilling purposes. This part provides the price for treated water (dollars per barrel) that is sold based on the storage formation considering industry use by region (USDA, 2014) (Energy and Environmental Research Center, 2013) (Bunch, Cort, Johnson, Elliott, & Stoughton, 2017). Costs were de-escalated to 2008 dollars (base year in model). For the modeler's awareness, the cost and industry (i.e., source) is also provided in this part and is pulled from the 'Geol DB Sal' sheet. Within the 'Geol DB Sal' sheet, columns AH and AI provide the secondary water use for each storage formation based on region and the associated treated water price, respectively. If an industry and price is not provided, the default value of $0.084/bbl is used. This treated water price is passed to the 'FinMod_Main' worksheet where it is used to calculate revenues from the sale of the treated water.

5.4 'Plume&Well Schedule' Worksheet

This worksheet provides the schedule of factors that are time-dependent and geology-dependent such as well counts, seismic effect, and growth of CO_2 plume. Within the four parts of the 'Plume&Well Schedule' worksheet, values are pulled from the 'Key_Inputs,' 'Activity_Inputs,' 'Water,' and 'Geo-Activity Interaction' worksheets and provided for informational purposes or calculated. Some parts of this worksheet are further broken down into sub-parts to provide more detail in the model. More information on high-level parts and sub-parts of the 'Plume&Well Schedule' worksheet are discussed below.

Part 1.0: Stage Durations and Operations Start and End Years. This part provides values pulled from Sub-part 1.4 of the 'Activity_Inputs' sheet for the project stage durations and operations period start and end years. These values are originally user inputs on the 'Key_Inputs' sheet with the operations years calculated per those inputs.

Part 2.0: Start and End Times for Different Well Types. This part provides begin and end years for different well types. Values are pulled from the timing table for Sub-parts 4.1–4.10 in the 'Activity_Inputs' sheet, but original values are defined in the 'Key_Inputs' worksheet.

Part 3.0: CO_2 Plume and Various Area and Length Quantities. This part provides various values for CO_2 plume and 2-D and 3-D seismic. The maximum CO_2 plume area (Cell D27) is pulled from Part 1.0 in the 'Geo-activity Interaction' worksheet, but the value originates from the 'Geol Sal' sheet. Multipliers for the CO_2 plume uncertainty area and pressure front AoR (cells D28 and D29) and 2-D and 3-D seismic margin values outside the plume (cells D30 and D31) are pulled from inputs provided by the user in the 'Key_Inputs' sheet. Remaining values (cells D32–D65) are inputs for or calculations of various items related to CO_2 plume and 2-D and 3-D seismic.

Part 4.0: Well Data. This part provides the number of strat test wells, monitoring wells, water production wells, and water disposal wells either calculated or pulled from values provided in the 'Key_Inputs,' 'Water,' or 'Geo-Activity Interaction' sheets and general inputs. Monitoring wells are provided for the CO_2 plume uncertainty area and pressure front area outside the CO_2 plume uncertainty area. Timeframes for certain aspects of the project, like installation during operations, is also provided for monitoring wells. There are two sub-parts within this part that provide other relevant data and various quantities in different years:

Sub-part 4.1: Other Relevant Data. The depth to bottom of injection formation (Cell D129) that is pulled from a calculation provided in the 'Geo-Activity Interaction' sheet is provided in this sub-part. The control for calculating the plume pressure front and 3-D seismic area, which is pulled from the 'Key_Inputs' sheet is also provided in this sub-part (Cell D130).

Sub-part 4.2: Various Quantities (Areas, Lengths, and Wells Counts) in Different Years. This sub-part provides a well drilling and completion timeline across 200 years for different well types. It also provides various quantities (CO_2 plume area, seismic effect areas and lengths, and well counts) in different years. Items related to the CO_2 plume area, CO_2 pressure front area, and CO_2 uncertainty area as well as 2-D and 3-D seismic areas is provided within rows 136–160. The CO_2 plume area, CO_2 pressure front area, and CO_2 uncertainty area are calculated and used to decide the monitoring well construction schedule and cost calculations for activities like laser system and LIDAR. The The3-D seismic areas and 2-D seismic area and length is calculated for cost estimation in the 'Back-End_Cost Items' worksheet. The well counts for strat wells, injection wells, water production wells, and water disposal wells across all 200 project years are calculated in rows 161–185. Rows 188–206, 207–225, 226–244, 247–253, and 254–260 calculate the well count schedule for above seal monitoring wells, in reservoir monitoring wells, dual completion monitoring wells, groundwater monitoring wells, and vadose zone monitoring wells, respectively, based on the well calculation methodology and related parameters defined in the 'Key_Inputs' worksheet. Well requiring corrective action are provided and corrective action well counts are also provided in this sub-part starting in Row 262.

After the plume and well calculations are done, the information is sent to the 'Back-End_Cost Items' worksheet to determine costs that are paid on the basis of well counts or plume size as well as the 'Key_Inputs' and 'Summ_Output' worksheets to display the results for the modeler.

5.5 'GEO-ACTIVITY INTERACTION' WORKSHEET

This worksheet provides information on the geology values transferred from the geology module to the activity cost module (i.e., the 'Activity_Inputs,' 'Surf Eq Cost,' and 'Drilling Costs' worksheets) or used for calculations within the project management module (i.e., 'Key_Inputs' and all five hidden results sheets), geology module (i.e., 'Water' and 'Plume&Well Schedule' worksheets) or financial module (i.e., 'FinMod_Main' worksheet). There are two parts within the 'Geo-Activity Interaction' worksheet that consist of values that are either pulled from other worksheets within the model or calculated; however, there are also four user inputs on this sheet. More information on the parts of the 'Geo-Activity Interaction' worksheet are discussed below:

Part 1.0: Parameters Determined by Geology. This part includes values pulled from the 'Geo Sal' worksheet that are either used for calculations in the aforementioned worksheets of the project management, financial, and activity cost modules or provided for informational purposes. It also includes two modeler inputs: 1) rathole depth (Cell E26), which is the extra hole drilled below the base of the target formation to accommodate wireline tool length and allow the whole target section to be logged and 2) additional depth for strat well (Cell E27), which provides for the well to assess the strata below the initial target formation. Default values for the rathole depth and additional depth for strat well are 50 ft and 500 ft, respectively, in the model. These values are added to well depths in Part 2.0.

Part 2.0: Values Determined by Geology and Universal Activity Assumptions. Calculations that use values from Part 1.0 and the 'Water' worksheet are provided in this part. This part also provides two user inputs: 1) groundwater well depth (Cell E36), which is the depth from the land surface to the groundwater and 2) vadose zone well depth (Cell E37), which is the depth between the land surface and the groundwater table (Holden & Fierer, 2005). The defaults of the groundwater well depth and vadose zone well depth in the model are 500 ft and 10 ft, respectively. All values within this part are used in well-related activity calculations in the 'Activity_Inputs' and 'Drilling Costs' worksheets of the activity cost module.

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APPENDIX: RATIONALE BEHIND KEY FINANCIAL PARAMETERS

The United States (U.S.) Department of Energy Office of Fossil Energy and Carbon Management (FECM) National Energy Technology Laboratory (NETL) developed a techno-economic model for storing carbon dioxide (CO_2) in deep geologic saline formations. This model is called the FECM/NETL CO_2 Saline Storage Cost Model, also known as CO2_S_COM. Since its last public release in September 2017, the model has undergone several modifications.

To be consistent with costs in NETL's energy system studies, which are in 2023 dollars, an escalation rate was introduced to escalate prices, revenues, and costs in the model from the base year of 2008 to a different project start year, which by default, is 2023. In addition, a methodology to obtain costs in real dollars is included in the model. Exhibit A-1 provides the suggested values for key financial variables in the model. This appendix provides the basis behind the values provided in Exhibit A-1.

Exhibit A-1. Key financial parameters in the CO2_S_COM

Financial Parameter	Real Value	Nominal Value	Location in 'Key_Inputs' Sheet
Variable indicating which escalation rate to use from base year to first year of project	0 = use default value for lower 48 states 1 = use value for region (state) (from Sub-part 14.1) 2 = use user input	0 = use default value for lower 48 states 1 = use value for region (state) (from Sub-part 14.1) 2 = use user input	Cell AC15
Variable indicating which set of escalation rates to use from base year to first year of project	1 = use Handy Whitman cost indices from 2008 (overall) to 2018 (overall) 2 = use Handy Whitman cost indices from 2008 (overall) to January 1, 2023 3 = use user input Any other number = use Handy Whitman cost indices from 2008 (overall) to January 1, 2023	1 = use Handy Whitman cost indices from 2008 (overall) to 2018 (overall) 2 = use Handy Whitman cost indices from 2008 (overall) to January 1, 2023 3 = use user input Any other number = use Handy Whitman cost indices from 2008 (overall) to January 1, 2023	Cell AC16
Escalation rate input by user to use from base year to first year of project (%/yr)	0	3.0	Cell AC23
Escalation rate to use from start of project onward (%/yr)	0	2.3	Cell AC24
Cost of equity (%/yr)	10.77	13.30	Cell AC11

Financial Parameter	Real Value	Nominal Value	Location in 'Key_Inputs' Sheet
Cost of debt (%/yr)	3.91	6.30	Cell AC12
Percent equity (remainder is debt) (%)	45	45	Cell AC10
Tax rate (%/yr)	25.74	25.74	Cell AC13

Note: Base year = 2008 and default project start year = 2023. The escalation rate variables tie into the "escalation rate from base year to start of project" in the model, which is used to escalate revenues and costs from the base year to the start year. The "escalation rate from start of project" refers to escalation of revenues and costs after the project starts.

In the model, the term "real" dollar analysis means that all prices, revenues, and costs are held constant throughout the analysis. In other words, the escalation rate applied to cash flows is zero. This analysis type is often called constant dollar analysis since it is assumed that after the effects of inflation are factored out, all prices, revenues, and costs will be constant for the duration of the project. In the future, inflation-adjusted prices, revenues, and costs are likely to increase or decrease but no attempt was made to estimate these effects in the model. In a financial analysis that uses nominal (i.e., escalated) revenues and costs, the interest on debt and the minimum desired internal rate of return on equity are provided as nominal rates that depend on the assumed escalation rate. In a real or constant dollar analysis, these rates need to be adjusted to remove the influence of inflation.

The CO2_S_COM provides two escalation rates. The first escalation rate escalates costs from the base year to the project start year (i.e., 2008 to 2023 for the purposes of this manual). The CO2_S_COM provides the user with three options for choosing this escalation rate. The Handy-Whitman indices of public utilities were used to estimate escalation rates from 2008 to 2023. The closest analog to CO_2 saline storage within these indices is natural gas storage. Thus, the Handy-Whitman Index of Public Utility Construction Costs, 1912 to January 1, 2023 – Cost Trends of Gas Utility Construction was used (Whitman, Requardt, and Associates, LLP, 2023). Handy-Whitman divides the lower 48 states in the United States into six regions and provides indices for each region. Escalation rates for 2008 to 2023 derived from the indices for each region are provided in the CO2_S_COM in Sub-part 14.2 in the 'Key_Inputs' sheet. Sub-part 14.2 also has escalation rates from 2008 to 2018; in earlier NETL energy system studies, costs were provided in 2018 dollars. The escalation rates for the six regions range 3.3–3.6 percent/yr with a median value of 3.5 percent/yr. When this rate is compounded from 2008 to 2023, a cost in 2023 is roughly 1.663 times greater than the cost for the same item in 2008. Using the Consumer Price Index inflation calculator provided online by the U.S. Bureau of Labor Statistics, the general rate of inflation from 2008 to 2023 resulted in an item in 2023 costing 1.46 times as much as the same item in 2008. Thus, natural gas storage costs increased at a faster rate than the general rate of inflation (U.S. Bureau of Labor Statistics, 2024).

The first option for selecting the escalation rate from base year to project start year is to use the median value of 3.5 percent/yr as the representative value for the lower 48 states in the United States. This value of 3.5 percent/yr is the default value for the first escalation rate. The second option for selecting the escalation rate is to use the regional value associated with the state where the storage formation is located. The third option for selecting the escalation rate is to use a value input by the user. If the user wants to use a project start year other than 2023, the user must use the third option and input an escalation rate appropriate for escalating prices, revenues, and costs from 2008 to the project start year. The appropriate variable for the escalation rate (see Exhibit A-1) to use is entered by the user in Cell AC23 of the 'Key_Inputs' sheet. The user indicates which escalation rate to use and which set of escalation rates to use by inputting the associated variable in cells AC15 and AC16, respectively, in the 'Key_Inputs' sheet (see Exhibit A-1).

The second escalation rate escalates prices, revenues, and costs from the project start year onward. It can be set to 0 percent/yr if the user desires to conduct an analysis in real or constant dollars. For nominal dollar analysis, the second escalation rate should be the user's best estimate for how costs in the CO_2 saline storage industry will increase over the next 30–80 years. In recent years, the U.S. Energy Information Administration used an escalation rate of about 2.3 percent/yr as their long-term inflation rate in the National Energy Modeling System (Goudarzi, 2017). This rate is consistent with the Federal Reserve's 30-year expected inflation rate of about 2.3 percent/yr in February 2024. This rate of 2.3 percent/yr is the default for the second escalation rate in the model (see Exhibit A-1).

The nominal and real rates of return on equity and the nominal and real interest rates on debt were determined in a three-step process. In the first step, the nominal rate of return on equity and the nominal interest rate on debt were determined using 2018 data. A nominal rate of return on equity for 2018 was determined using the capital asset pricing model (CAPM). Data from 1990 to 2018 was collected on the nine largest natural gas storage and transportation holding companies since natural gas storage is a reasonable analog to CO_2 saline storage. The working natural gas and return on equity for each of these managed companies was determined using the CAPM. The return on equity for these companies ranged 5.9–19.8 percent/yr. The average of these companies weighted by the working natural gas they managed was 13.0 percent/yr. This value is the nominal rate of return on equity in 2018.

A nominal rate of return on debt for 2018 was determined by referencing the nominal interest on debt (5.0 percent/yr) used in NETL energy system studies for the electric industry (i.e., power plants) (Theis, February 2021). The nominal rate of return on equity in this industry is roughly 10 percent/yr, which is lower than the nominal rate of return on equity for natural gas storage and transportation holding companies, suggesting that the electric industry is viewed as a lower risk investment (Theis, February 2021). As such, a slightly higher nominal interest rate on debt of 6.0 percent/yr is used for 2018.

In the second step, the nominal minimum rate of return on equity and nominal interest rate on debt were converted to real values using the Fisher equation (Eq. A-1) (Saylor.org):

$$(1 + i) = (1 + e) \cdot (1 + r) \qquad \textbf{\textit{Eq. A-1}}$$

Where

i = nominal interest rate on debt or nominal minimum rate of return on equity (1/yr)

e = escalation or inflation rate (1/yr)

r = real interest rate on debt or real minimum rate of return on equity (1/yr)

Rearranging the variables results in Eq. A-2 for the real minimum rate of return on equity or real interest rate on debt:

$$r = \frac{(1+i)}{(1+e)} - 1 \quad \textbf{\textit{Eq. A-2}}$$

The average real gross domestic product deflator of 2.01 percent/yr from 1990 to 2018 was used as the inflation rate to estimate the real rates of return on equity and the real interest rate on debt. Using Eq. A-2 with a nominal minimum rate of return on equity of 13.0 percent/yr and inflation rate of 2.01 percent/yr results in a real minimum rate of return on equity of 10.77 percent/yr. Similarly, using Eq. A-2 with a nominal interest rate of 6.0 percent/yr for debt and inflation rate of 2.01 percent/yr results in a real interest rate for debt of 3.91 percent/yr. These values are the default real minimum rate of return on equity and default real interest rate on debt in the model.

In a third step, the real rate of return on equity and real interest rate on debt are used in Eq. A-1 with the expected long-term interest rate of 2.3 percent/yr to calculate the nominal minimum rate of return on equity and nominal interest rate on debt for 2023 and beyond. Using Eq. A-1 with a real minimum rate of return on equity of 10.77 percent/yr and inflation rate of 2.3 percent/yr results in a nominal minimum rate of return on equity of 13.30 percent/yr. Similarly, using Eq. A-1 with a real interest rate of 3.91 percent/yr for debt and inflation rate of 2.3 percent/yr results in a nominal interest rate for debt of 6.30 percent/yr. These values are the default nominal minimum rate of return on equity and default nominal interest rate on debt in the model.

To be consistent with NETL energy system studies, even though the natural gas storage industries may pose a higher investment risk, the fraction of equity used for financing in the electric industry, 45%, percent, was used as the default in the CO2_S_COM (see Exhibit A-1 for cell reference) (Theis, February 2021).

An effective tax rate, which is the average rate a corporation's pre-tax earnings are taxed (Kagan, 2024), was included as a default in the model to be consistent with the tax rate used in NETL energy system studies (Theis, February 2021). The effective tax rate includes 21 percent federal corporate income tax and 6 percent to cover all state and local taxes. Since state and local taxes are deductible from federal income taxes, the effective tax rate is lower than the sum of these two individual tax rates. The effective tax rate is derived as follows. The state and local taxes are calculated with Eq. A-3:

$$tax_{S-L} = EBIT \cdot r_{S-L} \quad \textbf{\textit{Eq. A-3}}$$

Where

tax_{S-L} = state and local taxes (in escalated dollars)

EBIT = earnings before interest and taxes (in escalated dollars)

r_{S-L} = effective state and local income tax rate (1/yr)

The federal income taxes are calculated with Eq. A-4:

$$tax_F = (EBIT - tax_{S-L}) \cdot r_F \qquad \textit{Eq. A-4}$$

Where

tax_F = federal income taxes (in escalated dollars)

r_F = federal income tax rate (1/yr)

This equation includes the deduction of state and local taxes from EBIT before federal income taxes are paid. When Eq. A-3 is substituted into Eq. A-4, the following equation results (after some grouping of terms) (Eq. A-5).

$$tax_F = EBIT \cdot (1 - r_{S-L}) \cdot r_F \qquad \textit{Eq. A-5}$$

The total taxes paid is the sum of federal income taxes and state and local taxes, which is determined by adding Eq. A-3 and Eq. A-5 together. After grouping terms, the total taxes paid is given by Eq. A-6:

$$tax_T = EBIT \cdot ((1 - r_{S-L})) \cdot r_F + r_{S-LF} r_{S-L}) \qquad \textit{Eq. A-6}$$

Where

tax_T = total taxes paid (in escalated dollars)

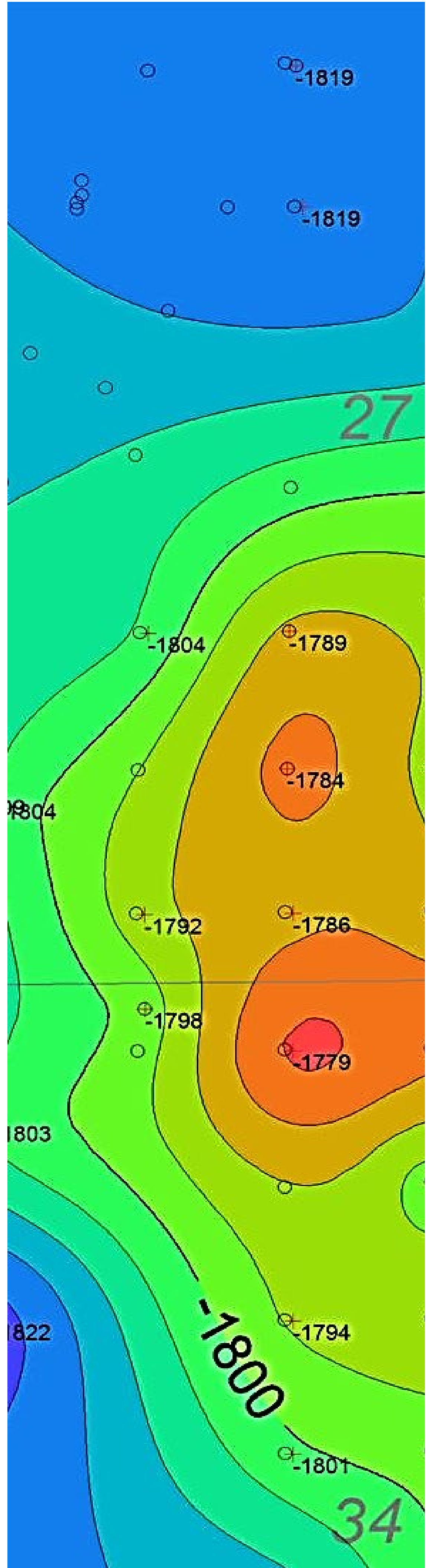
The effective income tax rate is the expression used to multiply EBIT (Eq. A-7).

$$r_{eff} = (1 - r_{S-L})) \cdot r_F + r_{S-LF} r_{S-L} \qquad \textit{Eq. A-7}$$

Where

r_{eff} = effective income tax rate (1/yr)

Substituting 0.21 (21 percent for the federal income tax rate and 0.06 (6 percent) for the effective state and local income tax rate into Eq. A-7 gives an effective income tax rate of 0.2574 (25.74 percent).



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