CCUS in Cement Industry: Conceptual Design Report for NEMS Implementation

Prepared by OnLocation, Inc. for DOE Office of Fossil Energy

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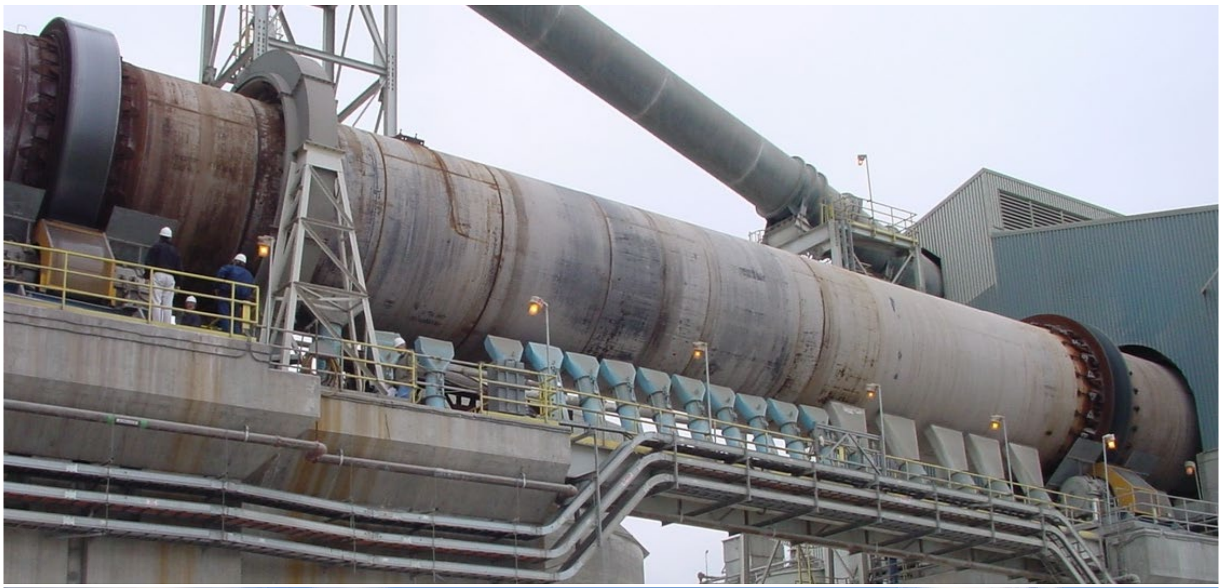

Abstract

This document provides the conceptual design report to implement carbon capture, utilization & storage (CCUS) and other CO_2 emissions technologies as applied to the cement industry in the National Energy Modeling System (NEMS). This work was performed for the U.S. DOE Office of Fossil Energy and Carbon Management (FECM). In preparation for this report, two previous reports were submitted in June 2021: 1. Cement Carbon Capture, Utilization and Storage (CCUS): Technology and Trends and 2. CCUS in Cement Industry: Assessment of the Industrial Demand Module (IDM) in NEMS. The first report summarized the technology options available to achieve CO_2 mitigation in the cement industry. The second report summarized the current state of cement industry calculations in the NEMS Industrial Demand Module (IDM).

The current calculations in the IDM were studied with respect to regionality, technology shares, and retrofits, all of which are pre-requisites for the application of the technology options available. It is found that the IDM today uses data at a highly aggregated level that is incompatible with the granularity required in the modules that would use the CO_2 captured, such as CTUS. A unit-level calculation approach is preferred but requires that a new way be proposed to calculate technology replacements for existing units and technology choice for new units. We also suggest rebuilding the process step calculations in the cement industry instead of only targeting the steps with CO_2 mitigation opportunities, irrespective of whether these calculations are housed in the existing IDM, as a new separate module, or in a new programming language. The multinomial logit function used for the technology share calculation would be challenging to use for this model because it was found to be insensitive to market conditions. It also is not compatible with a unit-level calculation approach. The IDM also lacks a retrofit capability for existing units, which consists of the majority of the opportunity for CO_2 mitigation technology.

The development of the DOE-FECM database of all the cement plants in the U.S. is a promising new data source that is available to utilize for unit-level calculations of these technologies. Before we use the database, it needs to be enhanced by adding the energy consumption data for the listed plants, the ratio of additives in the final product, data on emissions that are not reported, and the vintage of each plant.

We propose a modeling framework based on a Knowledge-Based Modeling (KBM) approach that consists of four areas of development: expansion of the knowledge base with additional data, reconciliation of data with current NEMS model, generation of input data for the model, and building model calculations.

In order to execute this project, we propose the activities of knowledge base enhancement and input generation, model development, integration with NEMS and testing at OnLocation, documentation, and optionally, integration with EIA's version of NEMS. These activities would include a plan for updating the model on a regular basis, a model specification document, and a final report. We estimate that it would take approximately 33 weeks to implement the proposed model changes. This schedule would potentially support integration with the AEO2023 version of NEMS.

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Introduction

This document provides the conceptual design to implement carbon capture, utilization & storage (CCUS), and other CO_2 emissions technologies as applied to the cement industry in the National Energy Modeling System (NEMS). In preparation for this report, two previous reports were submitted in June 2021, and their findings are summarized below.

Report on CCUS Trends for Cement Industry[1]

This paper provided an overview of the current state and trends of carbon mitigation technologies and strategies in the cement industry. It detailed the common non-capture strategies for reducing CO_2 emissions, including energy efficiency, the use of alternative fuels, and the increased use of blended cement types. It also gave details on capture technologies, including chemical absorption (amine scrubbing, chilled ammonia process, and the SkyMine® process), oxy-combustion, calcium looping, membranes, and direct capture. Technical details of each process were provided as well as a summary of pilot and demonstration plants using those technologies and an evaluation of the technology's market readiness. A literature review of the costs of these technologies was performed, and a new data source developed by DOE-FECM for the cement industry was evaluated for its usefulness in developing inputs for modeling these technologies in the National Energy Modeling System (NEMS). While no full-scale commercial capture facilities exist in the cement industry, research and development have significantly advanced in the last 7-10 years with multiple pilot demonstrations across the capture technologies. Additionally, the global cement industry has committed to reducing carbon emissions, and research and development of these technologies are actively being pursued. Amine scrubbing is the most advanced and proven technology for carbon capture in the cement industry. As it is a proven technology in the power industry, it has more quickly been translated to the cement industry; however, it comes with high energy costs. Oxy firing and calcium looping lag behind in the R&D pipeline but show promise for the future.

Exhibit 1 summarizes the technology options available for the cement industry with respect to reducing CO_2 emissions. All the potential options studied will be considered available to be adopted by the cement industry in our modeling approach.

Exhibit 1: Available technologies for CO_2 emissions reduction

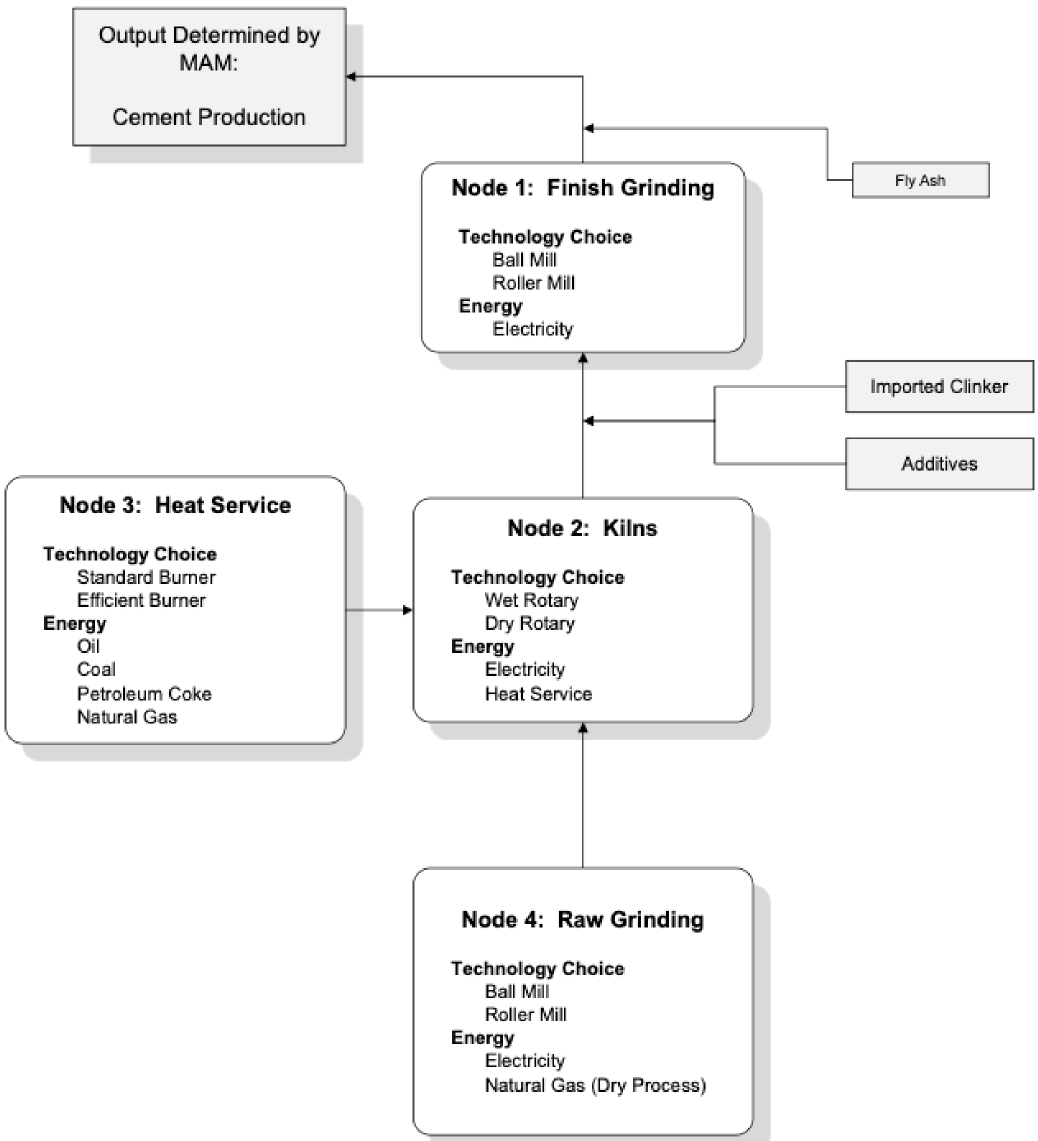
CCUS Technologies	Non-capture Strategies
• Chemical absorption • Oxy-combustion • Calcium looping • Membranes • Direct capture	• Energy efficiency improvements • Alternative fuels • Use of blended cements

[1] Cement Carbon Capture, Utilization and Storage (CCUS): Technology and Trends, submitted to DOE-FE, June 21 2021

Report on Cement Industry Calculations in Industrial Demand Module[2]

This report provides a summary of the Cement Industry submodule within the Industrial Demand Module (IDM) of NEMS. The IDM generates long-term projections of industrial sector energy demand for 21 different industry groups, including cement. The cement industry is one of the energy-intensive manufacturing industries in the IDM.

Exhibit 2: Cement Industry Calculation Flow in IDM



Source: U.S. Energy Information Administration

The IDM calculates the fuel consumption in the cement industry in four steps in reverse order of the actual process, starting with the final output (see Exhibit 2). The four steps are finished grinding, kiln, burner

[2] CCUS in Cement Industry: Assessment of the Industrial Demand Module (IDM) in NEMS, submitted to DOE-FE, June 30 2021

(heat service for kiln), and raw grinding. While all the steps use electricity as an energy source, only the kiln heat service and raw grinding steps use thermal energy via natural gas and other fuels. The inputs to these calculations consist of cement production at a census region level, technology types available for each step, costs and fuel consumption for each technology, and input constants required for calculation. Typical calculations in each step involve determining surviving base and added capacities from previous years and then determining the technology shares of added capacity for the current year using an iterative process. While the base capacities retire linearly, the added capacities retire based on a survival function, and the technology shares are determined using a multinomial logit function. The outputs of the model are again at the census region level and include the physical output and value, energy consumption by fuel, and clinker CO_2 emissions from the kiln step.

The goal of adding CCUS technologies to these calculations was then discussed from the following perspectives: 1. Producing results in the regionality that is required in other NEMS modules (for example, the Carbon, Transport, Utilization and Storage (CTUS) model as well as the fuel supply modules), based on data available from other sources, 2. Accounting for the process and combustion CO_2 emissions, which would mean adding calculation steps 3. Adding steps to incorporate the costs and quantities of CO_2 capture based on available technologies, which would involve adding new technology types and proposing a way to do retrofits of existing capacity, and 4. Adding steps to incorporate the costs and quantities of CO_2 emissions reductions due to the use of alternative energy sources, changing cement blends, and more efficient technologies.

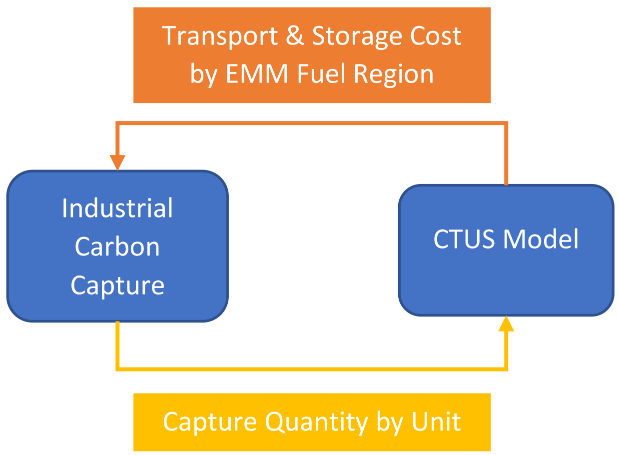
Impediments in the Current IDM for Implementing CCUS

Based on the current IDM approach to cement industry calculations from the perspective of our goal of adding CCUS and other CO_2 emissions reductions technologies to existing and new cement plants, we see several impediments in the current IDM that hinder the incorporation of CCUS. These are discussed in the following sections

Regionality

Currently, IDM performs calculations for the cement industry, as shown in Exhibit 2. It loops through each census region to calculate the required outputs at each step of the cement industry process. The census region is a suitable resolution in the NEMS context since many NEMS calculations are performed at the census division level. Historically data on the cement industry has not been available at a resolution higher than the census regions, and in fact, the technology shares of existing cement capacity were only available at the national level. However, in the context of CO_2 emissions, we are interested in accurately estimating the overall costs of CO_2 mitigating technologies as applied to the cement industry. One component of these costs is the transportation and storage costs of moving CO_2 from the point of capture to a sink, either an enhanced oil recovery (EOR) site or an underground saline formation. In the case of an EOR sink, there is no storage cost incurred, but the cost of transportation must still be known. Both these types of facilities are spread throughout the 48 states, and as such, require accurate distances to accurately calculate capture, transportation, and storage costs. Today the transportation and storage calculations are performed in NEMS using the Carbon Transport Utilization and Storage (CTUS) module and require capture quantities at individual locations of plants (today, the types of industries served by this module include power, ethanol, natural gas processing, and hydrogen). See Exhibit 3 for the typical flow of capture quantities and costs between the industrial capture models and the CTUS module. Reducing the regionality to the four census regions would provide potentially misleading information back to the cement industry calculations regarding the costs of CCUS and will lead to inaccurate projections of CCUS adoption within the industry. Moreover, we have new information on the locations, emissions, and technologies used for all individual cement production plants in the 48 states due to a database created by DOE-FE. This provides an opportunity to leverage unit-level information to better identify potential CCUS and other applications in the industry. Unit-level information can also be aggregated to any regionality as needed for reporting.

Exhibit 3: Data Flow between Industrial Capture & CTUS

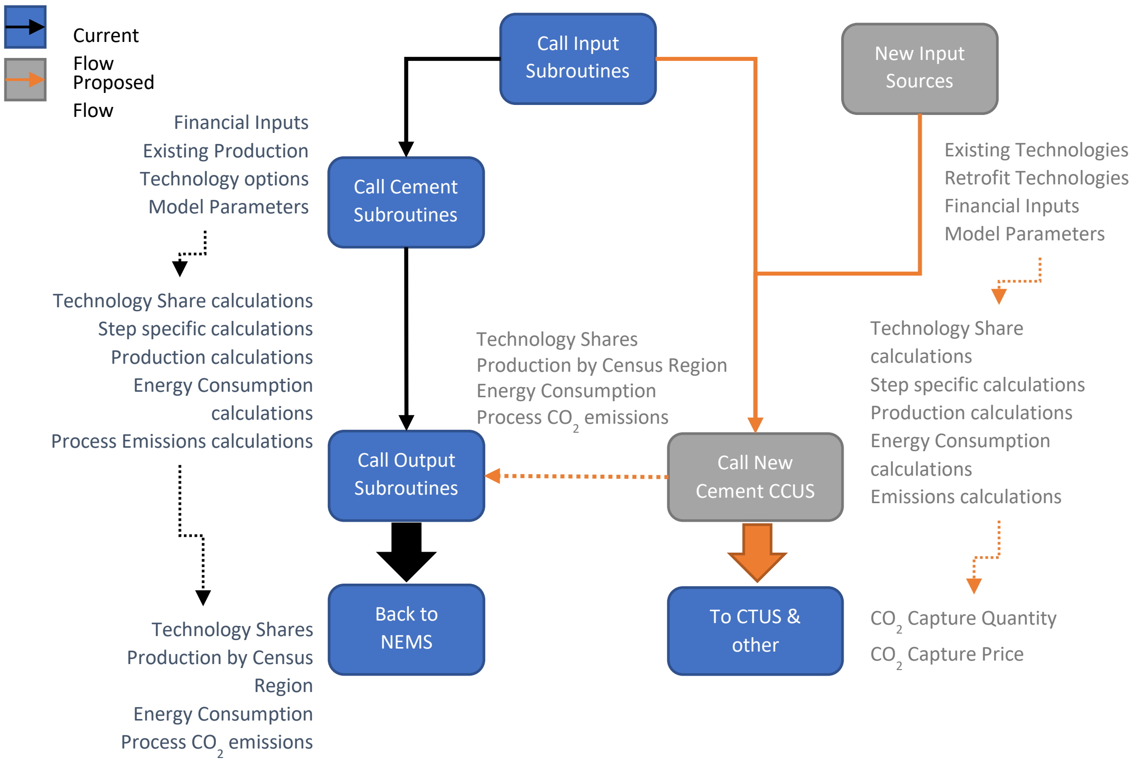


Challenges with Changes in Regionality

Today in the IDM, technology shares of added capacity are calculated using a multinomial logit function. Using user-specified parameters that weight different factors affecting technology choice, an iterative procedure determines the fractional share of technology in the new additions. In addition to the fact this calculation is found to have several issues in the way it is implemented today (see Section: Technology), this type of calculation is only suitable for aggregated data containing multiple units and does not make sense to use for individual units; a unit either uses one type of technology or another, but not both. As a result, once the calculations for CO_2 mitigation costs in the cement industry are carried out at the unit level, a new way of determining the choice of technology for the unit must be proposed. These can take many forms, and a potential solution is proposed in the model framework features section.

Working with data at the unit level poses a challenge to the way new and existing capacity is calculated in the IDM. One option is to introduce new subroutines in the IDM that perform cement industry calculations with CCUS technologies provided as options for both new and existing capacity and that perform these calculations at the unit level (see Exhibit 4). This leads to the question of which process steps in the cement industry and even which calculations within those steps should be part of these new subroutines. Not all process steps in the cement industry have CO_2 emissions; only the kiln step and the associated heat service contribute most of them. Even so, the most efficient way to create the new subroutines would be to recreate all the process steps in the new subroutines in order to avoid the issue of aggregating and disaggregating data between the old and new subroutines. This would also allow the introduction of CO_2 mitigating technologies to non-kiln steps of the process. The new subroutines would still provide the same outputs back to NEMS as are provided by the IDM today, but they will additionally provide CCUS adoption and capture quantities that can be used by CTUS.

Exhibit 4: Current and proposed data flow for cement industry subroutines



The new subroutines could potentially be in a new module altogether where all cement processing steps are done, leaving only the building energy consumption calculations in the IDM. Then it could be written in a language other than Fortran, like Python. We can also avoid connecting all the new outputs from cement back to the IDM, instead just replacing cement data in the rest of NEMS with these new outputs. It could still remain in Fortran since a knowledge base of how to connect Fortran code to NEMS exists.

Technology Share Calculation

As mentioned in the previous report, the total cement production in a given year includes the remaining capacity from the base year, added capacity from previous years, and new capacity required for the given year. New capacity additions for the given year need to include calculations to determine the share of each technology available to fulfill the requirement. In the IDM, this is done via a multinomial logit calculation, in which user provided weights are applied to each factor used to make a choice (capital & operating costs, fuel costs, emissions costs etc.) in a linear function and then exponentially weights each technology relative to the total in order to determine the share. An iterative procedure uses a given input share to develop a stable share for each technology using other user-provided constants. Since AEO21, added capacity shares used to calibrate the logit are different than base capacity shares, since the latter data is from 2005. However, there are seen to be some issues with these calculations as they occur in NEMS today and are listed below

- **Responsiveness**: It is seen to be not sensitive to changes in fuel prices, such as may occur due to a CO_2 pricing policy. This is an important issue that has been known to persist across AEO versions. See Exhibit 5, Exhibit 6, & Exhibit 7 that show that the burner technology share by fuel type is pretty much the same over time for three distinct AEO2020 scenarios: 1. Reference Case, 2. High Carbon Price after 2040, 3. Carbon price starting at $35/ton that rises at 5%/year. This can likely be rectified by adjusting the constants used in these calculations, but it still does not eliminate the problem of dependence on user-driven constants in the model.
- **Current implementation**: There are inconsistencies in how the calculation is applied. The common subroutines available in the IDM are not always used in the calculations but are rewritten in each step. Apart from the inefficiency of this approach, there is also an issue of the accuracy of these calculations.
- **Technology acceptance**: The only way to introduce new technology into the industry is by way of added capacity each year. Since the percentage of added capacity is usually somewhere along the order of magnitude of GDP growth plus annual retirements, new technology does not rapidly grow its share in the industry over time.
- **Regionality:** Technology shares for added capacity are only calculated at a national level since that is the available resolution. This dilutes the effect of regional prices and produces a generalized forecast that does not represent the local share accurately

If we provide CO_2 mitigating technology options for new capacity at the unit level, the logit function is no longer appropriate, as mentioned in the Section:

Challenges with Changes in Regionality.

Exhibit 5: Burner Technology Share for Scenario 1, Reference Case

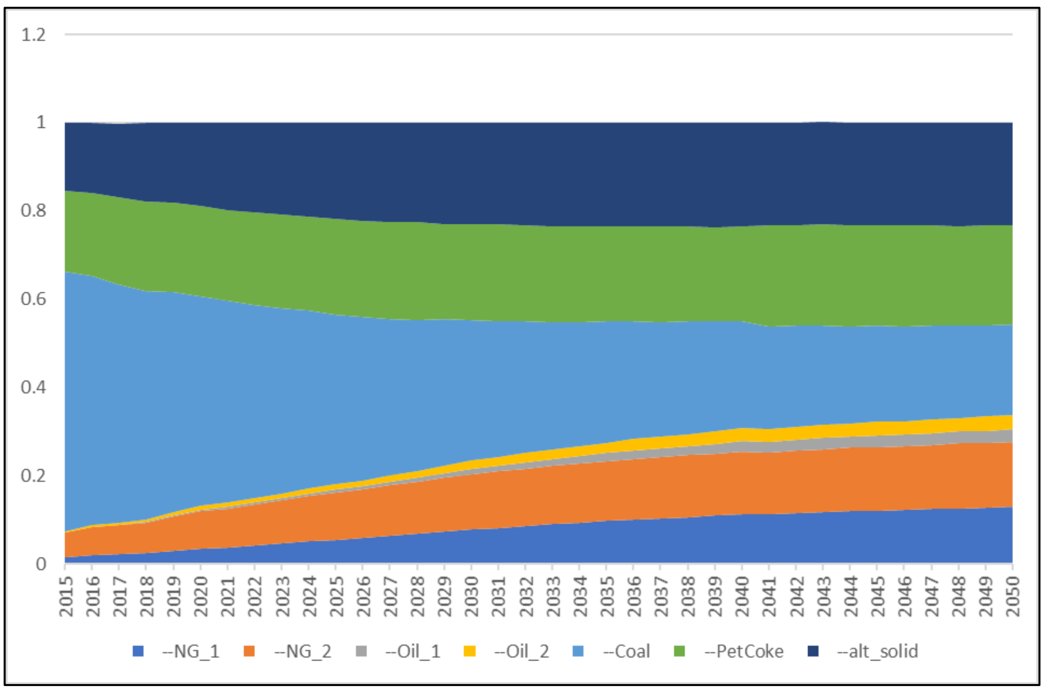


Exhibit 6: *Burner Technology Share for Scenario 2, High Carbon Price after 2040*

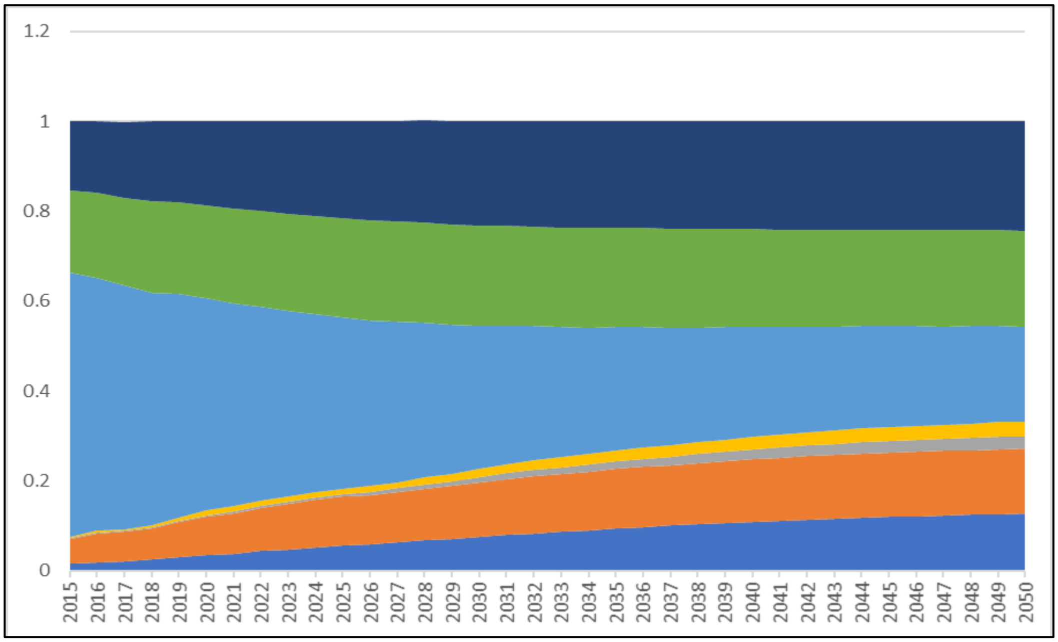
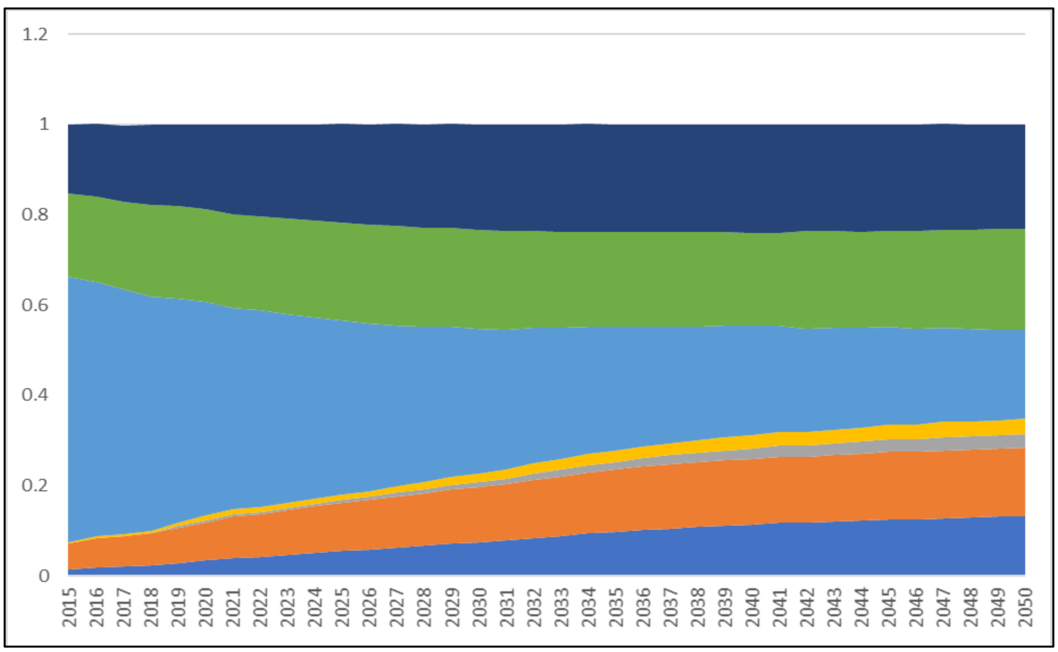


Exhibit 7: Burner Technology Share for Scenario 3, $35/ton Carbon Price rising at 5%/year



Retrofits to Existing Capacity

Currently, in the IDM, the total production in a given year includes the remaining capacity from the base year, added capacity from previous years, and any new capacity required for the given year. The existing capacity from the base year is the part left over from retiring base year capacity at a linear rate. The added capacity in previous years also retires but using a survival function that rapidly rises/falls in the start and end years of its life but retires approximately linearly in intermediate years. Note that the share of technology that is prevalent for base capacity and capacity added in previous years does not change, i.e., there are no retrofits for existing capacity in the IDM calculations. This poses a problem for the purpose of mitigating CO2 emissions in the cement industry since the new capacity is a small fraction of the total. The majority of the mitigation opportunity lies within the existing capacity either through retirements substituted by new sites or replacement of existing units by new technology. These replacements may include both CCUS technologies and non-CCUS related emissions reductions.

Utilization of New Data Sources

Currently, the cement industry calculations in the IDM are limited by the granularity of data that is available. Typically, these data are available only at the national and census region level via the MECS data which is updated once every few years. Industry data are also updated using annual state surveys, but typically they don't include unit-level information. DOE-FECM has sponsored the construction of a database of all cement industry units (and other heavy industries) in the 48 states using varied data sources such as the EPA CEMS database and USGS. The information available includes:

- Site name
- Geographical coordinates (city, state, latitude, longitude): This is most helpful for generating data for use in CTUS, which builds pipelines from specific capture locations to specific storage facilities.
- Details on each kiln at the site and their type: This helps identify opportunities for CCUS applications in terms of process CO_2 emissions that can be captured.
- Fuels used for the kiln heat service: This helps calculate current CO_2 emissions from combustion, and therefore the combustion capture opportunities. However, the proportion of fuels used in the case of multiple fuel usage is not known from this database. This creates an issue in terms of calculating the energy consumption for the industry by fuel and subsequent emissions as is needed by NEMS. It would also be difficult to calculate opportunities for capture for these units. We would also need to reconcile the known fuel consumption with what is reported in the industrial sector in NEMS.
- Stacks reporting emissions: This helps us understand what quantity of the CO_2 emissions is known if all the stacks do not report emissions. It also helps decide the point of capture for CCUS technologies.
- Clinker capacity: This provides production data that can be aggregated as needed for reporting purposes. It may require an additional step of reconciliation to ensure that the production quantities for the current year match the total quantity in NEMS. It also does not specify the additives and imports to the clinker that can be adjusted as part of any non-CCUS strategy for CO_2 mitigation.
- Capacity factor: This is another element that helps calculate the opportunity for potential mitigation technologies.
- CO_2 emissions per clinker quantity: This is the most critical information available that directly provides the potential capture opportunity from each unit from combustion and non-combustion sources. However, the emissions reported may not be 100% of the total emissions but depend on which stacks are reporting them. In some cases, a portion of the flue gas containing emissions may be used for pre-heating and be released through another stack that does not report the emissions. There would have to be an exercise that calculates the proportion of total CO_2

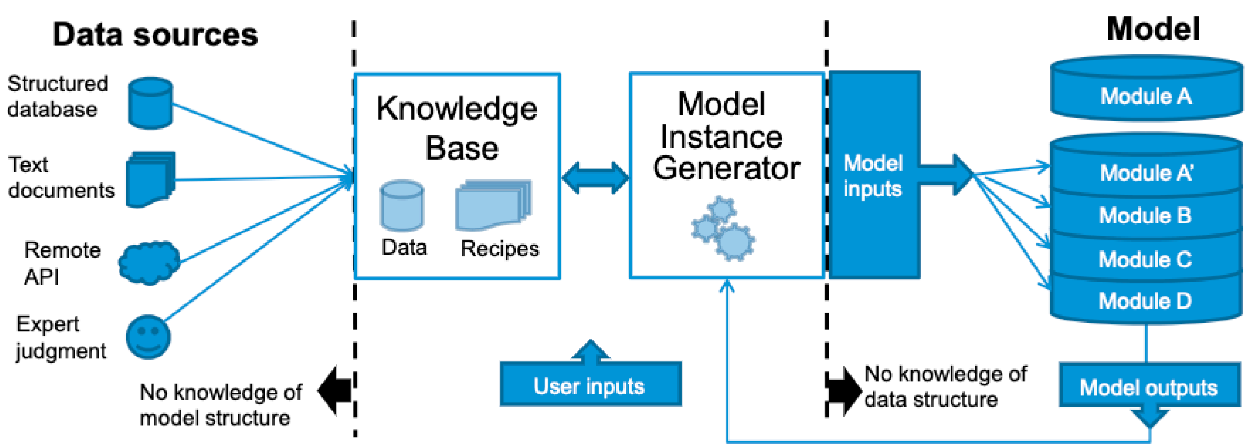
emissions that are reported and set a baseline for potential capture. The total emissions in would also have to be reconciled with the reported numbers in NEMS.

- Other non-CO_2 emissions (not comprehensive): This is not relevant for the current exercise but is mentioned for completeness
- Year built and last modified: For a small number of sites, the vintage of the site is known either by the year of construction or the year of last update, or both. This is required information in order to perform calculations regarding capture costs. If a unit is slated for retirement within the timeframe of the model, it limits the capture opportunity for the site and requires new capacity to replace it either at the same site or at a new predicted location. We, therefore, need an effort to fill in the vintage of each plant or the retirement year, plus make an estimation of where replacement capacity would be built.

Modeling Framework Features

Based on the previous discussion, it is apparent that the current approach in IDM for the cement industry cannot be directly utilized in order to introduce CCUS and other technologies. The regionality in the IDM is currently too aggregated; there is no retrofit capability for existing units, and the methodology used for new units has several issues. Therefore, we propose a much more granular approach to applying these technologies using a unit-level financial model that can be used for both existing and new units. This approach is loosely based on a Knowledge Based Model (KBM) Approach[3] that utilizes the system knowledge to formulate a model structure (see Exhibit 8). Today we have various sources of information regarding cement industry that are mainly encapsulated in the DOE-FECM database along with the list of potential technologies and their features. There are some deficiencies in that knowledge base that need to be addressed in order to feed into the necessary model calculation steps. This data can then be reconciled with the current NEMS data allowing for the seamless generation of the required input files to the model data. The components of the model development are sequentially listed as follows

Exhibit 8: Knowledge Based Modeling Framework



[3] Innovations in energy system modeling, APERC Annual Conference 2019 16 May 2019, David Daniels, Chief Energy Modeler

Expand knowledge base with additional data

The following additional data would be required to enhance the currently available unit level cement industry database, based on the discussion in the previous section. This data could either be part of the same database or be provided as supplemental information with a mapping to the sites in the current database (this may be the case if the current database is part of another project with its own deliverables). If this data is not available, then methods to impute the data will be constructed using information from the database and from MECS as currently used by IDM.

- Unit energy consumption of each unit
- The proportion of fuels used in each kiln, if multiple fuels are used
- Estimated total CO_2 emissions from each unit, in addition to the number reported today
- Percentage of additives in the final clinker production at each site
- Potential CO_2 capture opportunity for each site based on stack configuration
- Energy sources used by process steps other than the kiln steps
- Potential opportunity for energy efficiency improvements or fuel switching
- Vintage of each site with a potential year of replacement or retirement

The following information would need to be generated for the new mitigation technologies that are proposed, either from literature or previous reports:

- Type of technology: CCUS or Process Improvement
- Costs of technology: Capital & Operating
- The expected lifetime of the technology
- Minimum size to apply CCUS retrofit
- CO_2 capture percentage in case of CCUS
- Energy reduction quantity in case of energy efficiency improvements
- Unit energy consumption in case of alternative fuels
- Range of change in the proportion of additives to clinker
- Expected time of construction
- Other financial considerations such as depreciation schedules

We also need to create user inputs to determine the features of new capacity that is added on an annual basis. These are as follows and would be part of the model calculations:

- Forecasted new capacity requirement based on NEMS or another forecast at a more granular level subdivided by an algorithm into regional data.
- The threshold for required new capacity in a given region that triggers new sites being built, below which existing units are expanded or replaced with new larger units
- Location of new capacity, for example, if there is new capacity in a state, is it even spread out over existing sites in the state or is it concentrated in 1-2 specific locations
- The capacity factor of new units built, whether based on a national or regional average.

If, at the end of this phase, some information is still unknown, reasonable assumptions would be made to represent the data with the best possible estimate.

Reconcile data with current NEMS information

While the data in NEMS used for the IDM is generated from the top down, the cement industry data is built from the ground up. In an ideal scenario, the data at the individual unit level when added up to the national level, should approximately equal the numbers in NEMS. This is particularly important since the data for the cement industry is not used in isolation in NEMS but is part of the entire industrial sector, for which total production value, energy consumption by fuel, and emissions are known. Therefore, a reconciliation stage must follow the expansion of the knowledge base focusing on the three major areas: Total production and dollar ($) value, energy consumption by fuel, and CO_2 emissions. This reconciliation step can proportionally adjust the numbers at a national level in the knowledge base to match with the ones used by NEMS. An additional regional factor can also be applied to subdivide the data further based on the current proportion of production in each region.

Generate input data for the model

Once the knowledge has been enhanced with additional data and then reconciled with existing NEMS information, we can now generate a standardized input stream for the model. The input data would consist of the following data at the unit level, combining the existing database with the expanded knowledge:

- Site name
- Geographical coordinates (city, state, latitude, longitude
- Number of kilns at each site and their type
- Fuels used for the kiln heat service and their proportion
- Energy sources used for other process steps
- Unit energy consumption of each kiln and grinding equipment (raw and finished)
- Point of capture for CO_2 emissions and its proportion of total emissions
- Clinker capacity and current proportion of additives
- Capacity factor
- Total CO_2 emissions per clinker quantity and proportion available for capture
- Vintage of the unit and potential remaining age

New technology options for CCUS and other mitigation technologies would be part of another table input and would contain the same data generated in the knowledge expansion step and would require no additional adjustment.

Build model calculations

Determine capacity additions required

This step determines how much additional production is needed at the regional level based on a national increase needed.

1. First, calculate the increase in regional capacity required based on the current NEMS algorithm[4]
2. Calculate the proportion of the current capacity in every region of the national total
3. Subdivide the required additional capacity into each region based on the above proportion
4. Classify the growth into existing sites and new sites based on the magnitude

[4] The Macroeconomic Module in NEMS produces industrial output and dollar value projections at the 9 census divisions.

5. Calculate the additional capacity in each step of the cement process in reverse order as is done in the IDM today

Determine retrofits for existing capacity and technology used for new capacity

This step would calculate the proportion of existing capacity that gets either retrofitted with CCUS technology or gets replaced a new unit, and the proportion of new capacity that comes with CCUS capability or has energy efficiency improvements by use of alternative fuels. For existing capacity, the following calculations would be carried out to make decisions:

1. Calculate the potential for technology change based on one or more of these existing characteristics
    a. Equipment is in retirement year
    b. Fuel for the kiln can be changed and is available regionally
    c. More efficient equipment types are available
    d. Current stack configuration allows for capture
2. Determine the cost of each of the following technology options:
    a. Keep existing technology and incur current fuel costs and emissions penalty (if any)
    b. Retrofit CCUS technology to existing unit
    c. Replace unit with new unit with similar fuel but with CCUS available
    d. Replace unit with alternative fuel without CCUS
    e. Replace unit with alternative fuel with CCUS
    f. For each of the replacement decisions, select among efficiency options if applicable

Note that each fuel and CCUS option consists of several choices in itself. An economic evaluation is done using the capital costs of new installations, operating costs including fuel costs, storage costs, and capture credits against an emissions penalty that would otherwise be incurred. Economic evaluations of this kind are performed in several NEMS modules. For example, the Oil & Gas Supply Module (OGSM) makes decisions on which oil/gas plays to develop using a Net Present Value (NPV) calculation and selecting those with the highest NPV. The commercial module uses technology life-cycle costs to evaluate energy efficiency options. One concern that may need to be verified and addressed in the prototyping stage is whether rapid retrofits of existing capacity using a single technology due to its favorability in a given year ("winner-take-all") occurs. Potential alternative approaches to avoid such a scenario include segmenting the production units by criteria (technology groups, financial rates) or limiting the rate of new technology adoption.

New capacity calculations would occur similarly with options with regards to technology choices but would start directly with the economic evaluation of various configuration options.

Once the economic costs at each site have been calculated, the choices can be sorted in order of the most to least profitable options (for example, from high to low NPV) and then apply the choices in order until some criteria are met. Depending on user choice, this can be either a cap on total expenditure, the production capacity retrofitted (such as a fraction per year), or the total reduction in emissions. Note that one of the choices for existing capacity is to retain the current equipment unchanged.

Calculate production, technology share, and energy consumption

Similar to the calculations in the IDM, once the technology choices have been made, the total production for the given year that satisfies the forecasted growth is calculated using the existing capacity with the existing and retrofitted technology, the previously added capacity with existing and retrofitted technology, and new capacity. The share of each technology across existing and new capacity would also be calculated, along with the energy consumption by fuel type. These numbers are calculated for each process step of the cement industry and will replace the existing outputs from the IDM. The cement industry process calculations will be deactivated in the IDM module as well in order to avoid double counting.

Report outputs back to NEMS

Once the decisions on retrofits and new capacity are made and energy consumption calculated, the results can be reported back to NEMS in the resolution needed. For CTUS, these would be the capture quantities each year from each site. For NEMS in general, the reported outputs will be rolled up to the census region level and include the total production and dollar value, energy consumption by fuel, and total CO_2 capture and net emissions. These reported outputs will replace the existing outputs from the IDM regarding the cement industry.

Implementation Plan and Timeline

In order to implement the proposed modeling framework, we propose the following rough outline of tasks that would be executed as part of the project when launched.

Project Execution

The modeling framework provides a good guideline for project execution. We propose the following activities to be carried out for the model implementation:

Knowledge Base Expansion and Inputs Generation

- We will first focus on the data collection activity that includes the three main areas of enhancing the cement database, creating a database of CO_2 mitigation technologies for cement, and creating an agreed upon methodology to introduce new capacity into the model.
- We will also create reasonable alternatives to the required data, in case procuring them is infeasible due to lack of availability, resources or long-term financial reasons. For example, some cement industry data may be proprietary and would need to be re-purchased on an annual basis or at least every several years. This is incompatible with the update methodology for NEMS which relies on publicly available information.
    - A review will be conducted at the end of this phase, where the procedure to update the data collected on a regular basis is provided.

Next, we will generate input data required for the model, that includes completing the reconciliation of the expanded industry data developed with existing NEMS information. This phase can be performed in close coordination with NEMS experts or with the EIA itself so that any data from the new sources is consistent with internal NEMS data when aggregated to the same regionality.

- Initially, we will develop a methodology for data reconciliation and any specifics related to the individual data types of production, energy consumption, and emissions.
- This will be followed by the implementation of the data reconciliation to the knowledge database created, which requires the completion of that step as a pre-requisite.
- The next step would be the creation of a data transformation tool that converts the data in the knowledge base into a standard format, ensuring reuse of the steps for all future model tests.

- There may be a prototype version of this tool first in a format (say Python) that is different from the version of the tool that is incorporated into the final model (say Fortran).

Model Development

The model development starts with document with a detailed description of the model calculations, followed by a review with the stakeholders. This will ensure that the work performed on the model is in line with the expected deliverables of the project. An important aspect of the model description will be the steps required for its integration into NEMS.

The model that calculates the costs of technology options and determines the mix that meets demand can be developed immediately thereafter. It includes the calculation of the required capacity additions, followed by retrofits of existing technology and new technology builds, based on the economic evaluation of each option. This may involve the development of a prototype Excel or Python version of the model that uses the model inputs created from the database. Once the test versions of the core model components are found to work within specifications, the reporting of outputs to NEMS would be developed in order to pass information to various modules. This includes testing whether the retrofits to existing capacity occur at realistic rates with diverse technologies. The final version of the model would incorporate all the required features of the model specification and would be ready for integration into the overall NEMS structure. Both the data transformation and model creation steps require skillsets in the required programming languages and good knowledge of NEMS model structures to ensure compatibility.

OnLocation Model Integration and Testing

Once the model is built, it must then be integrated with other NEMS models and then tested.

- The integration involves linking the outputs from the model to various modules in NEMS representing various optimization models (LPs) as well as the post-run reporting modules such as the FTAB. This may involve modification to the source of these modules to represent data from the new cement industry model.
- The integration phase would not be just for Cement CCS but also the full CTUS updates for other industries done by OnLocation. Currently, the CTUS updates to NEMS have been done in AEO 2020 version; thus, the development of the cement industry model can either be added to that AEO version, or all the updates can be implemented in the latest available AEO version. This provides the comprehensive package of CCUS model enhancements performed to date.
- The model will be tested under a range of scenarios in order to determine its sensitivity to potential scenarios of carbon capture regulations and tax policies. We will determine if the model effectively answers the questions defined in the requirements phase. Testing can include Independent Expert Reviews that assess the modeling approach and the assumptions and results.

Model Documentation & Handoff

- The model is documented through code annotations and, most importantly, through a written report. This is important not just for internal use by other modelers but also for peer-review of the model and the results that are subsequently produced.
- Updates to the model can occur whenever data sources to the model are updated as part of regular maintenance, or new features are required to be developed due to changed conditions.

These updates will also be needed to ensure the compatibility of the model with future AEO versions. As a result, the final delivery of the model will be accompanied by a recommendations document for future maintenance and updates for the model.

[Optional] Integration with EIA's version of NEMS

OnLocation would integrate and test the Cement CCUS and other CTUS enhancements in coordination with EIA. This step is optional and would depend on the priorities set at the start of the project. The deliverables of this integration would be modification and testing of the model in EIA's computing environment, along with documentation of the changes and support to EIA for addressing CTUS-specific issues arising from an AEO production cycle.

Implementation Timeline

The timeline for implementation must consider two aspects that are critical: the time taken to execute the project and the timing of the project with respect to other concurrent projects on the topic of carbon capture. The former is a standard requirement for any project to ensure timely implementation of the project within the bounds of available personnel and financial resources. The latter is important since there are various projects in place on the topic of carbon capture in NEMS that target various industries. It is important to ensure that this model that covers the cement industry integrated into NEMS can be merged easily with the versions of NEMS created for other industries. Also, the project must target a specific AEO vintage for integration and work backward from that timeline to suggest a start date for the project, assuming available resources. At the time of this report, it is too late to build a model regarding its integration into the AEO 2022 version. We estimate that it would take approximately 33 weeks to implement the proposed model changes. This schedule would potentially support integration with the AEO2023 version of NEMS (see Exhibit 9 for the project schedule).

Exhibit 9: Proposed Project Implementation Schedule

Milestone	Weeks from Start	Description
1	9	Knowledge Base Expansion and Inputs Generation
2	15	Model Development
3	24	OnLocation Model Integration & Testing
4	29	Model Documentation & Handoff
5	33	[Optional] Integration with EIA's version of NEMS