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Building Life-Cycle Analysis with the GREET Building Module: A User Guide

Energy Systems and Infrastructure Analysis Division

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SUMMARY

This User Guide provides instructions about how to conduct both the building material-level LCA and whole building LCA with the GREET Building Module. We have developed the GREET Building Module on the GREET Excel platform to leverage extensive background data available in GREET1, GREET2, and those newly generated within the Module. All the background data are fully accessible, editable, and expandable to maintain transparency, consistency, and capability to address different building systems that encompass individual building materials, components, technology solutions, as well as whole buildings and building designs.

The GREET Building Module develops an organic connection between the building material-level LCA modeling and whole building LCA modeling. The modeling results of individual building materials are automatically added to the background database of building materials, which provides a growing database of material options for architects, designers, and researchers to explore and address building sustainability during the building design, building material/component selections, and whole building LCA. The sustainability impacts of newly developed material choices that could be considered for whole building designs can be addressed through detailed, process-level LCA with the material-level modeling platform in the GREET Building Module. This closes the loop of building material supply chain for whole building design, construction, and operation. With both the material-level and whole building LCA capabilities, the GREET Building Module aims to provide detailed embodied energy use and emissions so that stakeholders can examine co-benefits and/or trade-offs between embodied operational sustainability impacts of building materials, components, technology solutions, as well as whole buildings and building designs.

With an interactive and step-by-step modeling framework, the GREET Building Module may be used by LCA researchers, building material developers, building owners, as well as architects and building designers and engineers to evaluate and compare building sustainability performance with consideration of embodied energy use and emissions and promote development, design, and application of sustainable building materials and whole building designs and operations. As the building community is moving fast towards decarbonization of the building and construction sectors, the GREET Building Module will continue to evolve and expand to include new building materials and technologies, to address emerging sustainability issues facing the building and construction sectors, and to help provide reliable insights to improve their sustainability.

Besides this User Guide, the GREET website (https://greet.es.anl.gov) presents all publications on development and research with the GREET suite models, including technical reports, technical memos, journal articles (those with open access from individual journals), and journal article abstracts (those without open access from individual journals). These are technical documentation of GREET LCA development and applications, from which the GREET Building Module benefits.

As in the past, users can send inquiries, questions, and comments to greet@anl.gov via email. For speedy responses from Argonne to the questions and comments directed to the GREET Building Module, please include GREET Building Module & LCA in your email subject line if your questions and comments are about the GREET Building LCA Module.

INTRODUCTION

As the buildings sector moves to holistically address environmental sustainability such as greenhouse (GHG) emission reductions, the embodied energy and environmental footprints of buildings and building components, as well as buildings operations, need to be quantified for improvements. Analyzing energy and emissions throughout the life cycle of buildings help our understanding of the sustainability of different building materials along with building design choices and decisions. With the support of the Building Technologies Office of the U.S. Department of Energy's Energy Efficiency and Renewable Energy Office, we have developed a building life-cycle analysis (LCA) module that integrates with the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET®) model to leverage extensive background data available from the long history of GREET development. We call it GREET Building Module.

The GREET Building Module is designed to be a transparent, consistent LCA tool for bottom-up assessment of embodied GHG emissions, energy use, and criteria air pollutant emissions across the supply chain of building materials, building technologies, and whole buildings. With an interactive step-by-step graphical user interface, the GREET Building Module enables users to conduct detailed, bottom-up LCA of specific building materials, components, and whole buildings. The GREET module includes conventional and new building materials and helps inform research and development (R&D) efforts of new building materials and components, as well as whole building designs and material choices for achieving reduced embodied energy use and emissions of building components and whole buildings. We hope that the GREET Building Module can inform technology developers, researchers, manufacturers, building designers and architects, and policy makers to holistically address embodied GHG and sustainability performance of building materials and whole buildings with a publicly accessible LCA tool with consistent and extensive background data.

The GREET Building Module is developed on a Microsoft Excel platform. It is synchronized with the Excel versions of GREET Fuel Cycle and Vehicle Cycle models (i.e., GREET1_2022 and GREET2_2022) to share data such as process energy types and common materials between each other. The GREET Building Module is included in the release package of the Excel versions of the GREET suite models. It is also available for download as a standalone module directly at the GREET website (https://greet.es.anl.gov) free of charge after a short user registration. The user can refer to a technical report for details about the methodology, data, and sample modeling results of the module (Cai et al., 2021a).

This User Guide aims to provide details about the structure, features, modeling techniques, and applications of the module for conducting both the building material-level LCA and whole building LCA. It adds the following new modeling features and capabilities to the 2021 version of the module (Cai et al., 2021b).

The Building Component Analysis module has been augmented to support time series modeling. Materials can be modeled in any year past 2020, and each subcomponent of a material can use a different year of data as surrogate. This means a material can be modeled in 2030, while using data for materials from 2020 as surrogate when the actual data is not available. When a material is modeled, GREET1 and GREET2 time-series data will be pulled to match the year the material is being modeled in.

The Whole Building Analysis Module has been augmented to provide options for sensitivity analysis. A Bill of Materials for a building, whence run through the initial LCA, can be set up for sensitivity analysis. The quantity, material type, loss factor, replacement period, and adjustment factor can be set up for each individual material, and the changes in emissions analyzed for each separate factor.

The Whole Building Analysis module has been augmented to allow for disaggregated life cycle results. Life Cycle Analysis results can be aggregated to the system boundary or disaggregated and calculated at each life cycle stage.

The LCProfiles database has been expanded into two worksheets to handle the disaggregated whole building analysis, as well as the time series analysis functions. The LCProfiles worksheet now stores the life cycle profiles of materials, aggregated to the Cradle to Gate life cycle stage. The new Aggregated LCProfiles worksheet stores the life cycle profiles of materials at each life cycle stage, as well as aggregated to the system boundary of the material. Both worksheets store life cycle data for each material for time series analysis as well. The Building Component Analysis module will always use Cradle to Gate data for materials, and therefore uses the LCProfiles worksheet. The Whole Building Analysis module uses the Aggregated LCProfiles database, as it can use material data beyond the cradle to gate boundary.

The Data Gaps feature of the Building Component Analysis module has been improved to allow the user to view and resolve the data gaps of the material loaded into the module, in addition to being able to view data gaps for all materials. The user can additionally see what years of data are available for a given material in a table on the BCA Dashboard.

Forward and backwards propagating LCA have been added to BC Analysis. Backwards Propagating LCA will recursively run LCA on all subcomponents of a material before running LCA on the material itself. Forward LCA will allow the user to select a group of materials that use the selected building material as a subcomponent, and additionally run LCA on those selected materials, to propagate the change in a material’s life cycle profile upwards.

A “Material Updates” list has been added to BC Analysis. This list keeps track of what materials are updated, and marks which materials also need to be updated due to using the original material as a subcomponent. This list is also connected with the forward propagating LCA feature, allowing the user to quickly update any materials that need to be re-run due to subcomponent updates.

OVERVIEW OF THE GREET BUILDING MODULE

When the GREET Building Module is opened up, four worksheets will show up by default: 1) an Overview worksheet to notify the copyright of this tool, as well as a brief introduction to the functionality and purposes of a list of worksheets in the Module; 2) a Building Module that provides an overview of the structure of the Module,; 3) a building material-level modeling platform called building component (BC) Analysis; and 4) a whole building LCA modeling platform called Whole Building Modeling.

To begin either the building material-level or the whole building LCA with the Module, a new user could start with the Building Module worksheet, as shown in Figure 1. From there, the Building Components button will take the user to the BC Analysis worksheet to perform detailed building material-level LCA modeling, and the Whole Buildings button will take the user to the Whole Building Modeling worksheet to conduct whole building LCA modeling. A list of interactive buttons will grant the user access to background data worksheets. These background data worksheets are hidden by default to avoid unintentional changes to the data, but the access to them offers the user transparency of the default databases and details of the modeling results. In addition, a button named "Import data from GREET1/GREET2" functions to fetch the latest background data from GREET1 and GREET2 to update the default databases with annual expansion and updates from the GREET1 and GREET2 models.

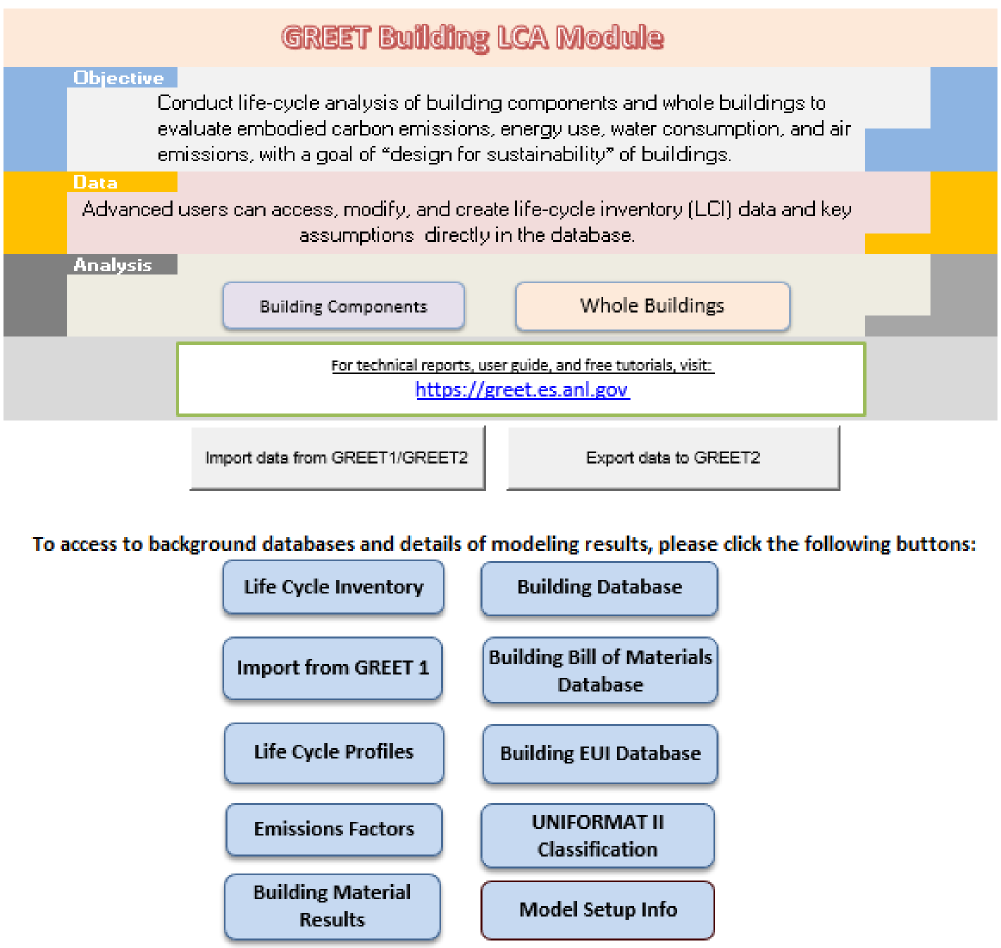


FIGURE 1: Overview of the GREET Building Module

In the following sections, we introduce the Graphical User Interface (GUI), features, and best practices to conduct detailed building material LCA and whole building LCA.

A BUILDING MATERIAL MODELING

A1 OVERVIEW OF THE BUILDING MATERIAL LCA PLATFORM

The building material LCA platform is located in the BC Analysis worksheet, as shown in Figure A1. It is designed to conduct process-level, detailed LCA to address embodied GHG and energy impacts of individual building materials, building components, and building technology solutions for a given system boundary that could vary from Cradle-to-Gate to Cradle-to-Cradle (Cai et al., 2021). A Graphical User Interface (GUI) is designed to provide an interactive modeling experience with quick access buttons to guide the user through the modeling process. The user will be prompted with pop-up data-entry windows to enter detailed life cycle inventory (LCI) data along the life-cycle stages that belong to a selected system boundary. An instructive step is available for the user to identify and address data gaps before running the simulation, and therefore, to improve the accuracy of the modeling. Once the simulation is completed, a dynamic Dashboard is available for the user to view, explore, and interpret the LCA results in detail. The Dashboard also provides an intuitive approach to visualizing detailed LCA results of selected building materials and compare the detailed LCA results of different building materials. When the simulation is completed, the newly generated LCA results will be aggregated to the selected system boundary and added as new data to the LCProfiles worksheet, ready to be used as process material that may be required to manufacture a new building material, building component, or building technology solution, and to be used as a new material option for designers and architects to consider when conducting a whole building/building design LCA with the Whole Building Modeling platform.

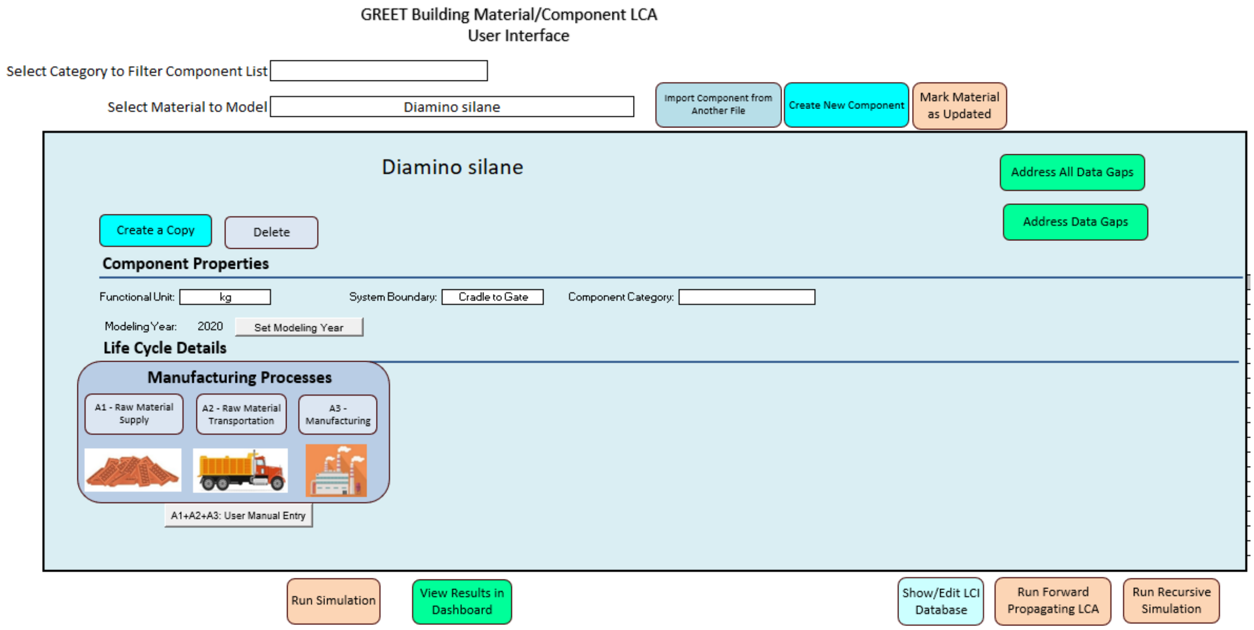


FIGURE A1: The building material LCA platform with a graphical user interface.

A2 CREATE A NEW BUILDING MATERIAL/COMPONENT

To begin a modeling, click on the "Create New Component" button in the top right corner. A pop-up window will show up prompting the user to enter a name for the new building material/component, as shown in Figure A2. Note that material names must not contain brackets or copy the name of an existing material because duplicated names are not allowed in the Module.

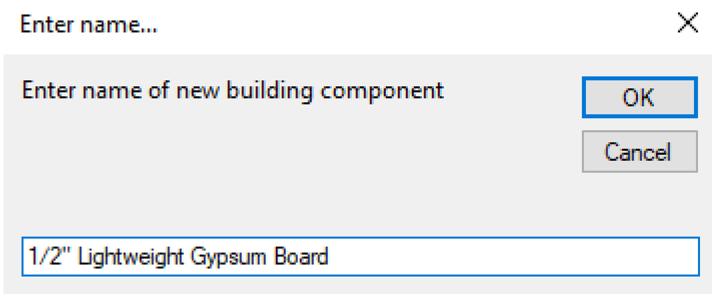


FIGURE A2: The pop-up window for entering the name of a new building

A3 SPECIFY THE LCA SYSTEM BOUNDARY AND FUNCTIONAL UNIT

Once a new building material is named, the next step is to specify the LCA system boundary and functional unit, two major methodology aspects as described in Cai et al. (2021). The user needs to 1) define an appropriate functional unit from a dropdown list, as shown in Figure A3. If a desired functional unit is not available from the default dropdown list, the user can go to the Building Module worksheet, click the "ModelSetupInfo" button to be taken to the "ModelSetupInfo" worksheet to add a new functional unit of interest in the next empty cell of Column A, as shown in Figure A4; 2) select a system boundary from a dropdown list, as shown in Figure A5. The life cycle stages will update accordingly to comply with the selected system boundary, providing an intuitive modeling experience for the user to provide detailed LCI and make key assumptions that may be pertinent to relevant life-cycle stages; and 3) categorize the new building material from a dropdown list of existing building material categories, such as envelope materials, or to specify a new building material category by entering the name of the new category directly in the entry, as shown in Figure A6.

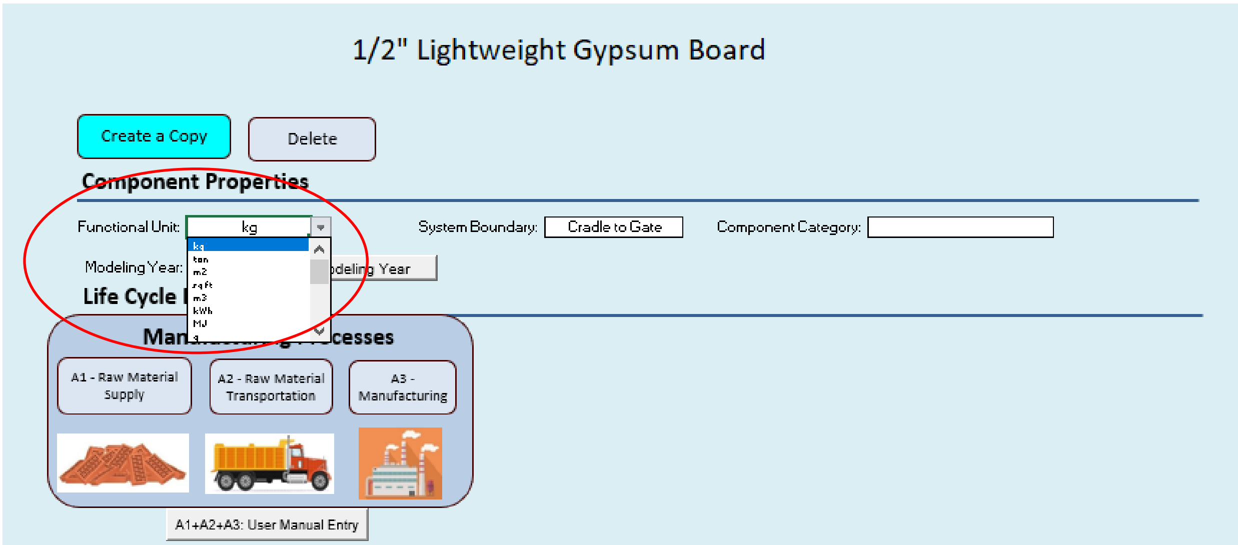


FIGURE A3: The dropdown list to select a functional unit for the new building material/component.

FIGURE A4: Adding a new functional unit in the "ModelSetupInfo" worksheet.

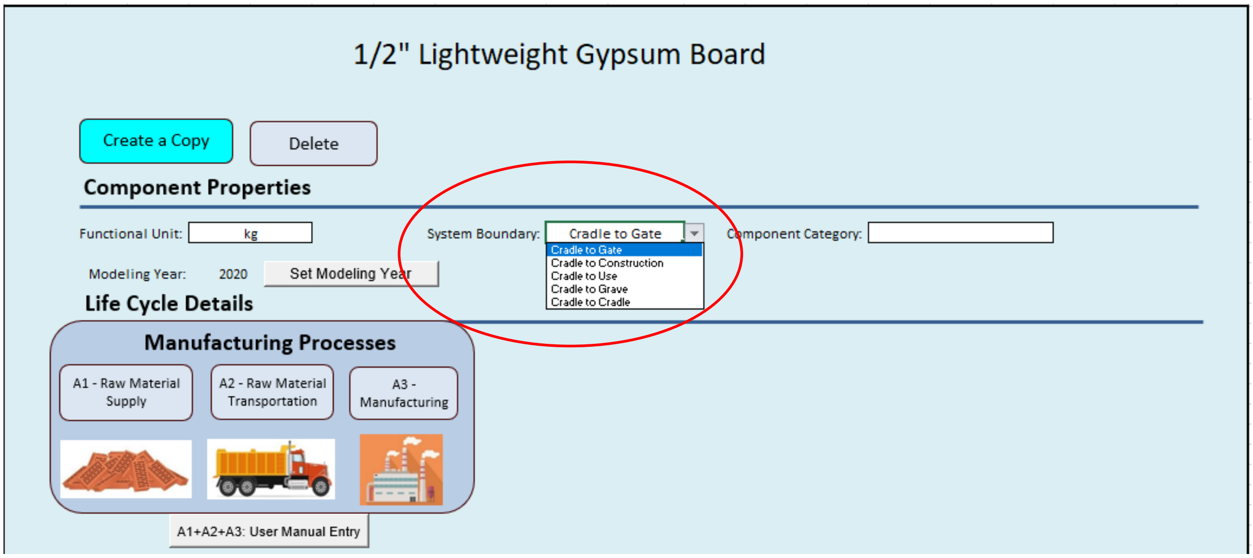


FIGURE A5: The dropdown list to select a system boundary to model the new building material/component.

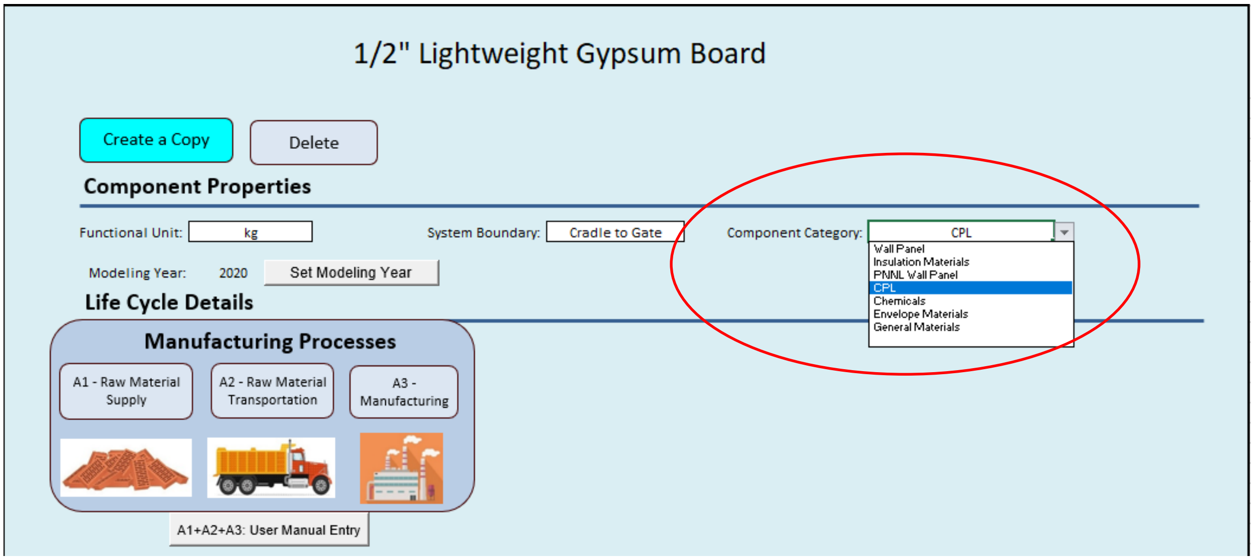


FIGURE A6: The dropdown list to specify a material category for the new building material/component.

A3.1 DEFINE A CONTEXT FOR A MATERIAL

A system boundary past cradle to gate is best defined in the context of a specific building project. Upon defining a system boundary larger than cradle to gate for a material, a button will be added to optionally copy the LCA for a material and rename it in context of a specific building added to the Building Info list (See Section B2.1). Upon choosing to define the material in context of a building, the LCI for the material will be duplicated to a new material profile, renamed to detail the building the material is defined in context of.

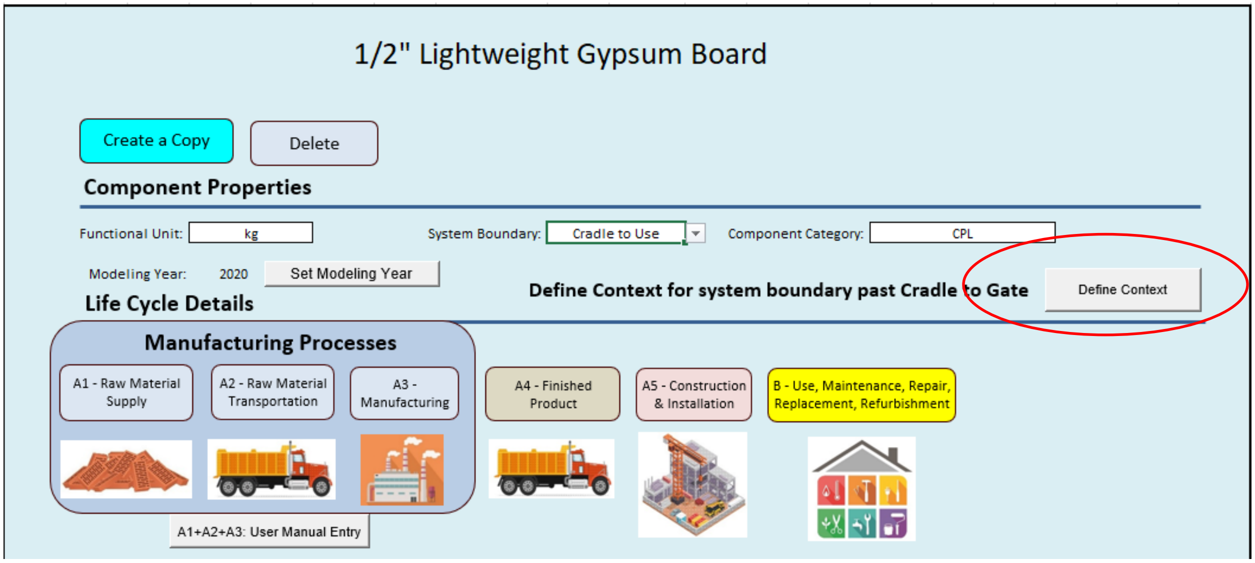


FIGURE A7: The button to define a building material in context of a specific building.

A4 BUILDING MATERIAL TIME SERIES MODELING

The building material LCA is equipped to handle time series modeling of different materials. Time series modeling is split into two different components; the modeling year of the material currently being modeled, and the modeling year of each individual component of a material being modeled. The modeling year of a material is used to determine what year of data is saved. A material can have multiple different LCProfiles, spread across multiple years. To change the year a material is modeled in, click the "Set Modeling Year" button located under component properties

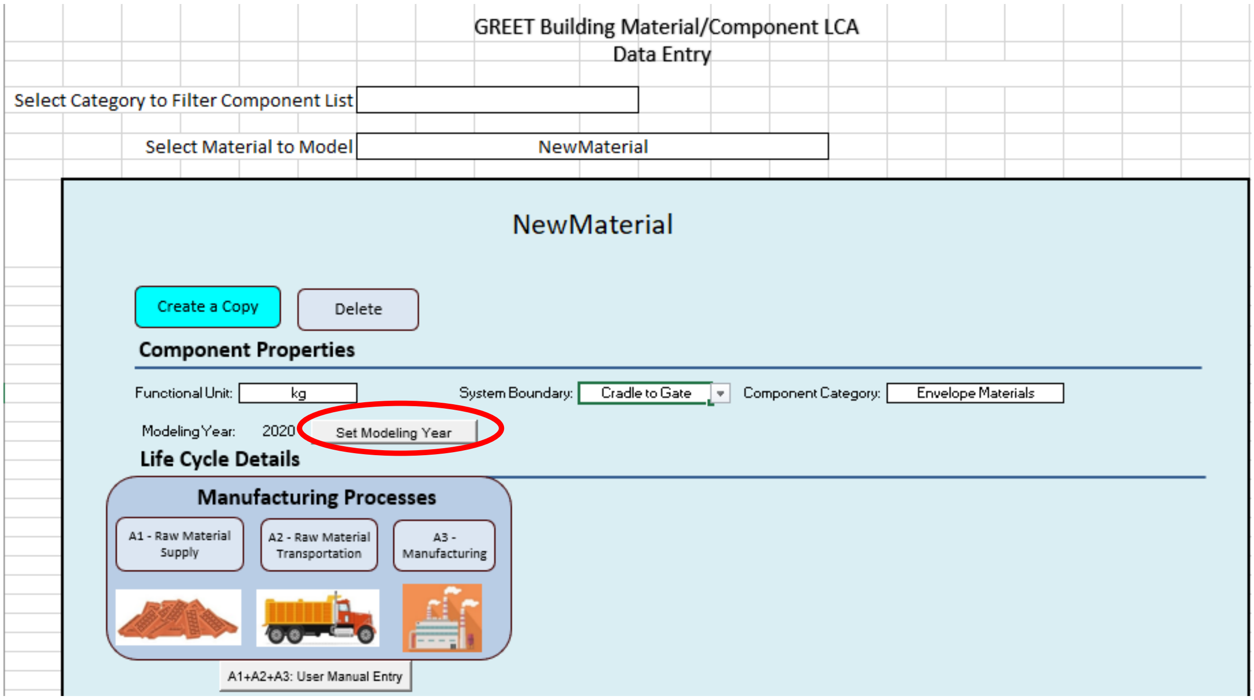


FIGURE A8: The Set Modeling Year button, used to change the year a material is being modeled in.

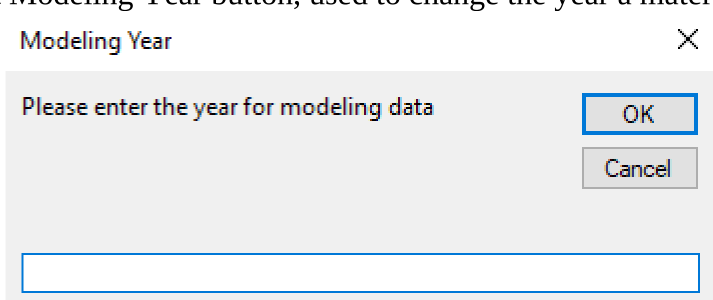


FIGURE A9: The User form to Enter the new Modeling Year for a material.

When the modeling year is changed, a prompt will allow the User to copy the LCI data from the previous modeling year to the new one. This will duplicate the LCI data from the original modeling year and copy it to the new modeling year. This will replace any LCI data in the new modeling year.

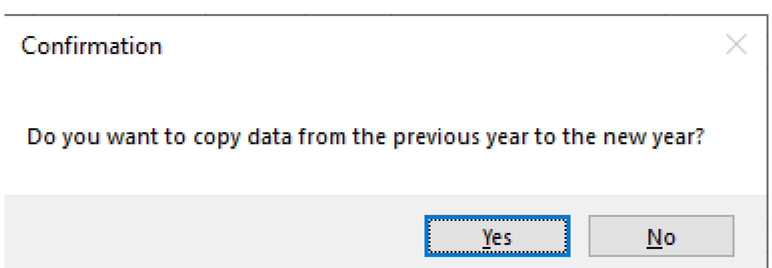


Figure A10: The Prompt to Copy data from the previous modeling year to the new modeling year.

When entering LCI information for a material, the user can specify the year of data used. This allows the user to use data from one year in modeling a material in a different material. For example, a material can be modeled in 2030, using component data modeled in 2020. If data is specified to be used for a material that does not have data for the specified year, a data gap will be flagged. Please see section A7 for more information on data gaps, and how to resolve them.

A5 ENTER LIFE CYCLE INVENTORY DATA AND MAKE KEY ASSUMPTIONS

It is critical to enter detailed LCI data and make key LCA modeling assumptions, such as co-product handling methods, loss factors across the supply chain, non-combustion or fugitive emissions, etc., which may be relevant to the material being modeled, for meaningful LCA modeling. This can be accomplished by entering energy and material inputs and outputs data and making assumptions with each of the life cycle stages according to the defined system boundary and functional unit. Figure A11 shows the GUI that assists the user with providing the complete, streamlined, and interconnected data required to model the embodied GHG emissions and energy impacts of a new building material.

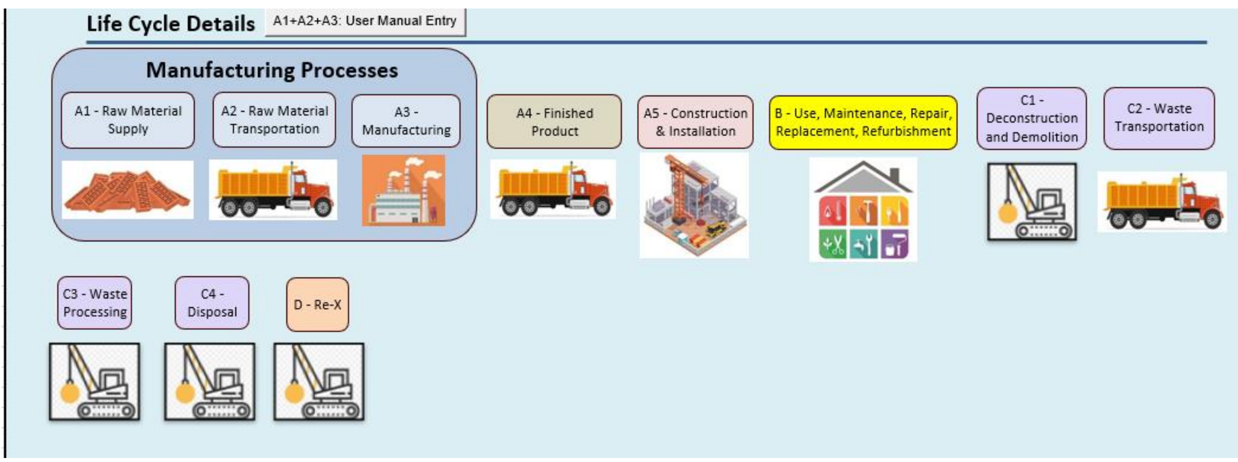


FIGURE A11: The life cycle stages of the selected system boundary to take detailed LCI data and make assumptions

A5.1 Cradle-to-Gate (A1-A3) Data Entries

For a Cradle-to-Gate system boundary, the user needs to specify the A1-A3 stages that conform to the EN-15978 Standard with energy and material inputs required to manufacture the building material and transport it to the construction site. This is the most common system boundary chosen to estimate embodied GHG emissions/energy use of a building or construction material. For modeling of this system boundary, the A1 to A3 stages are key to the manufacturing of a finished product. Therefore, we bundle the A1, A2, and A3 stages in an overall “Manufacturing Processes” group to streamline the modeling process. Once the user clicks the group, a pop-up GUI, as shown in Figure A12, will guide the user in providing the LCI data across the A1 to A3 stages.

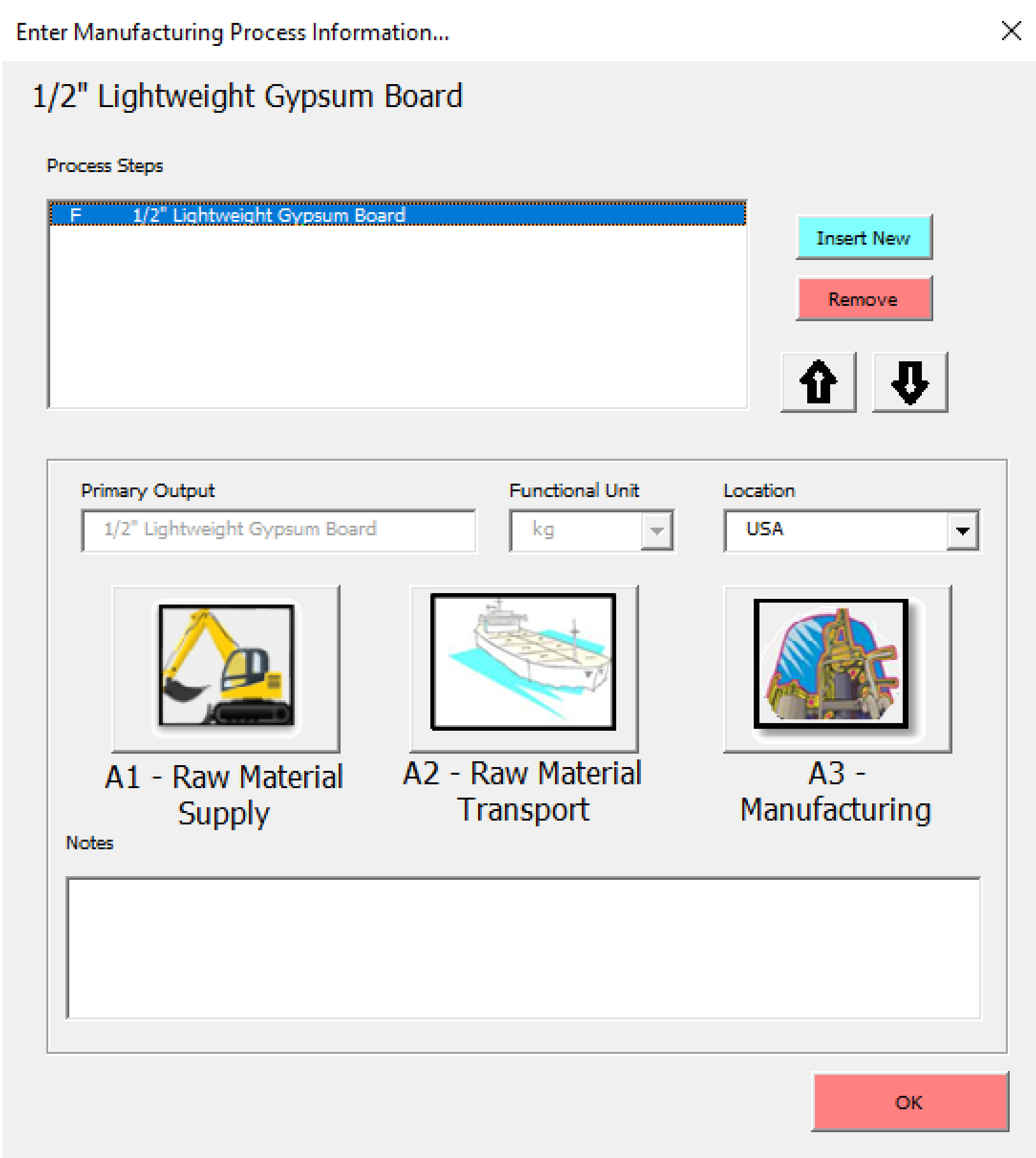


FIGURE A12: The graphical user interface for modeling the manufacturing processes.

To model complicated, potential multi-process manufacturing, we have developed a multi-process modeling approach with the capability to model each manufacturing process individually and in the order of the overall manufacturing processes. For each process, the user can model the A1 to A3 stages necessary to complete the process. Each individual manufacturing process will produce an intermediate product, which could be a required raw material input for any of the following manufacturing processes. This approach enables a streamlined, integrative modeling experience. The user can change the order of the manufacturing processes, add and insert a new manufacturing process, and modify or remove an existing manufacturing process.

Note that the A1-A3 group button will start with specifying the final manufacturing process by default, with a process step identification as “F”. The primary output of the final manufacturing process will be the target building material that the user is modeling (see Figure A2), with a default functional unit that is defined (see Figure A3). Note that the location of the manufacturing plant can be specified at the state level or generally be noted as in the United States. This information will be used to pull relevant state-level or national-level electricity generation data to calculate the emissions impacts of the manufacturing processes.

It is recommended that the user starts with the final manufacturing process by entering LCI data for raw material supply, raw material transportation, and process energy and material requirement via the A1, A2, and A3 buttons. Then, the user can define specific upstream manufacturing processes that produce intermediate outputs that may feed into the final manufacturing process as process materials, by entering LCI data for the A1, A2, and A3 life cycle stages the same way as for the final manufacturing process. For each upstream manufacturing process, it will have a process step identification number assigned to indicate its order in the overall manufacturing processes.

For an upstream manufacturing process, the name of the primary output can be specified from the Primary Output entry. By default, it will be the same as the process name. The functional unit of an intermediate product can be specified from a dropdown list, which gives the user flexibility to address any intermediate product that may need a different functional unit from the finished product. Figure A13 shows an example where a new upstream process called “Pre-processing” can be added.

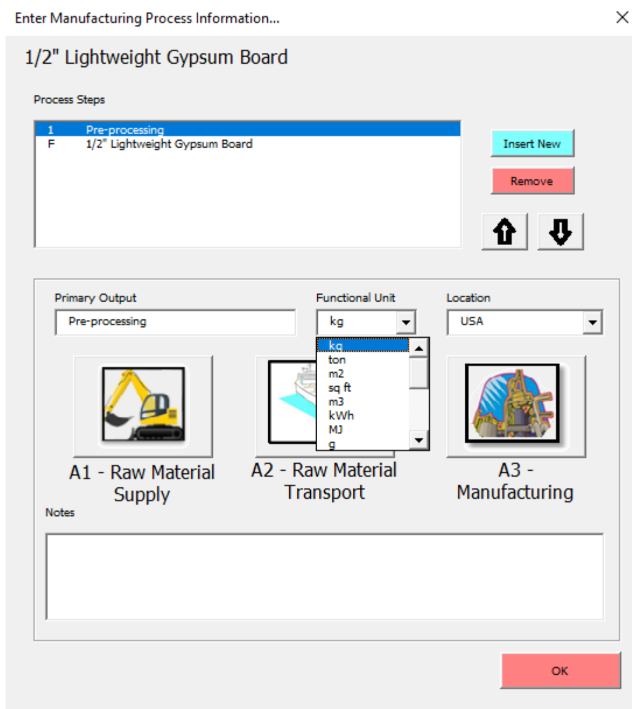


FIGURE A13: Adding a new manufacturing process and defining the functional unit of its output.

A5.2 Data Entries for A1

For a given manufacturing process, being the final manufacturing process or an upstream one, the data entry form for A1, or the Raw Material Supply stage, is the same. To start, the user can click the "Add" button to select an existing raw material from a dropdown list or add one if needed, as shown in Figure A10. The user can remove any raw material that is added by clicking the "Remove" button.

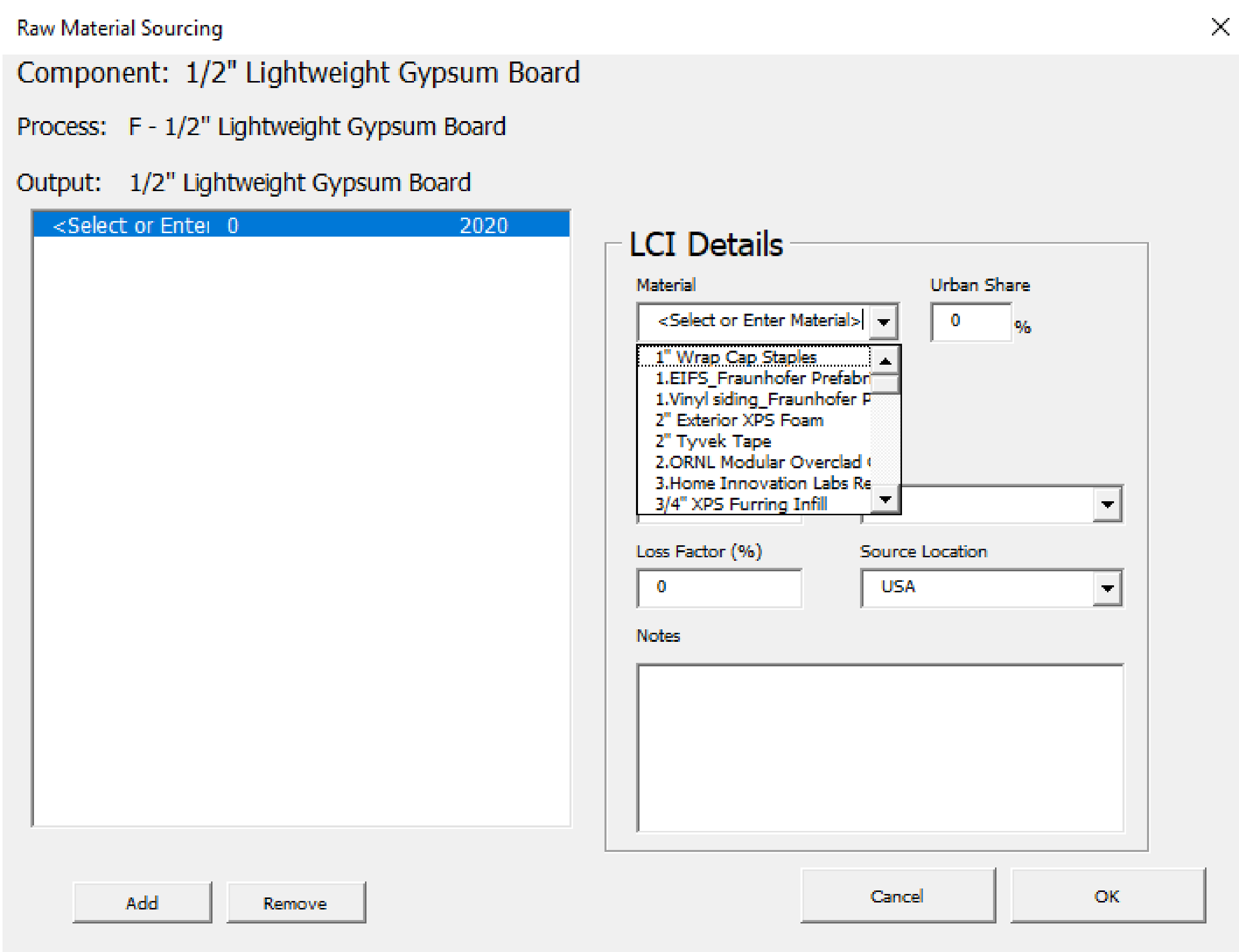


FIGURE A14: Adding a new raw material by selecting from a list of existing materials or entering a new raw material.

Then, the user can enter the quantity, unit, loss factor, urban share, and supply location directly into the entries or by selecting from a dropdown list for each raw material, as shown in Figure A11.

To enter a unit, the user can select one from a dropdown list. If the dropdown list does not contain the desired unit, the user can enter a new unit directly into the entry. If the new unit does not have a valid conversion, a warning message that no conversion factor is available to convert the new unit to the default unit of the selected material will appear, and the user will need to use a unit that can be converted to the default unit instead. See Figure A16 as an example.

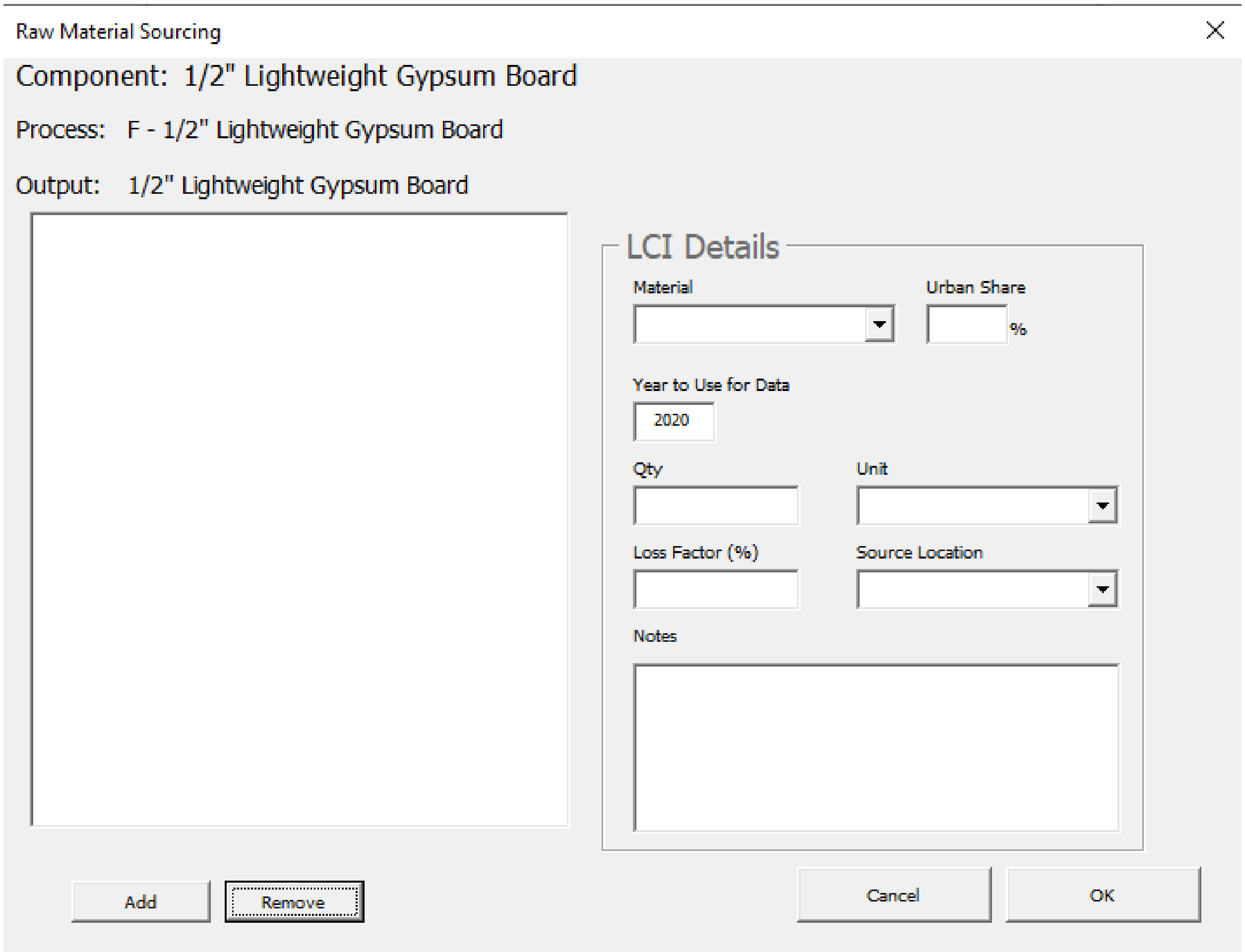


FIGURE A15: The data entry form to provide detailed LCI data related to the A1 stage.

The Loss Factor entry allows the user to specify any raw material loss that might happen at the supply/sourcing stage, prior to the transportation step (A2). A non-zero loss factor will lead to more raw material by "{1/(1-loss factor [in %])-1}×100%", which needs to be supplied/sourced so as to compensate the material loss and to meet the downstream demand.

The "Urban share" entry allows the user to specify how much of the raw material supply/sourcing activities come from municipal statistical areas.

A "Notes" section provides the user a convenient way to take notes about data sources, assumptions, or any other details that may help clarify the data entered at this stage. The data entered at this stage will be used to calculate the embodied impacts of sourcing and supplying raw materials required.

The "Year" entry allows the user to specify the year of data used for the component. By default, every component uses data for the same year that the building material is being modeled in. However, by changing the year entry, the user can change which year of data is used, to allow a component to use data from a different year than the entire material. Note that changing the year entry for a component does not change the year the LCA will be run in, i.e. modeling a material in 2030 while using a component with data from 2020 will still save the results in 2030, not 2020.

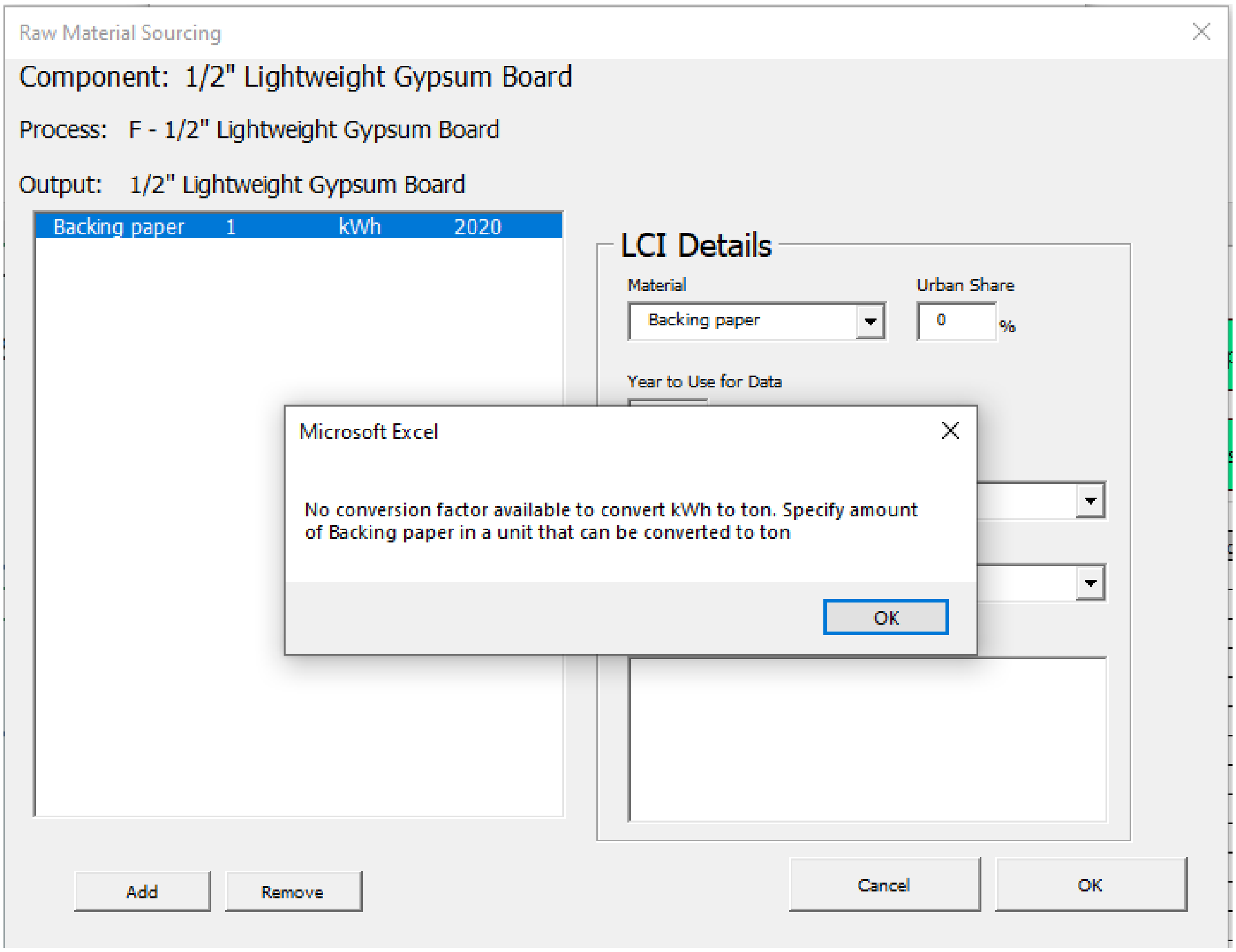


FIGURE A16: The warning message to specify a unit that can be converted to the default unit of a raw material.

Note that any entered data will be saved to the LCI database when the user clicks the "OK" button in the bottom right of the data entry form. No data that has been entered to the form will be saved if the user clicks the "Cancel" button or clicks the close the window button in the top right corner of the form.

Note that if the user enters a new raw material that does not exist in the dropdown list, this will be flagged as a data gap when the user proceeds to run the simulation, or when the user clicks the Address Data Gaps button to check potential data gaps. It is always recommended that efforts be made to address data gaps before running the simulations to generate LCA results for a building material. Ignoring any data gaps that may be associated with modeling a building material will not stop the program from running the simulation and generating results. In this case, the data gaps, as well as their associated embodied impacts, are simply ignored, leading to incomplete LCA results. This gives the user flexibility to proceed and generate results with the best data available and the flexibility to decide when and how to address the data gaps when further information becomes available. We discuss approaches designed in the GREET Building Module to addressing data gaps in Section B4.

A5.3 Data Entries for A2

In the A2 stage, or Raw Material Transportation stage, the user enters the raw transportation related data, including the transportation distance, payload, urban share, and fuel type by transportation mode, for each of the raw materials that are specified in the A1 stage. Figure A13 shows the data entry form used to specify detailed transportation information required to model the embodied impacts at this stage. For each raw material, four transportation modes can be considered: Class 8 heavy-duty truck, rail, barge, or ocean tanker. For each transportation mode, the default information on the payload and urban share from GREET1 is used and set by default. By default, for example, the fuel type of the truck is petroleum diesel. A list of alternative transportation fuel options, for example, renewable diesel, is available for consideration. The user can make changes to the default assumptions regarding payload and fuel type to reflect the actual situation of the transportation. Besides the default assumptions, the transportation distance is a required input for at least one of the transportation modes to complete the setup of the raw material transportation modeling.

Note that the Loss Factor entry allows the user to specify any raw material loss that might happen at the transportation stage. A non-zero loss factor will lead to more raw material by "{1/(1-loss factor [in %])-1}×100%", which needs to be transported to the manufacturing plant to compensate the material loss during the transportation and to meet the manufacturing demand.

Similar to the A1 stage, a "Notes" section provides the user a convenient way to take notes about data sources, assumptions, or any other details that may help clarify the data entered at this stage.

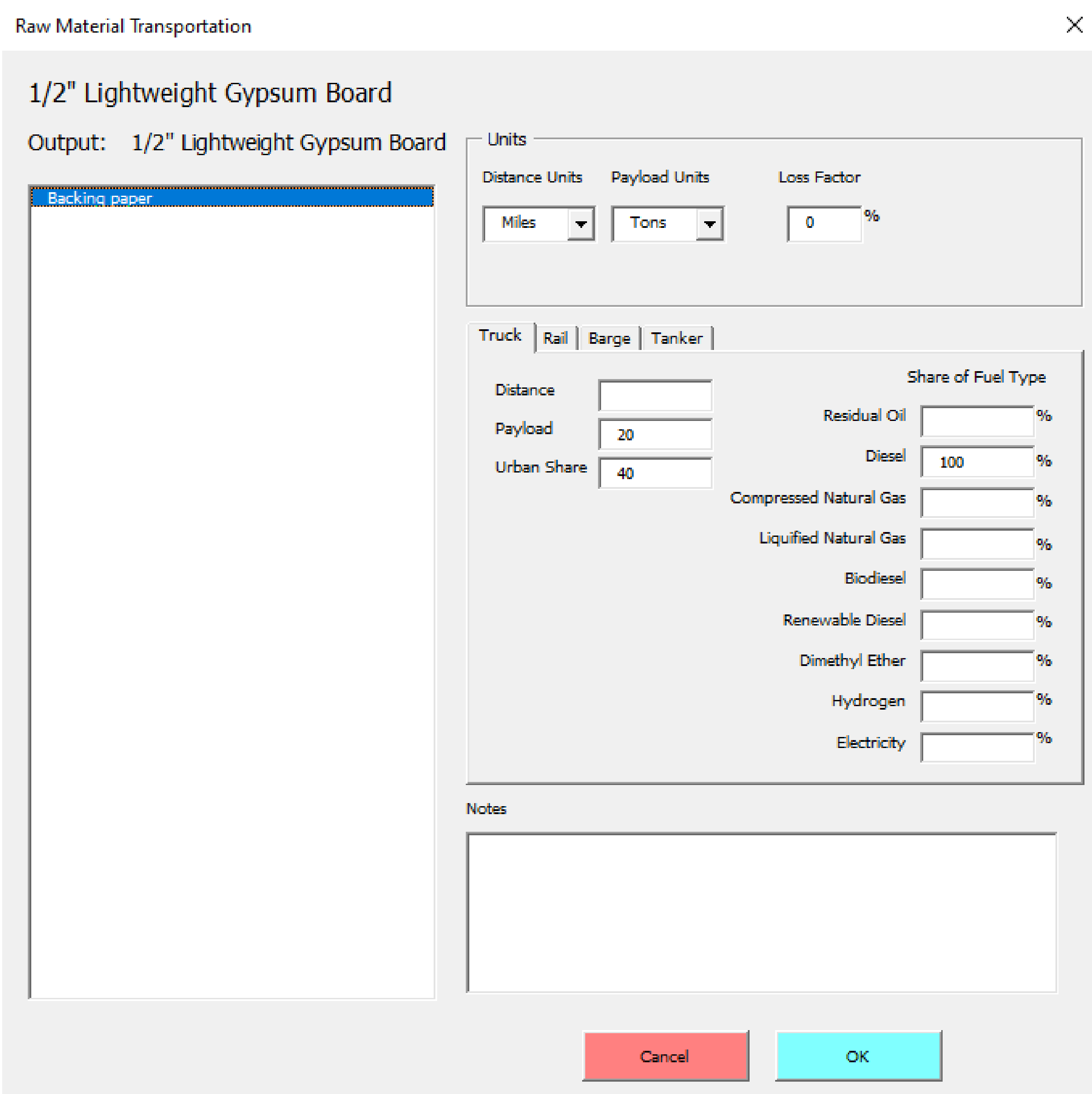


FIGURE A17: The transportation data entry interface to model raw material transportation impacts.

A5.4 Data Entries for A3

At the A3 stage, or the Manufacturing stage, the user will enter manufacturing related data, including process energy and material requirements, urban share, loss factor, co-products, component year, and non-combustion emissions, as shown in Figure A18.

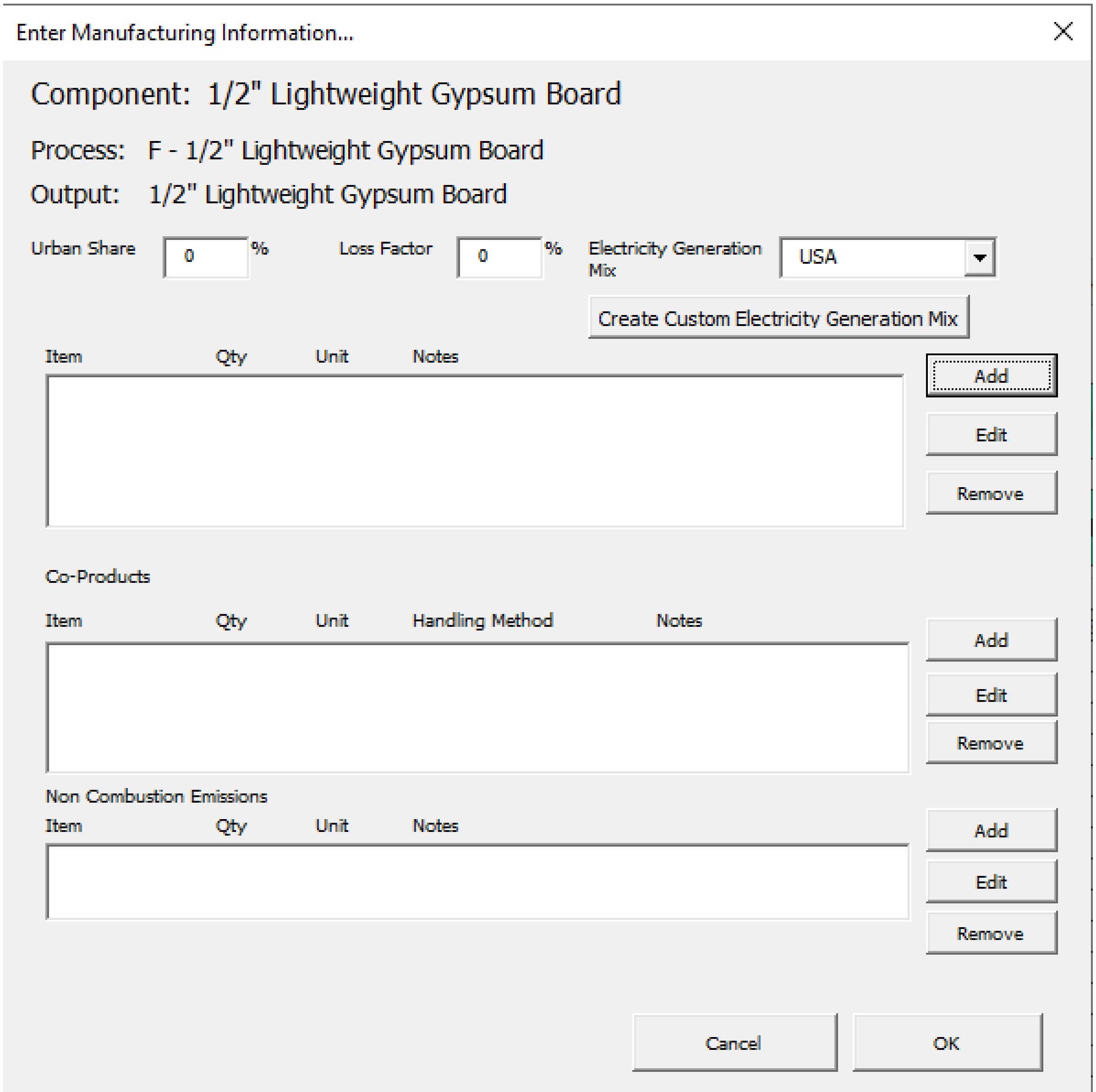


FIGURE A18: The data entry form to enter detailed information related to a specific manufacturing process

For each process energy input except for electricity, the user will be prompted with a new data entry form, as shown in Figure A15, to define the combustion technologies and relative combustion shares associated with using the process energy type. The relevant emission factors from GREET1 will be used to calculate the direct emissions from the using process energy via various combustion technologies, such as a boiler, turbine, engine, kiln, among others. For electricity, the electricity mix as the user defined in the overall Manufacturing Processes step will determine which specific local electricity generation mix and the associated life-cycle energy and emissions profiles will be used in the modeling. Additionally, a custom electricity generation mix can be defined at this step. For more information, see section A6.

Besides process energy inputs, the user can also specify process material inputs. Note that the process material inputs at this step do not require off-site transportation, which is different from those specified at the A1 step. This option offers the user to specify any on-site material inputs, such as intermediate products from previous manufacturing processes, that can feed into the current process to make other intermediate products or the finished product. Like the raw material entries in A1, any new process materials specified that are currently not available in the dropdown list, will be flagged as a data gap, which can be addressed separately. In addition, a data validation feature is implemented with regard to the unit entry, which will provide a warning message and guidance to specify an appropriate unit that can be converted to the default unit of a selected material that exists in the default database, as shown in Figure A19.

Any entered data can be edited or removed from the corresponding buttons to the right of the form (see Figure A18).

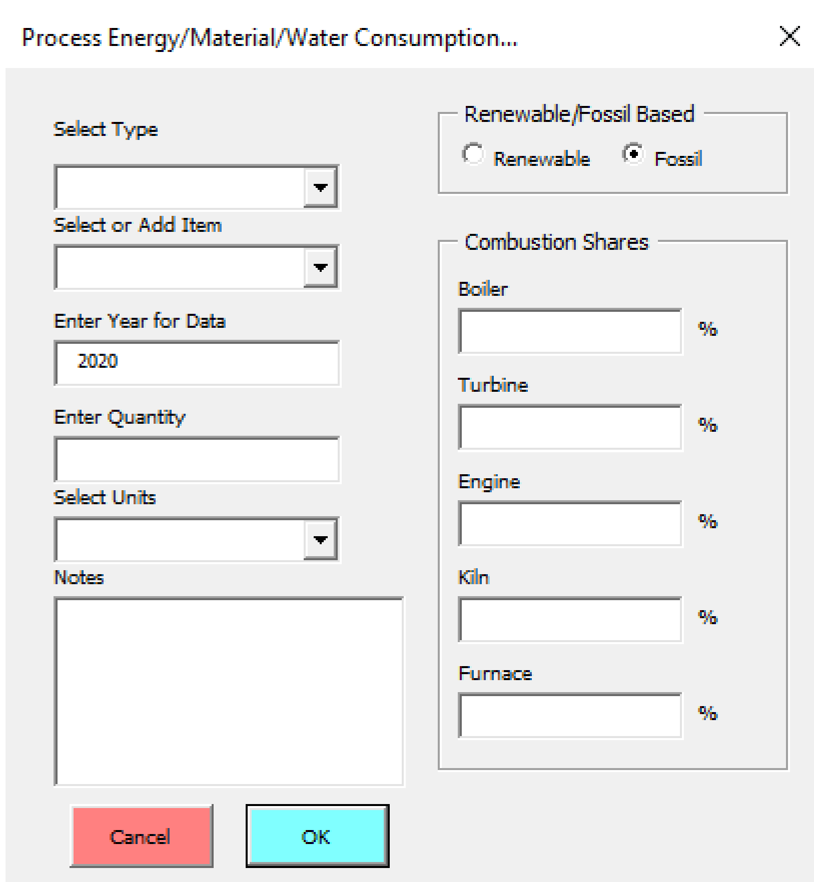


FIGURE A18: The data entry form to specify process energy and material inputs, as well as water consumption associated with a manufacturing process.

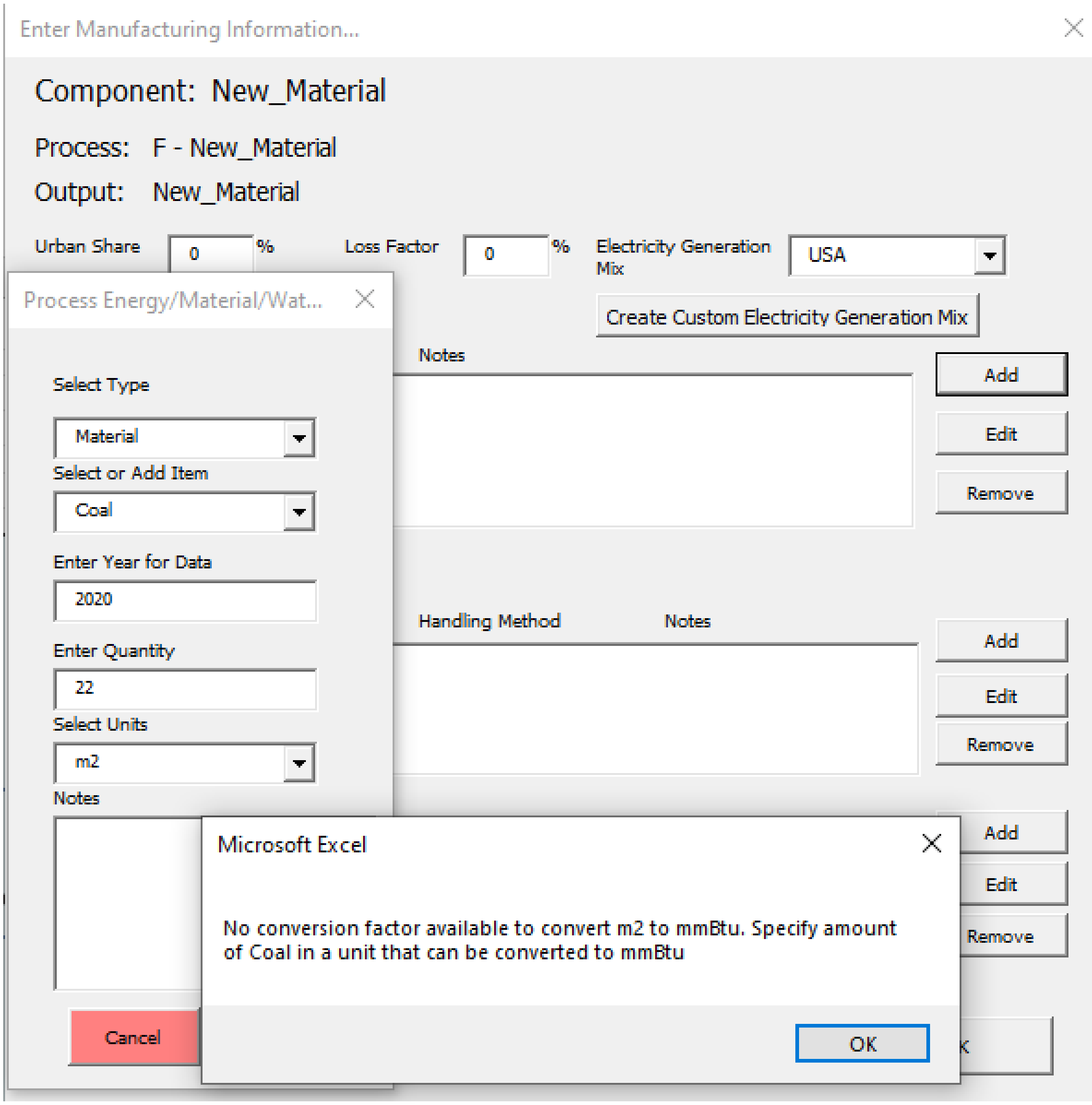


FIGURE A19: The warning message and guidance to specify an appropriate unit for a selected process material.

A unique modeling issue related to LCA in general, and one that may apply to building material LCA, as well, is to address the embodied impacts of co-products that may be present at the manufacturing stage. To begin, the user can click the “Add” button in the “Co-Products” panel of the A3 data entry form, as shown in Figure A20, and a data entry form to specify the name, quantity, unit, and handling method of co-products will open, as shown in Figure A21.

To add a co-product, either select one from the dropdown list or enter a new one if it is not available in the dropdown list. To specify the quantity and the associated unit, enter the quantity with a number and select a unit from the dropdown list. The same data validation feature with regard to the unit selection will apply here to ensure meaningful unit selection (see Figure A16). Use the "Notes" section to add any notes regarding the data entries. Finally, a co-product handling method can be chosen from a list of four options: 1) the displacement method. When this method is selected, a product that is displaced by the co-product needs to be specified from the "Product Displaced" data entry, together with a displacement ratio, which is set to be 100% by default, as shown in Figure A19; 2) an energy-based allocation method. When this method is selected, the energy-based relative share of the co-product out of the total product slate needs to be specified, as shown in Figure A20; 3) a market value-based allocation method. When this method is selected, the market value-based relative share of the co-product out of the total product slate needs to be specified; and 4) a mass-based allocation method. When this method is selected, the mass-based relative share of the co-product out of the total product slate needs to be specified. For the methodological implications of these co-product handling methods, see Want et al. (2011) and Cai et al. (2018).

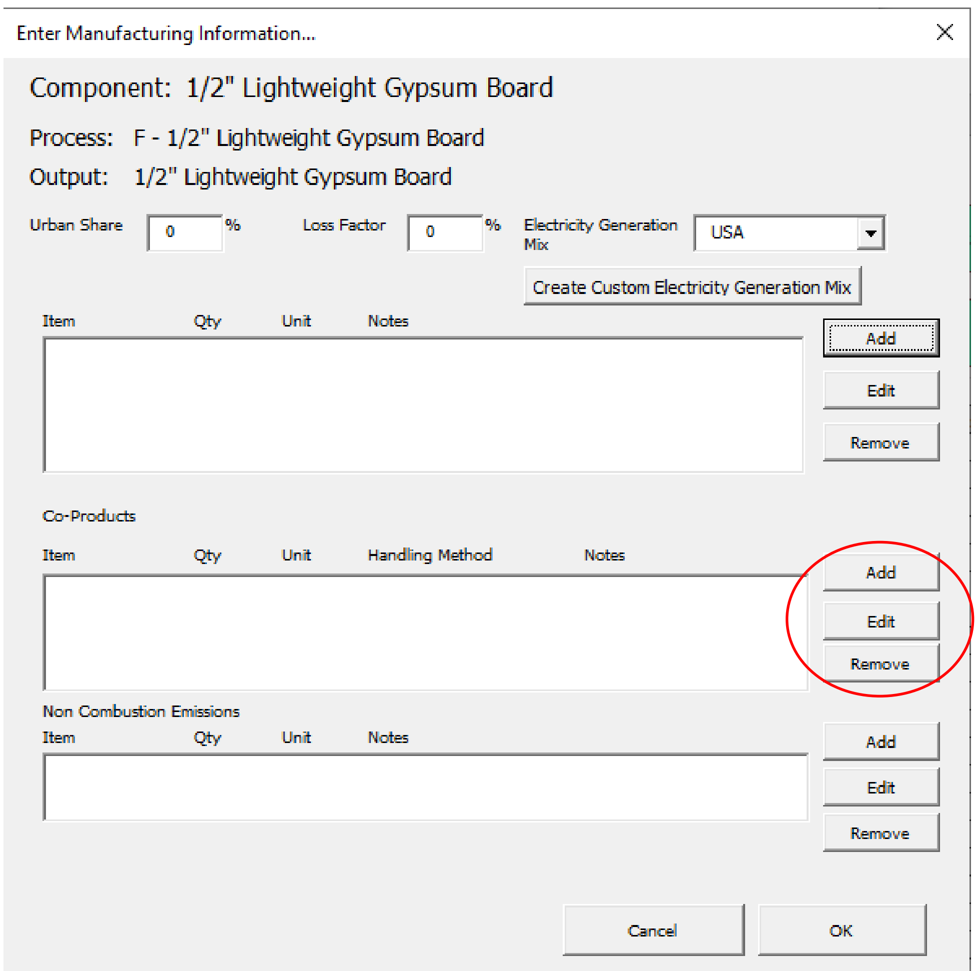


FIGURE A20: Add, edit, or remove co-products at the manufacturing stage.

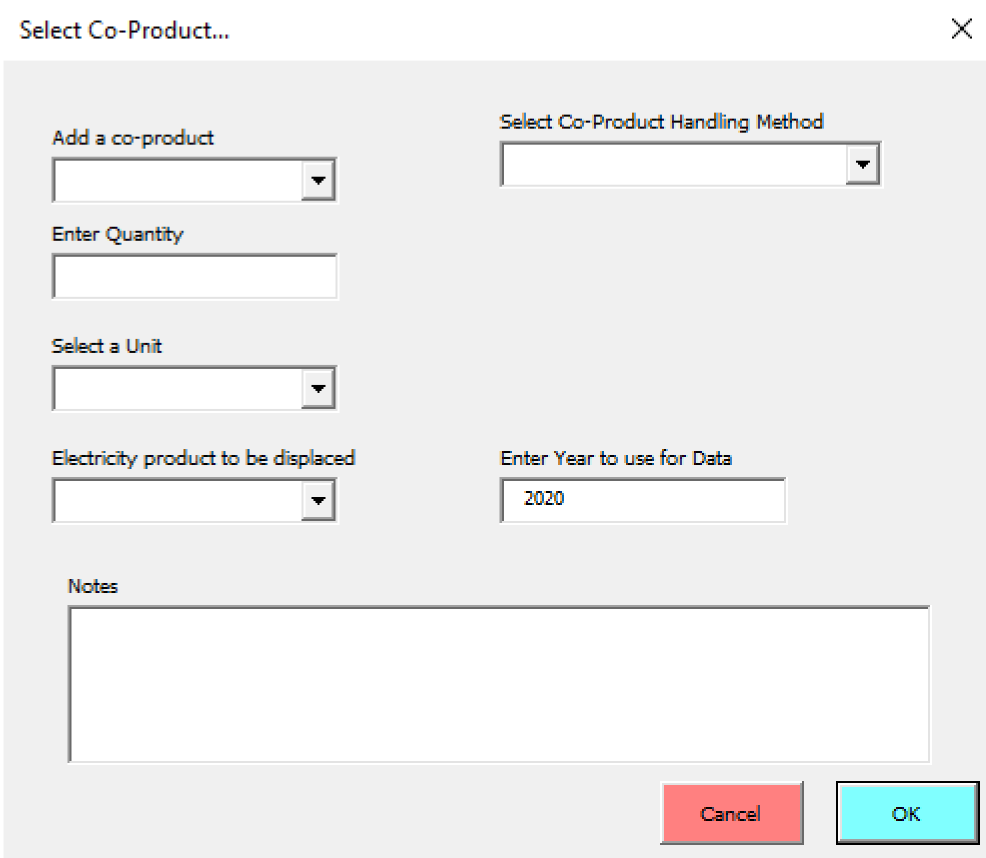


FIGURE A21: The data entry form to specify the name, quantity, unit, and handling method of co-products.

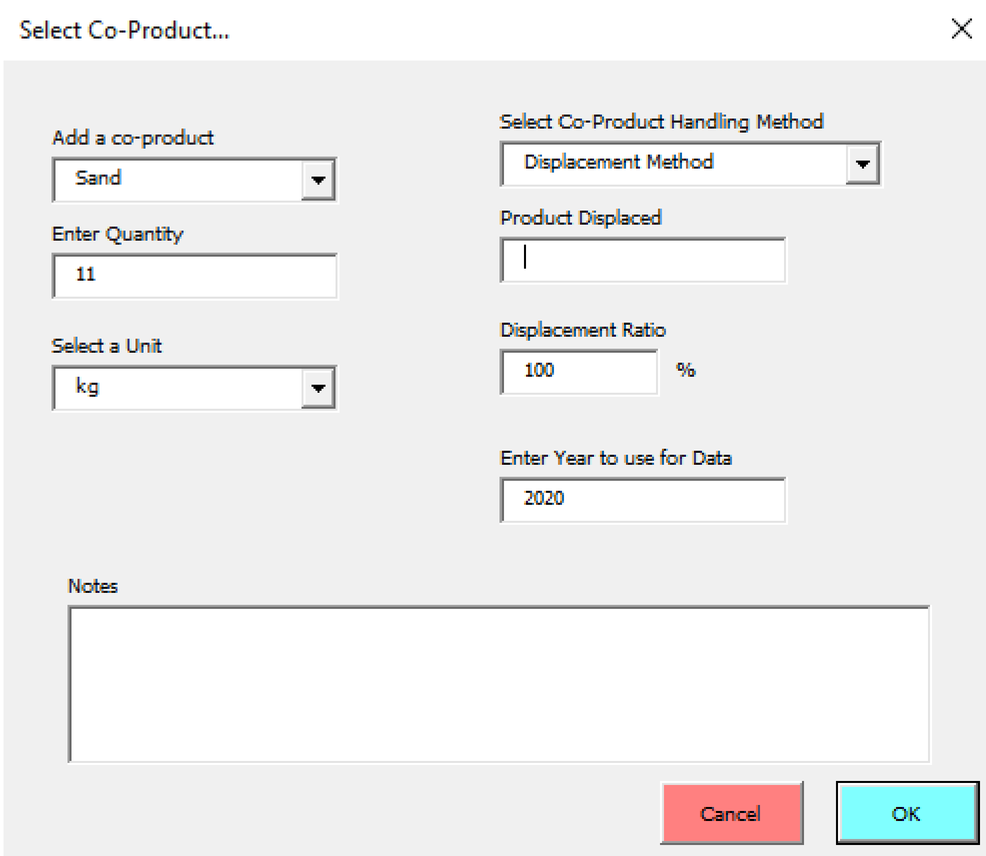


FIGURE A22: Specify the product to be displaced by the co-product and the displacement ratio when the displacement method is selected.

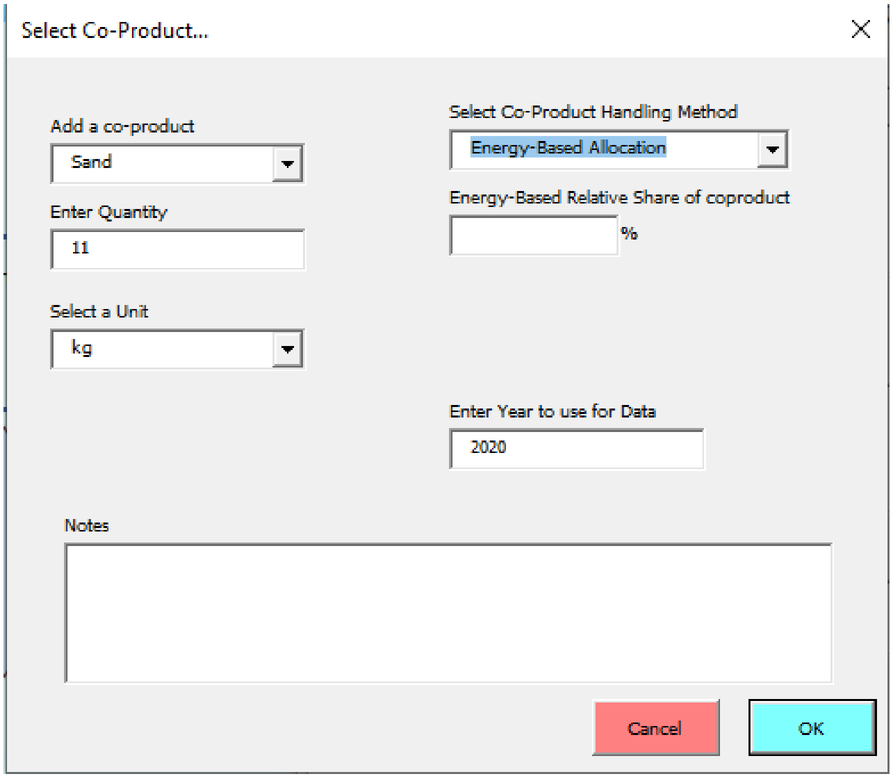


FIGURE A23: Specify the energy-based relative share of the co-product out of the total product slate when the energy-based allocation method is selected.

Another issue that could have significant impact on the embodied impact of a building material is to include any non-combustion related emissions, e.g., evaporative VOC emissions from use of solvent. Figure A24 shows the data entry form for specifying the type and quantity of any non-combustion GHG or criteria air pollutant emissions.

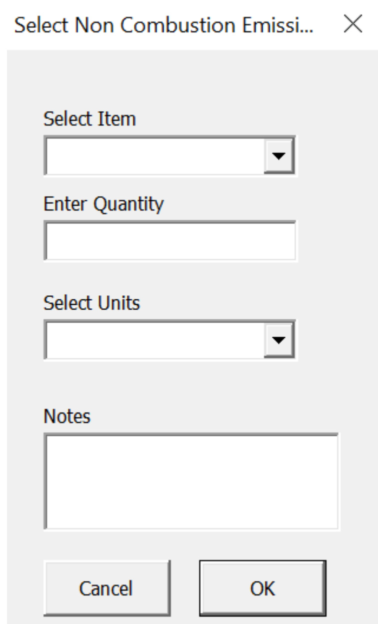


FIGURE A24: Data entry form to specify the type, quantity, and unit of non-combustion emissions, if any, during the manufacturing stage.

By now, the user will have completed data entries for A1, A2, and A3 for a given manufacturing process. The user can add additional manufacturing processes by repeating these steps until all the manufacturing processes related to producing the target building material are specified.

A5.5 Data Entries for A4

In the A4 stage, or the Finished Product Transportation stage, the user will enter related data, including the transportation distance, payload, urban share, and fuel type by transportation mode, for the finished product. Figure A25 shows the data entry form to specify detailed transportation information required to model the embodied impacts at this stage. Note that if the functional unit of the finished product as the user defined (see Figure A3) is not mass based, the data entry form will ask the user to specify the weight and the unit of the weight per the functional unit defined for the finished product. The Module will calculate the transportation related impacts the same as the calculations for the A2 stage.

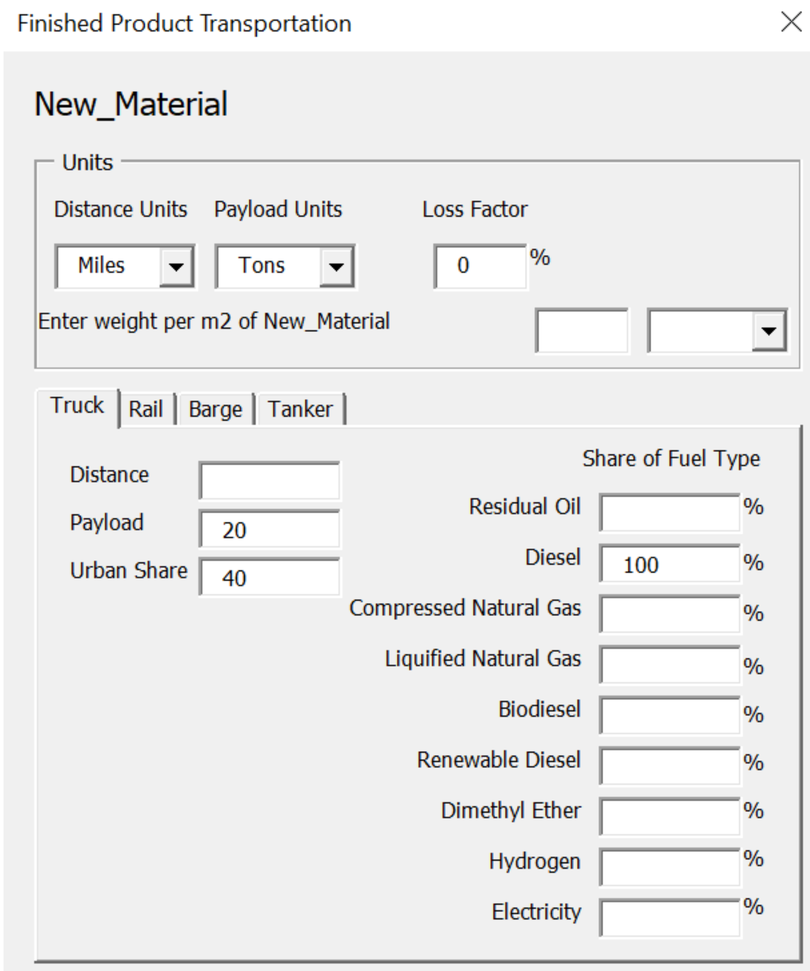


FIGURE A25: The data entry form to specify transportation details for the finished product transportation.

A5.6 Data Entries to Model Construction and Installation, Use Phase, End-of-Life, and Recycling

To model the emissions, energy, and water consumption impacts during the use phase, end-of-life, and recycling related practices and activities, the user can go to the BC Analysis worksheet, and click the relevant buttons, as shown in Figure A49. These life cycle stages include A5 – Construction & Installation, B – Use, Maintenance, Repair, Replacement, Refurbishment, C1 – Deconstruction & Demolition, C2 – Waste Transportation, C3 – Waste Processing, C4 – Disposal, and D – Re-X. Stages A5, B, C1, C3, and D have data entered in the same fashion as done in A3. The C2 stage represents the transportation of waste products during the end of life of the building material, and data is entered in the same manner as described in stages A2 and A4.

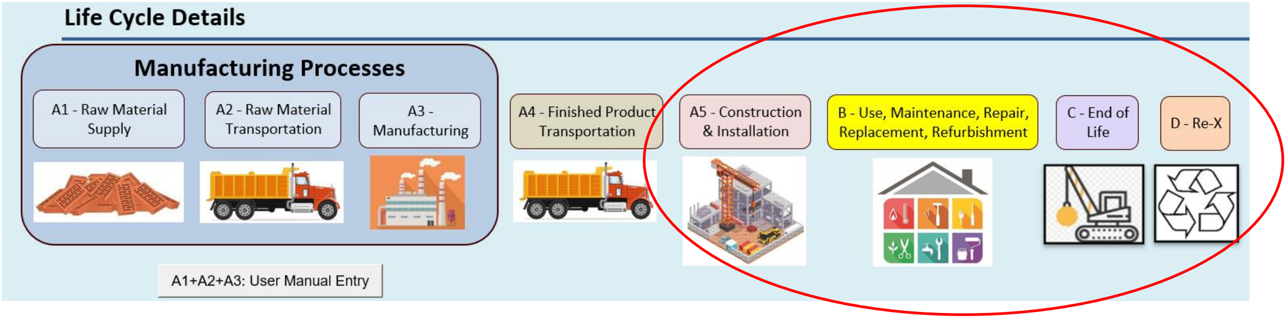


FIGURE A49: Interactive buttons in the BC Analysis worksheet to take data entries for modeling construction and installation (A5), use phase (B-stages), end-of-life (C1, C2, C3, and C4 Stages) and recycling/remanufacturing/reuse practices (D-stages).

For each of these life cycle stages, the corresponding button will open a generic data entry form that has the same data placeholders for entering direct process energy and material inputs, co-products related information, and any non-combustion emissions associated with activities and practices that take place at that stage.

As the system boundary expands from the Cradle-to-Gate stages, new LCA issues may require new LCA methodology, modeling capabilities and features to fully address in an integrated fashion. For example, replacement of a building material during the use phase may require a different functional unit from the one defined to address the Cradle-to-Gate impacts, which is beyond the current modeling capabilities that focus on a streamlined, integrated modeling approach in the BC Analysis modeling platform. However, direct impacts arising from any direct energy and material consumptions to complete the building material replacement can be modeled. The BC Analysis modeling platform is also capable of modeling direct impacts associated with other use phase operations, such as maintenance, end-of-life activities such as landfilling, as well as machinery operations and/or remanufacturing processes that may be required to complete the recycling and remanufacturing activities. In addition, similar to typical process-level LCA that focus on direct impacts associated with material and energy inputs and outputs, consequential impacts of certain life cycle stages, such as emissions and potential carbon sequestration impacts of landfilling, may require separate modeling platforms to address. As LCA methodology and data required to address such challenging issues evolve, Argonne will expand the GREET Building Module with additional modeling capabilities and features to address such issues and potential consequential impacts.

A6 DEFINING A CUSTOM ELECTRICITY GENERATION MIX

The GREET Building Module is equipped to allow the user to generate a custom electricity mix, by first defining a generation mix across common electricity generation sources, and then connecting with GREET 1 to generate life cycle data for the customized generation mix. This feature requires the user to also have GREET 1, and for the user to specify the filepath and file name of the GREET 1 file within the ModelSetupInfo worksheet. The file path and file name cells are located at cells X2 and Y2, respectively, as shown in Figure A26. The file path must contain the full file path, not including the file name of the GREET 1 file, and the file name must include the full name of the GREET 1 file.

X	Y
GREET1 FilePath	**GREET1 FileName**
Full File Path Not Including File Name	File Name

FIGURE A26: The cells containing the GREET 1 file path and file name, located on the ModelSetupInfo worksheet.

A custom electricity generation mix can be defined for use in either the building material LCA or whole building LCA. For use in building material LCA, this feature can be accessed from the Create Custom Electricity Generation Mix, located on the user form for the A3 stage, as well as all life cycle stages past the cradle to gate boundary. For use in whole building LCA, it can be accessed with the Generation Custom Electricity Mix button located on the Whole Building LCA worksheet. These buttons are shown in Figures A27 and A28.

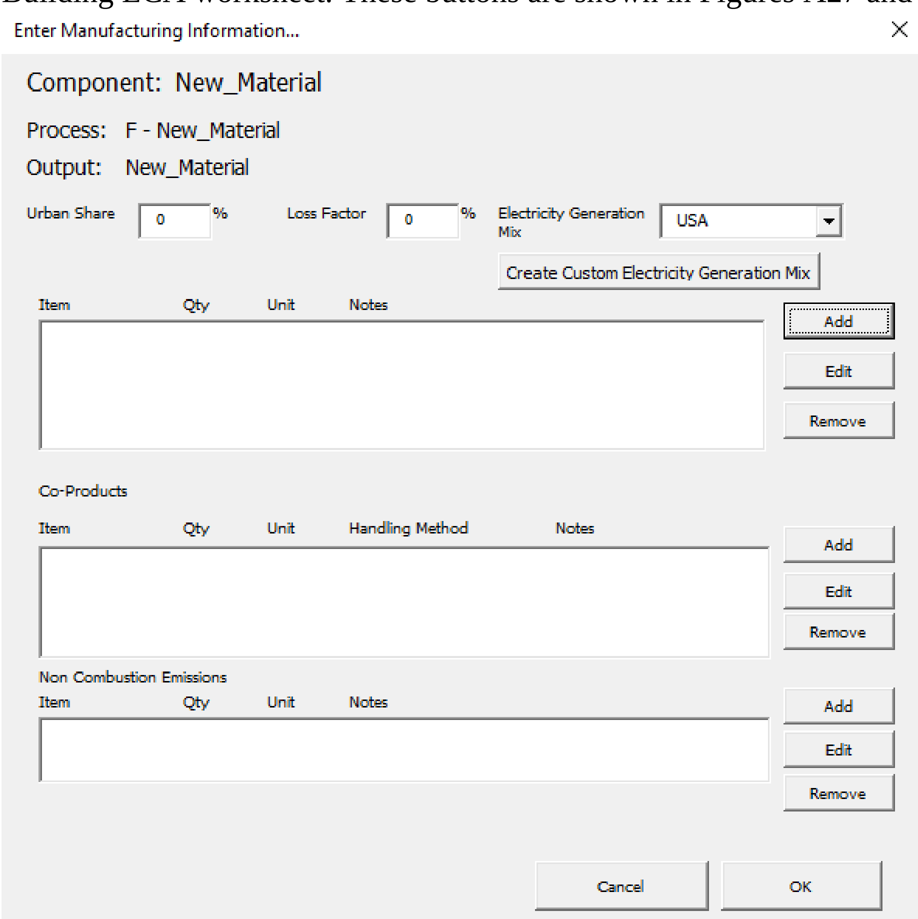


FIGURE A27: The Create Custom Electricity Mix button, used to generate custom electricity mixes used in Building Component LCA.

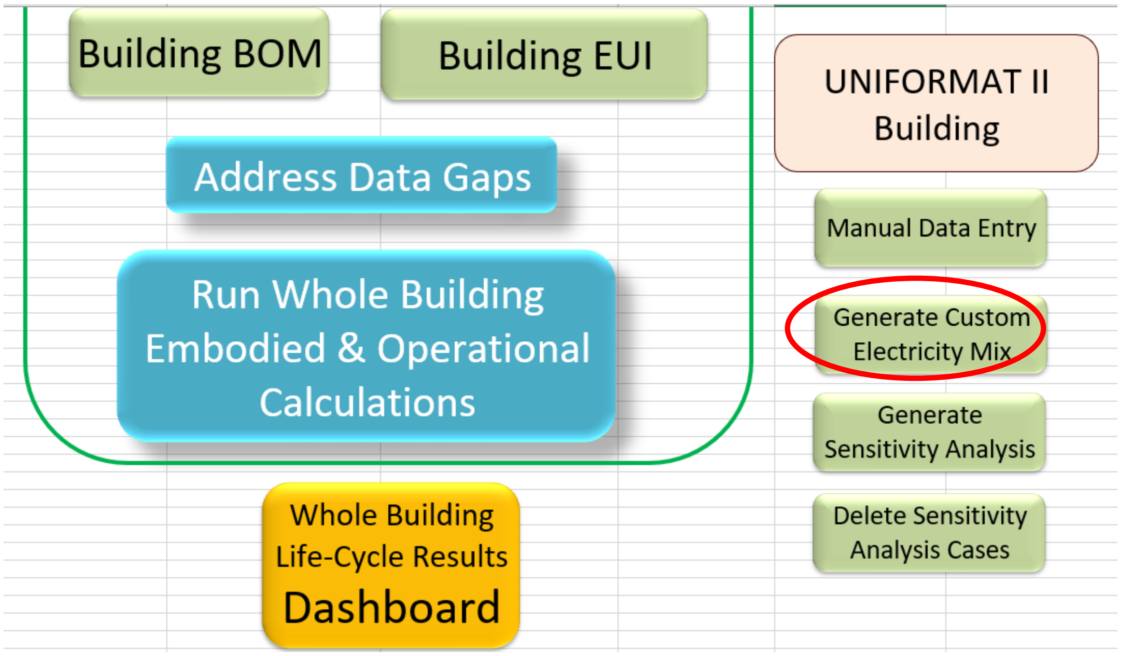


FIGURE A28: The Generate Custom Electricity mix, used to generate custom electricity mixes used for Whole Building LCA.

Note that a custom electricity generation mix will only be usable for the material selected in Building Component Analysis, or for a selected building. For Whole Building LCA, the user can specify whether the custom electricity mix should be usable in all Whole Building Analysis, or only for a specific building.

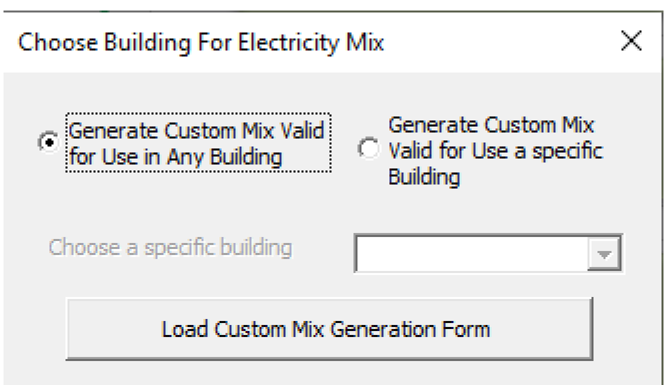


FIGURE A29: The user form to select which building to generate a custom electricity mix form. The user can specify a building from the dropdown list or allow the custom electricity generation mix to be usable for all Whole Building Analysis.

Upon clicking the Load Custom Mix Generation Form button on the above user form or clicking the Create Custom Electricity Generation Mix button located in the building component analysis user forms, a user form will appear to guide the user through the process of creating a custom electricity generation mix, shown in Figure A30. To enter generation data, the user enters the use percentage of residual oil, natural gas, coal, nuclear power, biomass, and other generation sources. For other generation sources, the “Others” category is further broken down into several common electricity sources including hydroelectric, geothermal, wind, and solar, while also including a further “Others” category to include all sources of electricity generation not specified above. In addition, the user can specify the electricity transmission and distribution loss associated with the custom generation mix.

For whole building LCA, by default, a custom generation mix will keep the same electricity mix from 2020 to 2080. However, the user can specify time series results to alter the generation mix from year to year. Note that the custom generation mix will always have data for every year from 2020 to 2080; the time series feature allows the user to change the generation mix breakdown from year to year. Even if the generation mix breakdown is kept the same, the life cycle results could change over time due to changes in the background data over time found in GREET 1. To activate, the user clicks the “Generate Time Series Results” option at the bottom of the user form. This expands the user form, allowing the user to view and change the generation mix across years, shown in Figure A31. The data preview in the top right of the form allows the user to see the breakdown of the electricity generation mix for every year from 2000 to 2080. The “Years to add Generation Mix To” textboxes allow the user to specify a range of years the currently entered generation mix should be applied to. A starting and ending year, inclusive, are added to each textbox respectively, and the Add Generation Mix to Selected Year Range button clicked to add the generation mix to the range of years. To add a generation mix to one year, the user clicks the desired year within the data preview window, and clicks the Add Generation Mix to Selected Year button. The Copy Generation Mix from Selected Year button allows the user to first click a year of data within the data preview window, then click the button to copy the generation mix to the text boxes on the left. This function allows the user to copy a generation mix entered in one year to one or more additional years.

When the user has specified the generation mix, the Create Generation Mix button will initialize the process of creating the electricity generation life cycle data. Please note that this process could take several minutes, during which Excel will be unresponsive. The generated electricity life cycle data can then be viewed in the GREET 1 Time Series worksheet in the GREET Building Module, and the generation mix breakdown can be viewed in the Custom Electricity Mix. Afterwards, the generation mix can be used for the building material selected during the initial process in BC Analysis, or the building(s) selected in the initial Whole Building Analysis process.

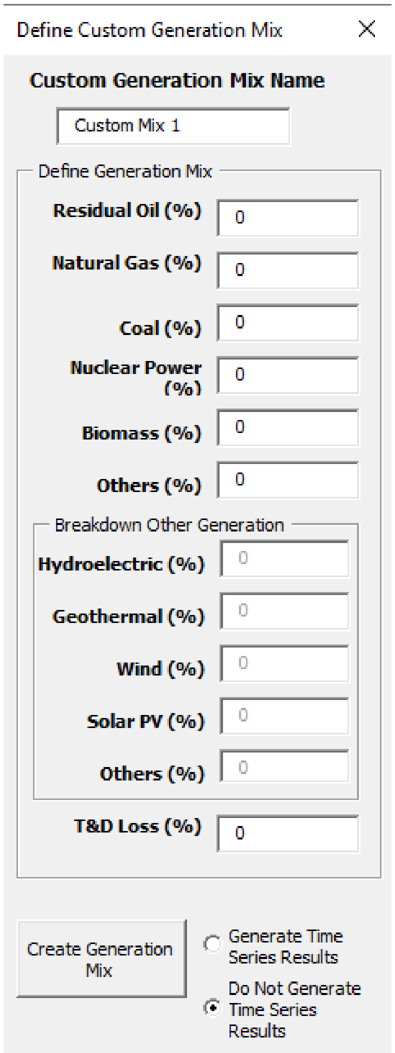


FIGURE A30: The Custom Electricity Generation Mix form, with time series results disabled.

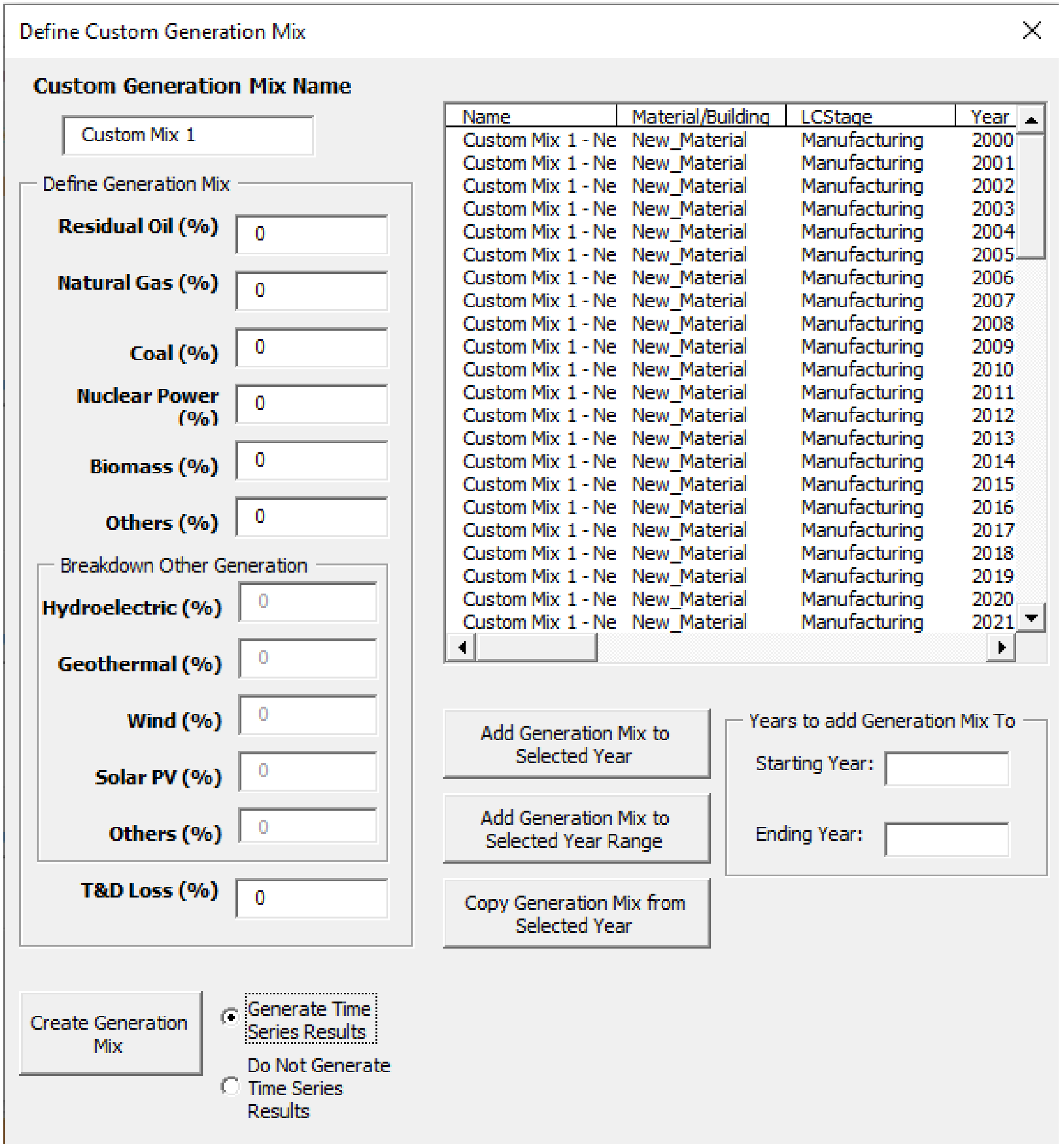


FIGURE A31: The Custom Electricity Generation Mix form, with time series results enabled.

A7 ADDRESS DATA GAPS

As noted in the A1 and A3 data entry stages, a data gap will be detected if a newly entered material is not available in the default life-cycle profile database (located in the LCProfiles worksheet). To address a data gap, the user has 4 options: 1) using the life-cycle profile of a material that is available from the default life-cycle profile database as a surrogate; 2) specifying a customized life-cycle profile, possibly from literature; 3) using a life-cycle profile of the same material modeled for a different year; and 4) generating the life-cycle profile of a data gap based on detailed, process-level data and modeling following the steps detailed in Section 1.3. There are two buttons available for listing and addressing data gaps: the "Address Data Gaps" button provides a user form for addressing data gaps found in the currently selected building material, while the “Address all Gaps” button provides a user form for addressing any material that is a data gap in the current modeling year.

Note that the list of data gaps for the current material is also shown on the BC Analysis interface, shown in Figure A34. This list shows the list of data gaps in the material, what year of data is intended to use for the material, and what years of data (if any) are available.

Upon clicking the Address Data Gaps button, a user form will appear to guide the user through resolving data gaps. This userform is shown as figure A32. The listbox in the userforms shows what materials are data gaps for the selected building material, as well as what year the data is being modeled in, and what alternate year(s) of data are available. The Select Alternate Modeling Year button allows the user to switch what year of data is used for a component. The “Use Closest Available Year for All Gaps” button allows the user to select the closest year with available data for each component. The “Resolve Data Gap” button allows the user to resolve a gap through modeling the gap, selecting a surrogate, or manually providing the life cycle data. To resolve a gap, click on the item in the list. Then, the user can either choose to switch the year of data, or resolve the gap through one of the other three methods listed above. See figure A33 for the userform for switching the year of a data gap.

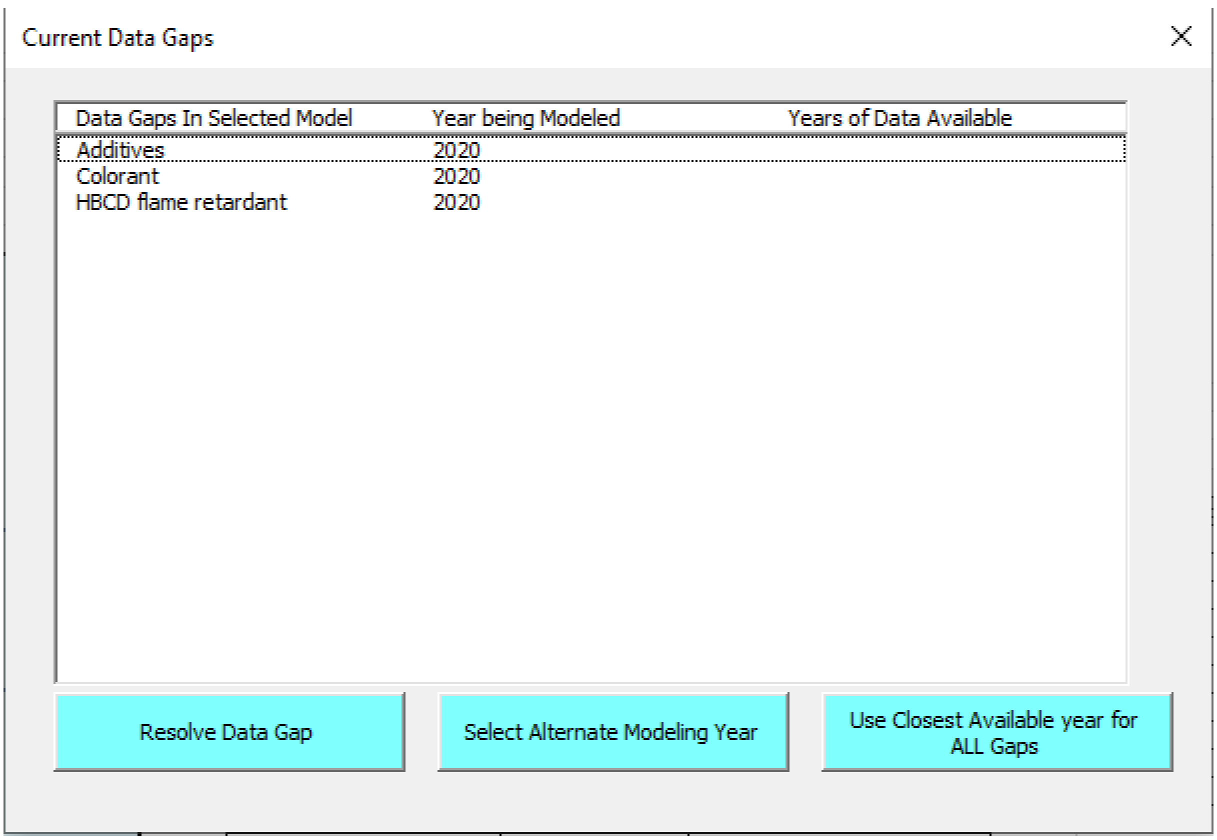


FIGURE A32: The user form for resolving data gaps for a selected building material.

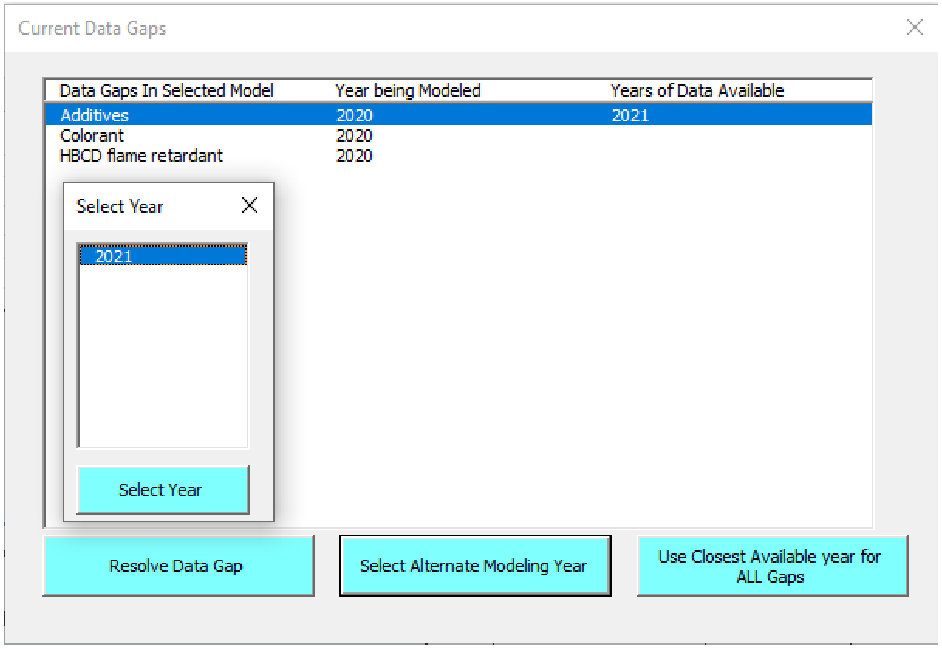


FIGURE A33: Selecting to use data modeled in 2021 for Additives, a component of the selected building material.

To address the list of all data gaps, click the "Address All Data Gaps" button. Figure A35 shows a list of data gaps that are identified and remaining for a range of building materials included in the GREET Building Module, after clicking the "Address Data Gaps" button in green, located in the BC Analysis worksheet. A list of data gaps that are identified and addressed can be accessible in the "Resolved Gaps" category. To address a data gap shown in the remaining data gap list, double click to open up the three options available, as shown in Figure A36.

Data Gaps In Selected Model	Year being Modeled	Years of Data Available
Offgas	2020	

FIGURE A34: The list of data gaps visible on the BC Analysis worksheet. This list contains all data gaps for the selected material, the year of data used for the subcomponent, and what years of data are available (if any).

To address a data gap, either by resolving a data gap in the current material's data gaps list or a data gap from the model's entire data gap list, there are three options, shown in user form in Figure A36.

When the "Choose a surrogate from existing data" option is selected, select an existing material from the dropdown list, as shown in Figure A37. After clicking the "OK" button, the life cycle profile of the selected material will be duplicated and assigned to the selected data gap. This will close the data gap by adding the life cycle profile of the selected data gap to the background LCProfiles database, together with a note that says, "Using the selected material as a surrogate". This note provides information on the data source and will be used to filter materials by data source when considered in a whole building design in the whole building LCA, which is detailed in Section B2.

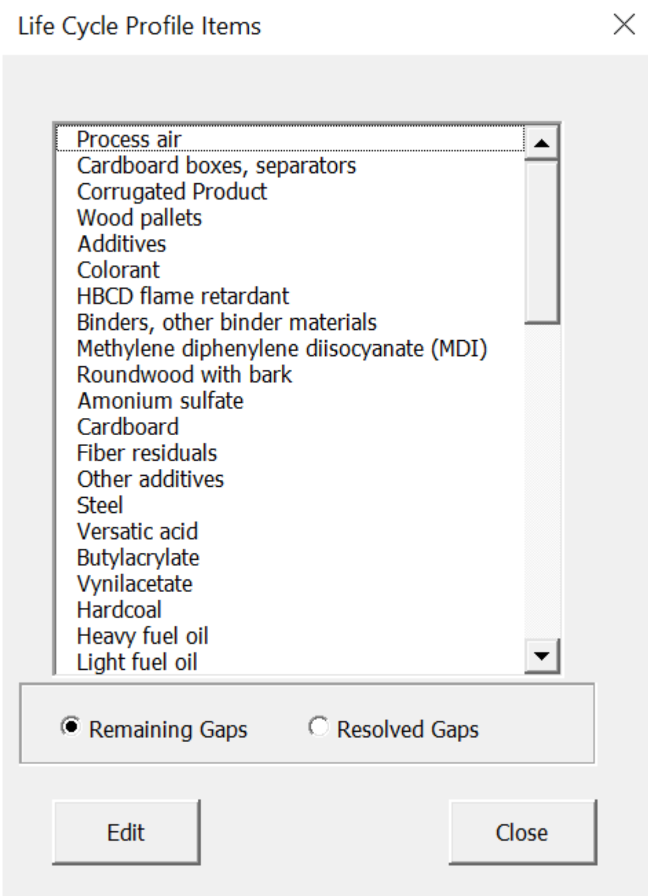


FIGURE A35: Data gaps detected and remaining across the entire model.

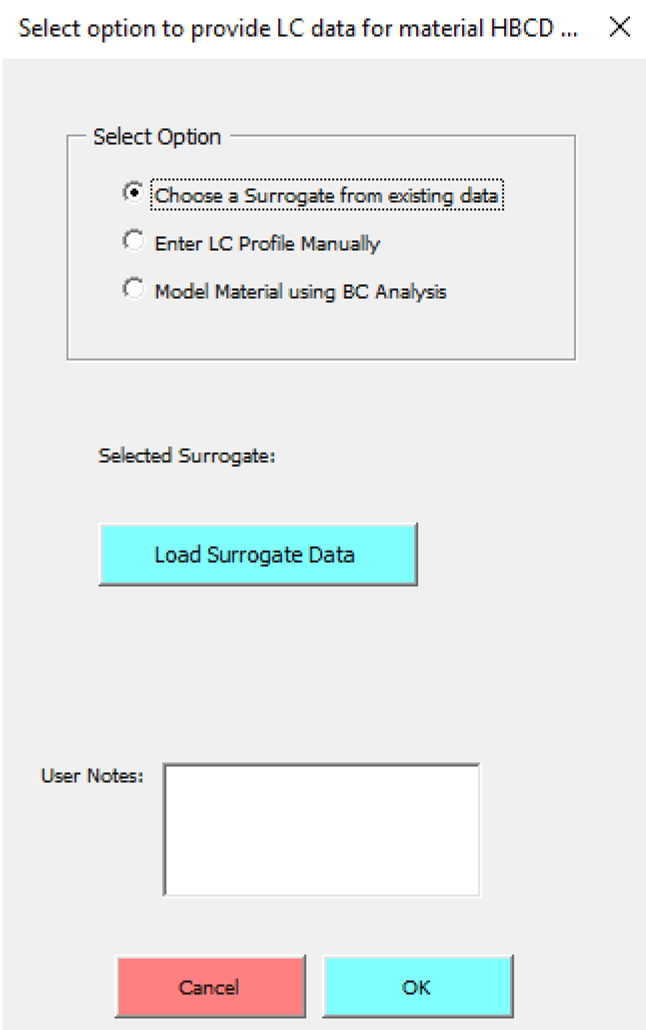


FIGURE A36: The three options to address a data gap. The user can choose to load a surrogate, enter a LCProfile manually, or model the material in BC Analysis.

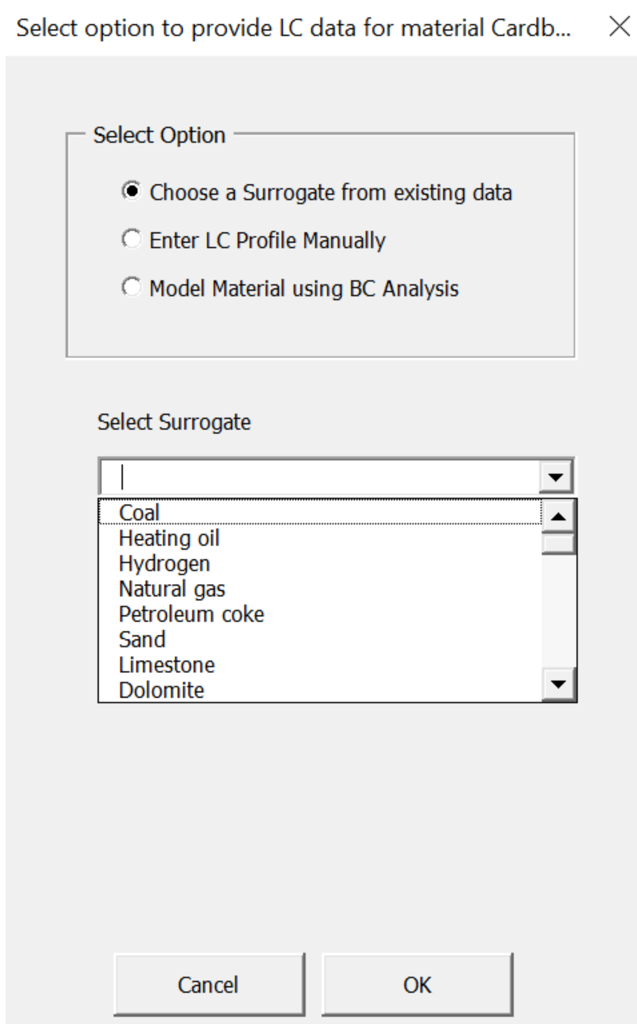


FIGURE A37: Address a data gap by selecting a material from a list of existing materials in the background database as a surrogate.

When the "Enter LC Profile Manually" option is selected, enter the life cycle results metrics for the material manually, as shown in Figure A38.

When the "Model Material using BC Analysis" option is selected, the user will be taken to the BC Analysis worksheet to conduct a process-level, detailed LCA following the steps given in Section A1.3, together with a message window about this overall procedure, as shown in Figure A39. After clicking "OK" to close the message window, the user can start to enter detailed LCI across the supply chain of the gap material before clicking the "Run Simulation" button to generate the LCA results for the gap material, which will be saved and added to the background LCProfiles database, with a comment noting that this is "User Modeled Data". This note provides information on the data source and will be used to filter materials by data source when considered in a whole building design in the whole building LCA, which is detailed in Section B.

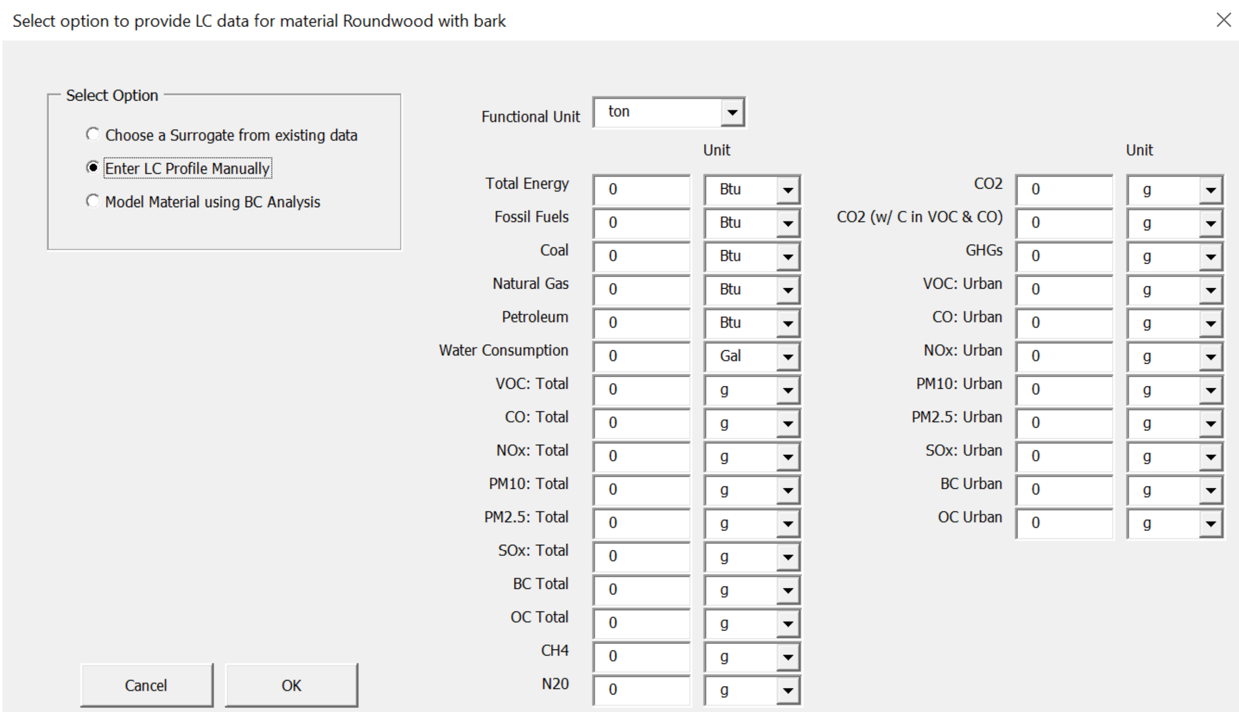


FIGURE A38: Address a data gap by manually entering a life cycle profile containing 27 life cycle results metrics for the selected gap material.

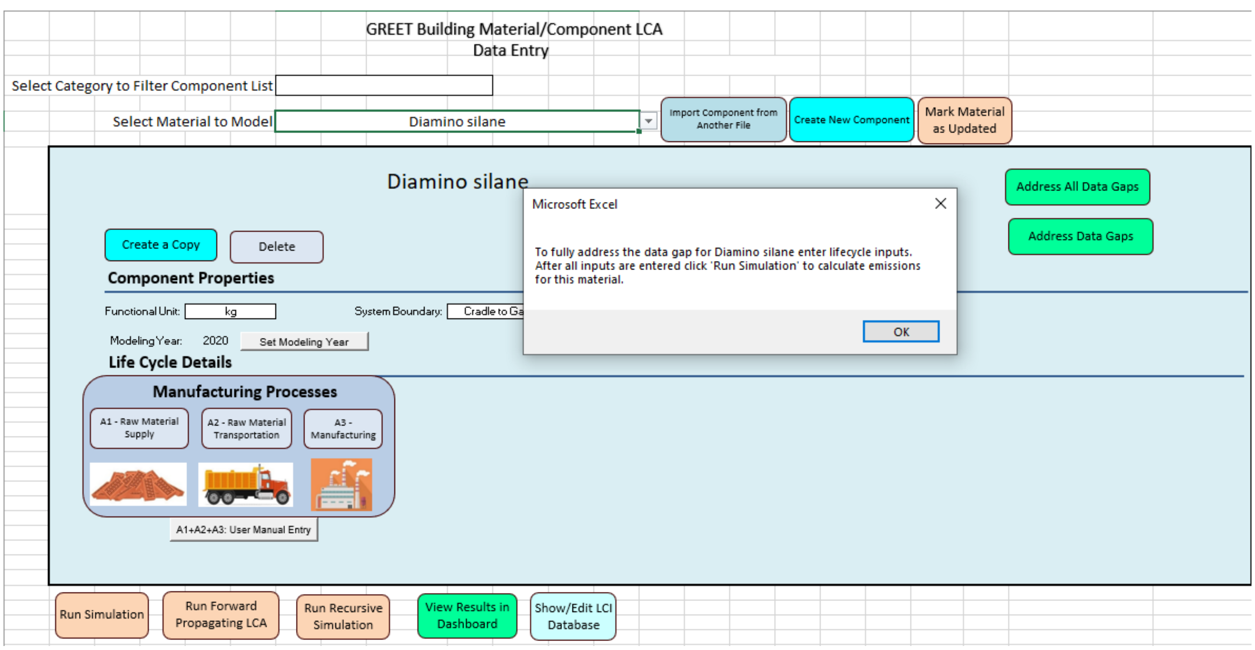


FIGURE A39: Address a data gap by conducting a process-level, detailed LCA with the BC Analysis worksheet.

A8 RUN SIMULATION TO GENERATE LCA RESULTS

After entering LCI data across the life cycle stages for a given system boundary, the user can run a simulation to generate LCA results by clicking the "Run Simulation" button in the BC Analysis worksheet. Note that the data gap detection and addressing feature described in Section A7 is baked into this step, which automatically detects if there are any data gaps that could be addressed before proceeding to run the simulation. If any data gaps are detected, a message window will pop up, as shown in Figure A40, to remind the user of the issue. The user can decide whether to ignore any data gaps or address them. Proceeding with the simulation without addressing the data gaps will generating somewhat incomplete results, without accounting for the impacts of the gap materials. Again, this simulation procedure gives the user flexibility to proceed and generate results with the best data available, especially when the data gaps account for a small fraction of the bill of materials and thus might have a small impact on the simulation results. Meanwhile, the data gaps detected will be listed in the "Data Gaps in Selected Model" block. Later, when the user selects the same building material from the BC Analysis GUI, the data gaps that have been detected previously will show up in the "Data Gaps in Selected Model" block, reminding the user to address them when further data and information become available.

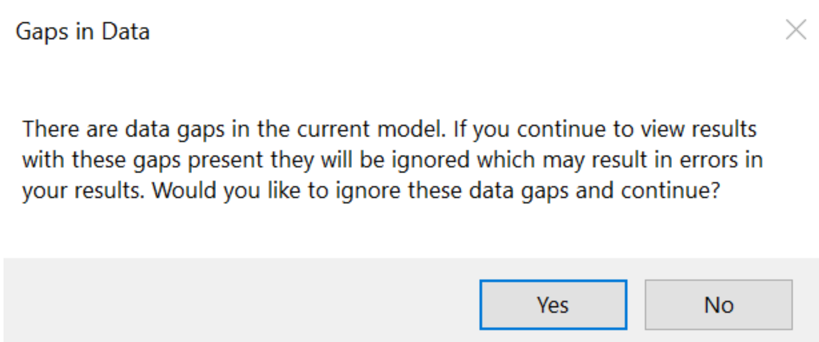


FIGURE A40: The message window warning the user of gaps detected before running the simulation

When no data gaps are detected after clicking the "Run Simulation" button, the program will proceed to calculate and generate the LCA results. A progress bar will pop up, showing the real-time progress of running the simulation, as shown in Figure A41. Depending on the number of data records that are involved with a simulation, it could take from seconds to minutes to complete the simulation.

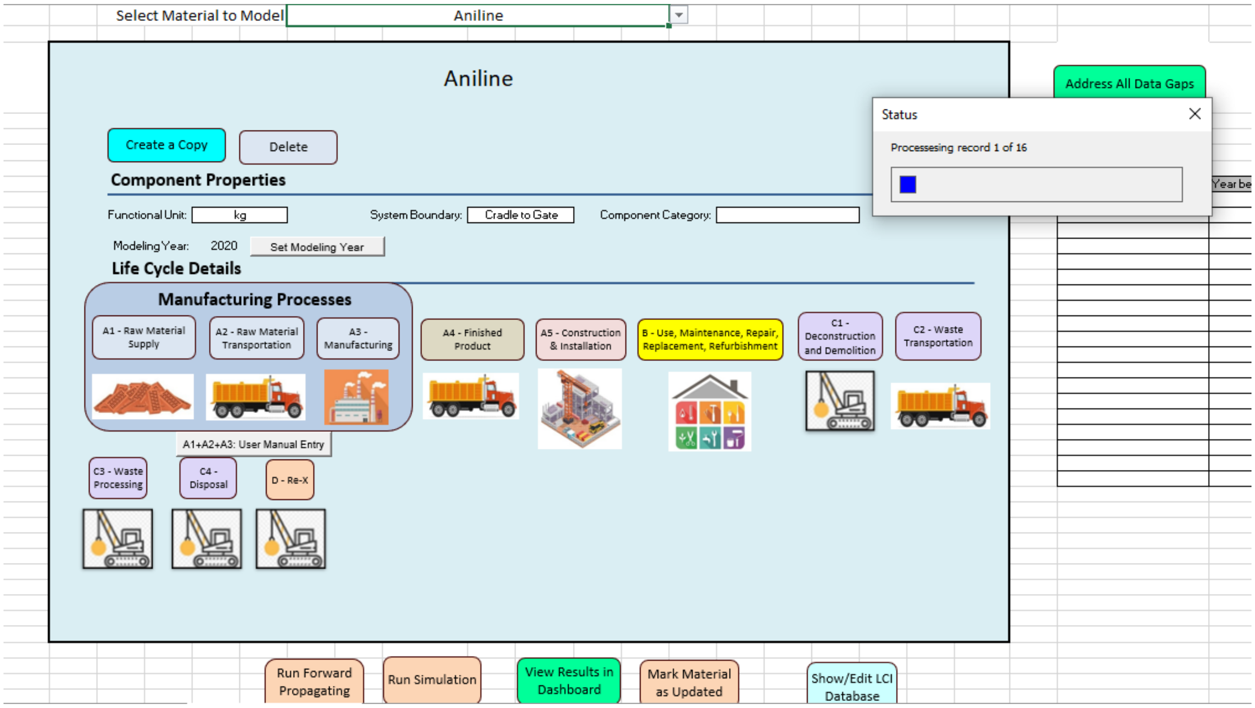


FIGURE A41: A progress bar showing the real-time progress of running the simulation.

A9 FORWARD AND BACKWARDS RECURSIVE LCA

In addition to running the Building Component Life Cycle Analysis normally, the user can also select to run a forward or backwards running recursive LCA by clicking the relevant buttons on the BC Analysis worksheet, shown in Figure A1.

A9.1 Backwards Recursive LCA

Backwards recursive LCA is designed to enable a streamlined update of modeling the top-level material by recursively incorporating updates/changes at the sub-component level It will first run the LCA on all subcomponents on a material, before running on the material itself. For example, if material A has subcomponents B and C, then B and C will be run through the Building Component LCA before material A is run. This process continues recursively down the entire material tree of the original building component. In the previous example, if materials D and E are subcomponents of material C, then materials D and E will be run through the LCA before material C, and material C will be run before material A.

Note that this process will take considerably longer to run than the default Life Cycle Analysis, as the LCA process will have to be repeated for each subcomponent.

A9.2 Forward Recursive LCA

Forward recursive LCA is designed to enable a streamlined update of all the materials that may be affected by updates/changes of other materials or background data, in an order that propagates the chain of causal effects starting with such updates/changes. It will allow the user to first run LCA on a selected building component(s), and then run LCA on any building component that uses the original components and any background data as inputs. For example, if material A has subcomponents B and C and if some background data that may affect subcomponent C has been updated, the user can choose to run forward recursive LCA on material A. The module will start with an update LCA on material C, then run LCA on A. Upon clicking the forward propagating LCA button, a user form will pop up to allow the user to select which materials will have the LCA run on them. To add materials, select the name in the combo box, then click the Add above material button. The list of materials which need updates can also be added by clicking the button below. Finally, a material can be removed by selecting it in the list and clicking the remove button.

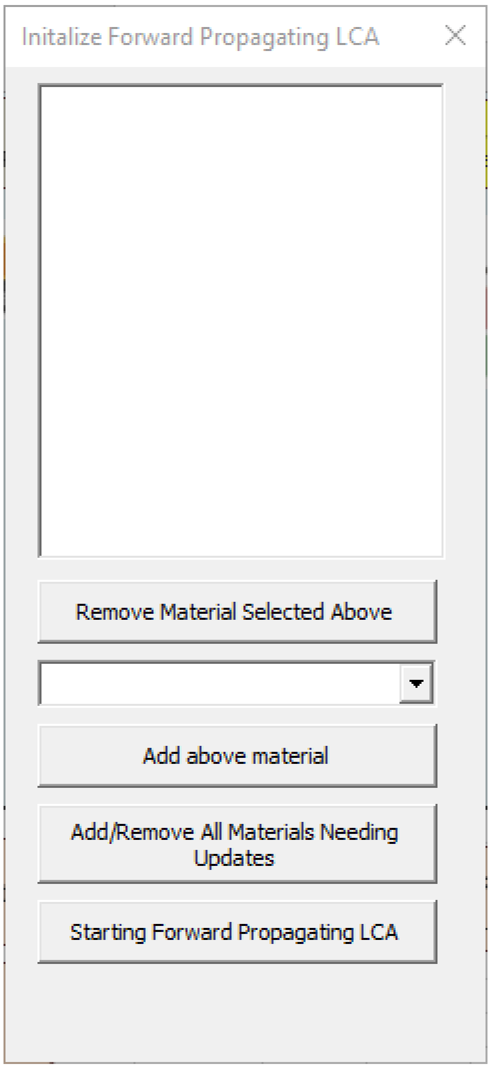


FIGURE A43: The userform for initializing forward propagating LCA.

Next, a userform will appear to allow the user to select which materials will be run in the LCA, as shown in the userform below. Each line in the listbox shows which material will be added, and the necessary subcomponent for running that material. If a material is selected to be run in the LCA, the relevant subcomponent must also be run. For example, in the figure below, MDI may be run without selecting Polyiso Roof, but Polyiso Roof may only be run if MDI is also run. Before finalizing the LCA, a final userform will appear to show the user which materials will be run through the LCA, and in what order.

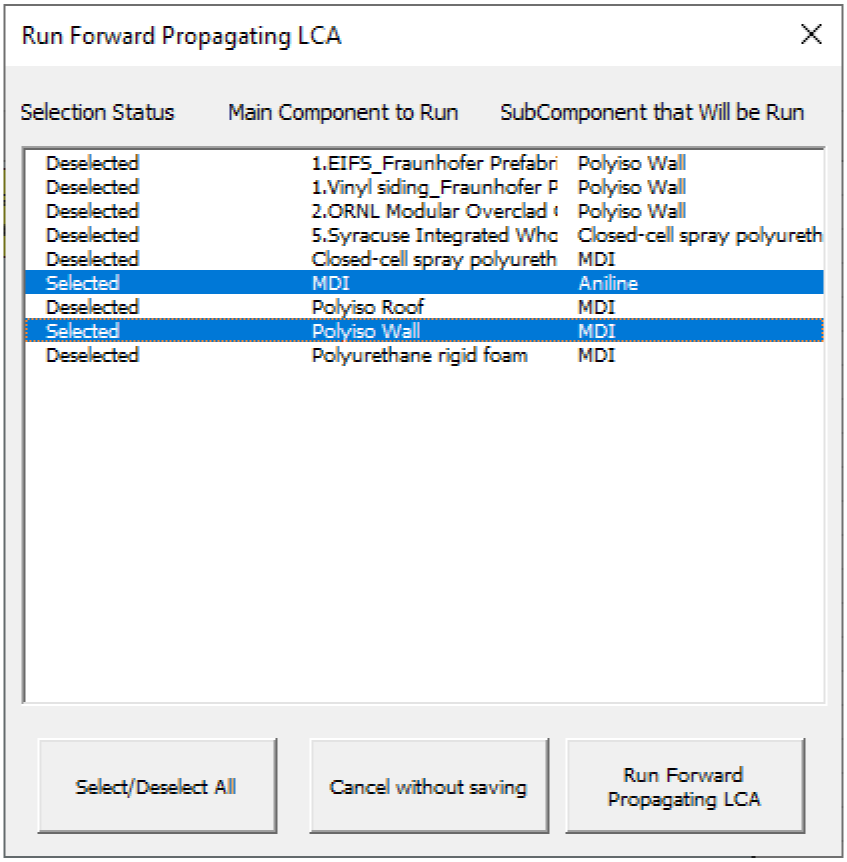


FIGURE A44: The user form for finalizing what materials are run through the forward propagating LCA.

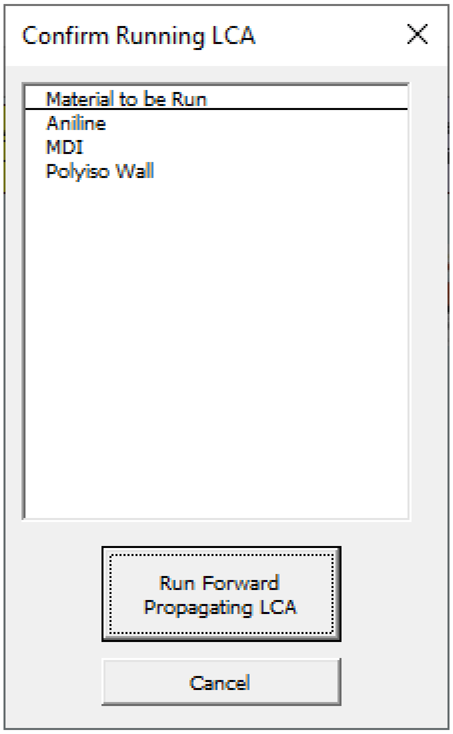


FIGURE A45: The final user form confirming what materials will be run through the forward propagating LCA, and in what order.

A10 VIEW AND EXPLORE LIFE CYCLE RESULTS

After a simulation is completed, the user can click the "View Results in Dashboard" button in green, located in the BC Analysis worksheet, to view and explore details of the LCA results in a dynamic Dashboard.

On the Dashboard, the LCA results are broken into two categories. First, the embodied GHG emissions or other embodied impact metrics, such as embodied fossil energy consumption, embodied water consumption, etc., are visualized in dynamic PivotCharts; Second, a table of LCA results across the life-cycle stages of the last building material that is modeled.

A10.1 View, Explore, and Compare Embodied Results with PivotCharts

The embodied GHG results are displayed as a series of PivotCharts and associated filters, or slicers, on the BC Analysis Dashboard (Figure A29). To view the results of newly modeled materials, right click the PivotChart at the top of the results display and click "Refresh" after running calculations. This will update the display to show the proper results. There are four PivotCharts set up to visualize the embodied GHG emissions, by default, across the life cycle stages, both stacked and unstacked, as well as contributions of material and energy inputs across the life cycle stages. Additionally, users can choose to select only specific building materials, life cycle stages, material and energy inputs, and life cycle metrics of interest through four groups of filters/slicers to control the PivotCharts (Figure A30). Selecting a filter/slicer button will enable only that option to be shown on the PivotCharts. Holding the Control key and clicking multiple buttons will display all clicked options in the results. Note that any changes through the filters/slicers with change all the four preset PivotCharts as they are dynamically connected. Additionally, the user can change the unit used with each type of metric by changing the cells located at G4-I4.

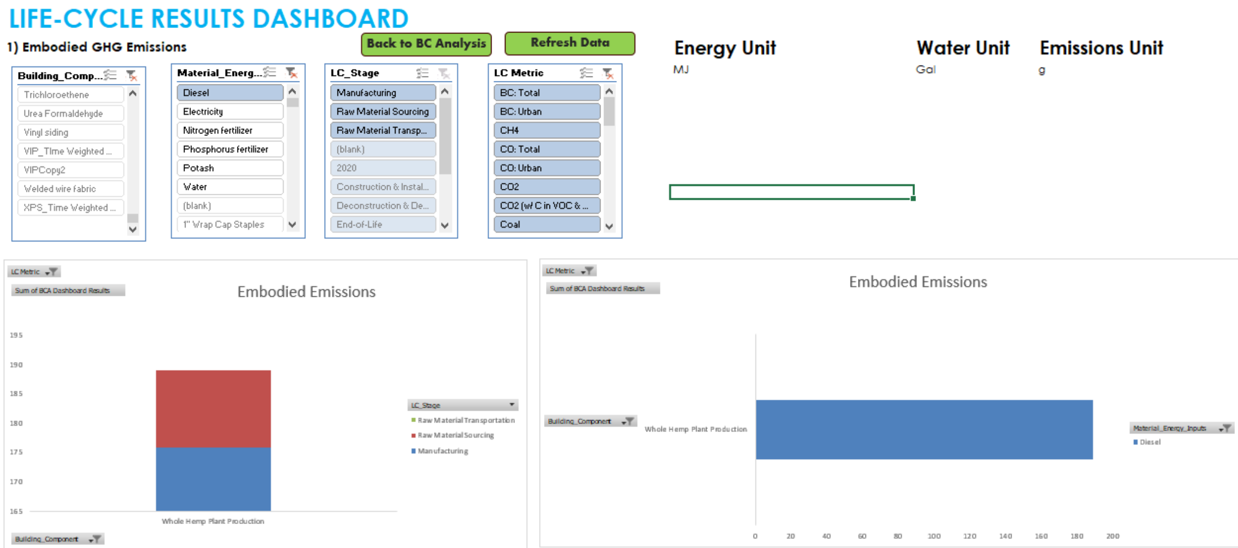


FIGURE A46: The Dashboard to view, explore, and compare embodied GHG emissions and other impact metrics of building materials through dynamic PivotCharts.

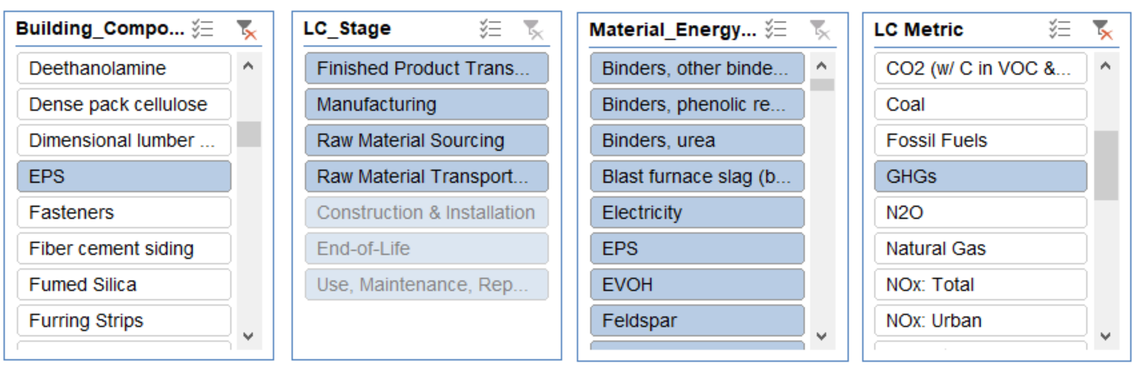


FIGURE A47: Filters/slicers that are dynamically connected to the PivotCharts to control contents to view and compare among building materials.

A10.2View Numerical Embodied Results

A summary table of LCA results across life cycle stages for embodied GHG emissions, as well as a range of other impact metrics encompassing embodied energy consumption, water consumption, and criteria air pollutant emissions, is available for the last building material that has been modeled, as shown in Figure A48. These numerical results in absolute values complement the visuals shown in PivotCharts shown in Section A10.1.

2) Summary of Life-Cycle Energy Consumption, Water Consumption, GHG Emissions, and Criteria Air Pollutant Emissions at Each Stage for the Modeled Material

	Asphalt Impregnated Paper	Raw Material Sourcing	Raw Material Transportation	Manufacturing	Finished Product Transportation	Construction & Installation	Use, Maintenance, Repair, Replacement	End-of-Li	Recycling, remanufacturing, and Reuse	Cradle-to-Gate	Cradle-to-Installation	Cradle-to-Use	Cradle-to-Grave	Cradle-to-Cradle
in Btu	Total energy	31,734	149	0	30	0	0	0	0	31,883	31,913	31,913	31,913	31,913
in Btu	Fossil fuels	19,304	148	0	30	0	0	0	0	19,453	19,482	19,482	19,482	19,482
in Btu	Coal	7,569	1	0	0	0	0	0	0	7,570	7,570	7,570	7,570	7,570
in Btu	Natural gas	10,137	15	0	3	0	0	0	0	10,152	10,155	10,155	10,155	10,155
in Btu	Petroleum	1,942	132	0	26	0	0	0	0	2,074	2,101	2,101	2,101	2,101
in gallon	Water Consumption	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	2.4	2.4	2.4	2.4
in grams	VOC: Total	0.229	0.004	0.000	0.001	0.000	0.000	0.000	0.000	0.233	0.234	0.234	0.234	0.234
in grams	CO: Total	0.760	0.012	0.000	0.002	0.000	0.000	0.000	0.000	0.772	0.775	0.775	0.775	0.775
in grams	NOx: Total	2.014	0.028	0.000	0.006	0.000	0.000	0.000	0.000	2.043	2.048	2.048	2.048	2.048
in grams	PM10: Total	0.190	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.191	0.191	0.191	0.191	0.191
in grams	PM2.5: Total	0.110	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.111	0.111	0.111	0.111	0.111
in grams	SOx: Total	44.313	0.001	0.000	0.000	0.000	0.000	0.000	0.000	44.314	44.314	44.314	44.314	44.314
in grams	BC Total	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.015	0.015	0.015	0.015
in grams	OC Total	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.042	0.042	0.042	0.042
in grams	CH4	7.852	0.016	0.000	0.003	0.000	0.000	0.000	0.000	7.867	7.870	7.870	7.870	7.870
in grams	N2O	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.031	0.031	0.031	0.031
in grams	CO2	1,852	11	0	2	0	0	0	0	1,864	1,866	1,866	1,866	1,866
in grams	CO2 (w/ C in VOC & CO)	1,839	11	0	2	0	0	0	0	1,850	1,852	1,852	1,852	1,852
in grams	**GHGs**	**2,082**	**12**	**0**	**2**	**0**	**0**	**0**	**0**	**2,094**	**2,096**	**2,096**	**2,096**	**2,096**
in grams	VOC: Urban	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.016	0.016	0.016	0.016
in grams	CO: Urban	0.088	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.088	0.088	0.088	0.088	0.088
in grams	NOx: Urban	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190	0.190	0.190
in grams	PM10: Urban	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.014	0.014	0.014	0.014
in grams	PM2.5: Urban	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011	0.011	0.011	0.011
in grams	SOx: Urban	0.523	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.523	0.523	0.523	0.523	0.523
in grams	BC Urban	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
in grams	OC Urban	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.003	0.003

FIGURE A48: The summary table of life-cycle results across life cycle stages for embodied GHG emissions and other impact metrics for the last building material modeled.

A12 CREATE A COPY OR DELETE RECORDS OF EXISTING BUILDING MATERIALS

To model a new building material that may undergo similar manufacturing processes or has a similar raw material composition to an existing building material, the user can use the "Create a Copy" feature to create an exact copy of all the foreground LCI data of a selected building material, for example, asphalt impregnated paper, as shown in Figure A50, and save the record for a new building material with a different name. For small changes to material profiles, it may be easier to use the building material LCA GUI based on what are already included.

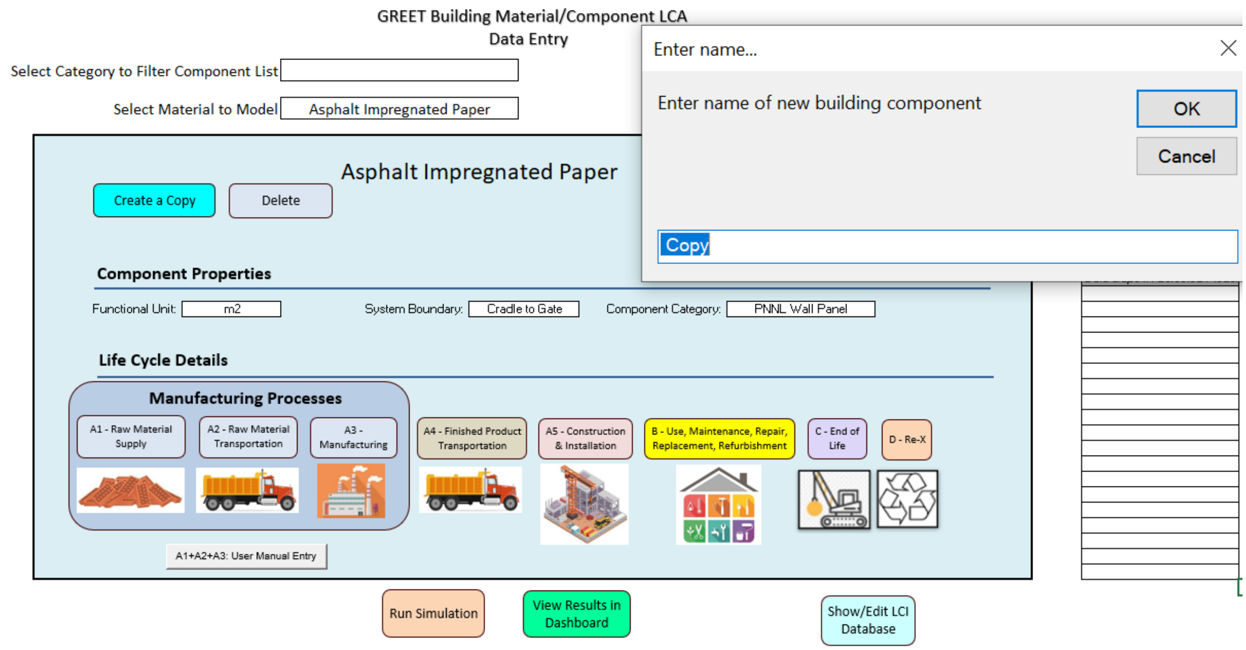


FIGURE A50: Name a new building material that is a copy of an existing building material.

To delete a building material from the Module, select it from the “Select Material to Model” dropdown list located at the BC Analysis worksheet and click the “Delete” button in the building material LCA GUI. A message window will pop up to confirm the operation, as shown in Figure A51. Note that the data and record removed from this operation are unreversible.

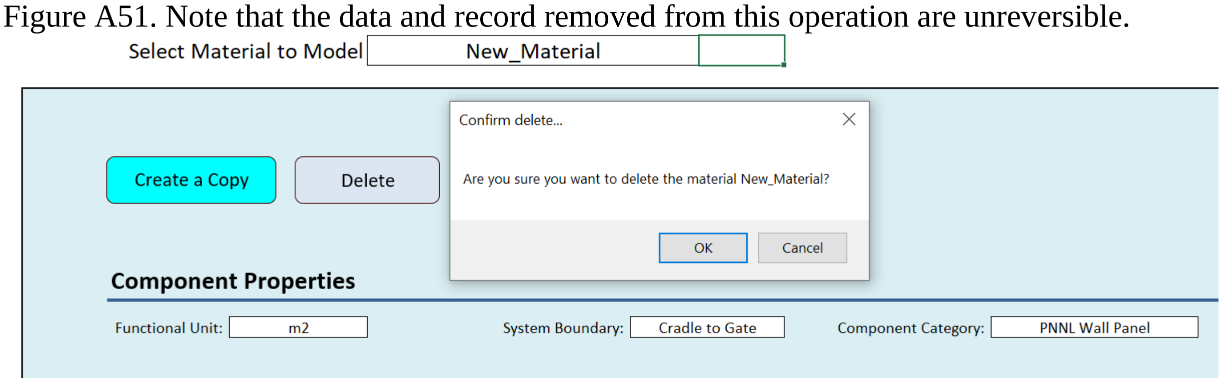


FIGURE A51: Delete a building material.

A12.1Add Cradle-to-Gate Data Manually

To include LCA results that are reported in literature and open sources for further analysis beyond the system boundary and for whole building LCA as additional data sources, the GREET Building Module allows manual entries of Cradle-to-Gate (from A1 to A3) embodied results. To do so, the user can click the “A1+A2+A3: User Manual Entry” button located at the BC Analysis worksheet, and enter the data, including the functional unit, using a data entry form shown in Figure A52. The user can also make notes about details, such as data sources, key assumptions, limitations, etc., of the data.

The data added will be saved to the LCProfiles database, serving as a new data source for a building material that may be considered for a whole building design and LCA modeling. It also serves as the basis for extending the analysis of that building materials from the Cradle-to-Gate system boundary to including other impacts during use phase, end-of-life-, and/or recycling, remanufacturing, and reuse scenarios.

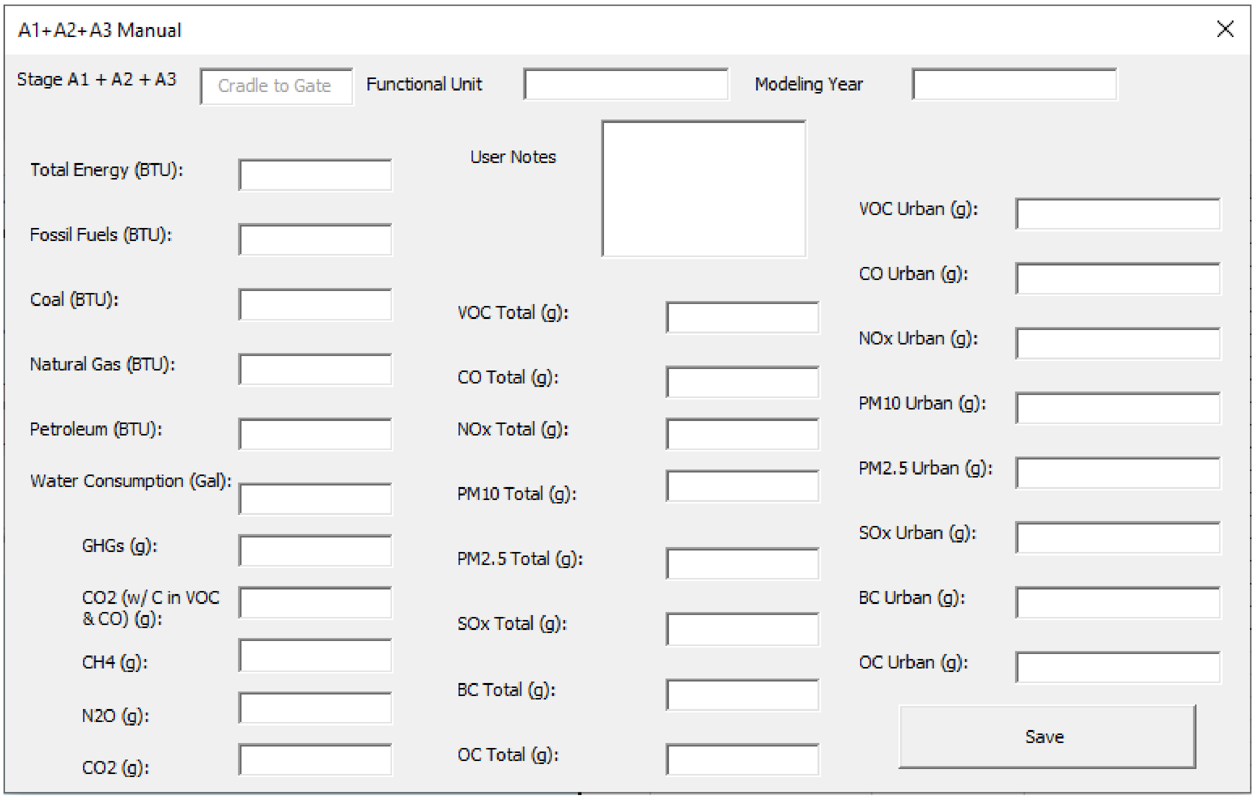


FIGURE A52: The data entry form to add Cradle-to-Gate results from literature manually.

A13 IMPORT DATA FROM ANOTHER FILE

To facilitate parallel efforts by individuals or teams, who may be using the GREET Building Module to conduct LCA of different building materials in separate, but parallel, efforts, we have included a feature to import data from another GREET Building Module working file that is in the local computer drive. To begin, click the “Import Component from Another File” button located at the BC Analysis worksheet. A warning message window, as shown in Figure A53, will pop up to remind the user to first backup the version of the GREET Building Module receiving the import data prior to importing data.

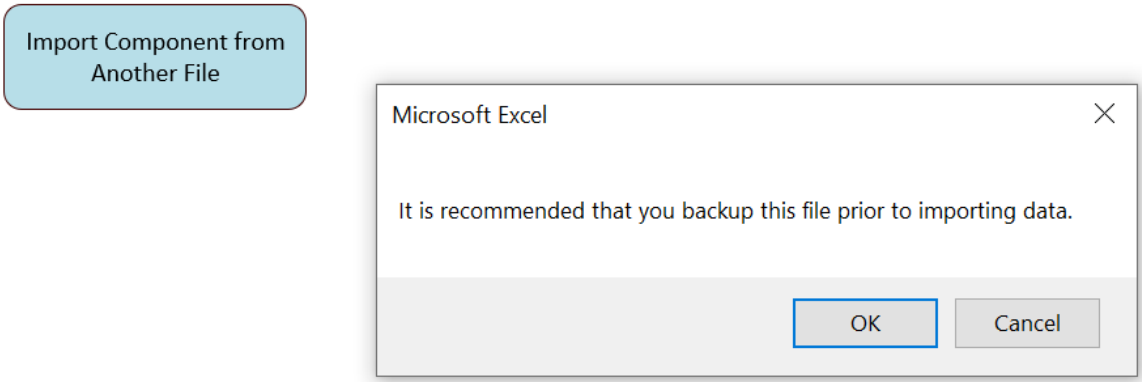


FIGURE A53: The warning message to always backup the GREET Building Module file prior to importing data from other files.

When it is ready to import data, open a different version of the GREET Building Module file to import data from, and a data import window will pop up, providing a dropdown list to select which building materials from the file to import, as shown in Figure A54. Note that when importing a building material that has the same name of another material already existing in the receiving GREET Building Module file, the import data will overwrite that of the default one, with a warning window for the user to decide on the import. The user will need to run a simulation of the imported building material to generate or update the LCA results.

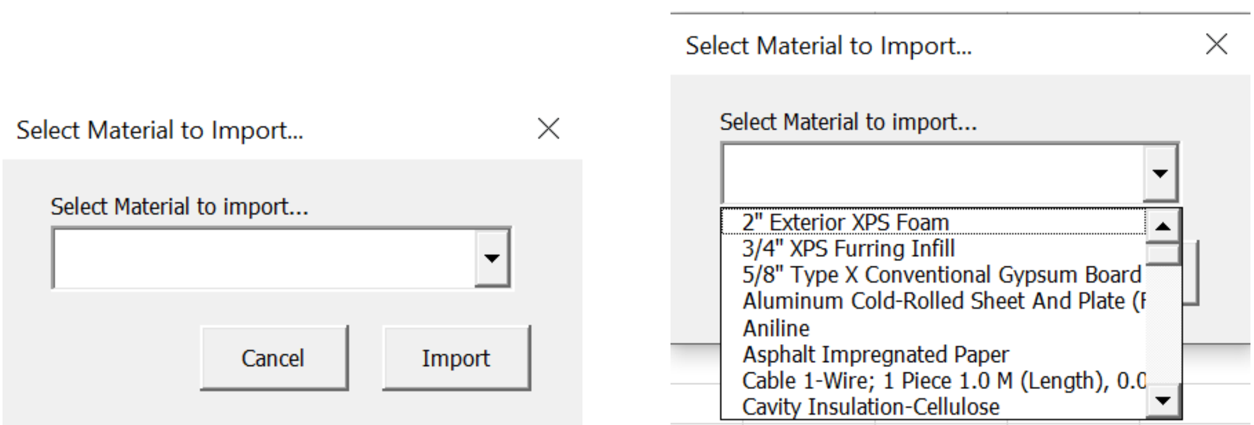


FIGURE A54: Selection of building material to import from another GREET Building Module file.

B WHOLE BUILDING MODELING

In addition to modeling individual building materials, the GREET Building Module is equipped to model embodied and operational GHG and energy impacts for a whole building or a building design. The whole building LCA modeling is broken down into three parts: 1) Information on the building, 2) Information on the Bill of Materials (BOM), and 3) operational energy consumption, or Energy Use Intensity (EUI) information. In general, these foreground data required for a whole building LCA can be entered into the Module in one of two ways. Users can interact with user interface forms designed to simplify the data entering process, or users can manually enter data into the Module directly through data worksheets. Both processes begin on the whole building LCA dashboard located at a worksheet named “Whole Building Modeling”.

B1 OVERVIEW OF THE WHOLE BUILDING LCA PLATFORM

The Whole Building LCA Platform can be found on the worksheet titled “Whole Building Modeling. There are three buttons to operate the user interfaces to enter data regarding building information, building BOM, and building EUI. A separate button to manually enter the same categories of data in three different worksheets is also available (Figure B1). After which, there are buttons to address data gaps, run the calculations, and view the results. Additionally, buttons are present to configure sensitivity analysis for Whole Building LCA, as discussed in section B5

Note that the GREET whole building LCA modeling fully incorporates the UNIFORMAT II classification for building elements and related sitework, which is detailed in ASTM Standard E1557. UNIFORMAT classification has been recommended by the Construction Specifications Institute/Construction Specifications Canada (CSI/CSC) to structure schematic phase specifications, and by the Design-Build Institute of America for performance specifications. The Standard UNIFORMAT II classification provides a common structure linking the building design, specifications, and life-cycle analysis. Its integration into the GREET whole building LCA framework enables comparability of life cycle analysis results of alternative building designs, material choices, and construction practices.

A button is available to take the user to review details of the UNIFORMAT II classification, which has three mandatory categories and a fourth tier of recommended category of building elements. For users who are not familiar with the UNIFORMAT II classification, it is recommended that he/she check the details before preparing and entering itemized BOM data that can be compatible with the UNIFORMAT II classification as much as possible.

Once the required data for embodied and operational impacts modeling are entered, a following button will allow the user to detect and address any potential data gaps by automatically checking the itemized BOM data entered against the default material/energy database located in the LCProfiles worksheet in the Module. The user will get feedback on potential gaps and guidance on how to address identified data gaps in an interactive process as detailed below in Section B3. After that, the user can click a button to calculate the whole building embodied and operational impacts of buildings.

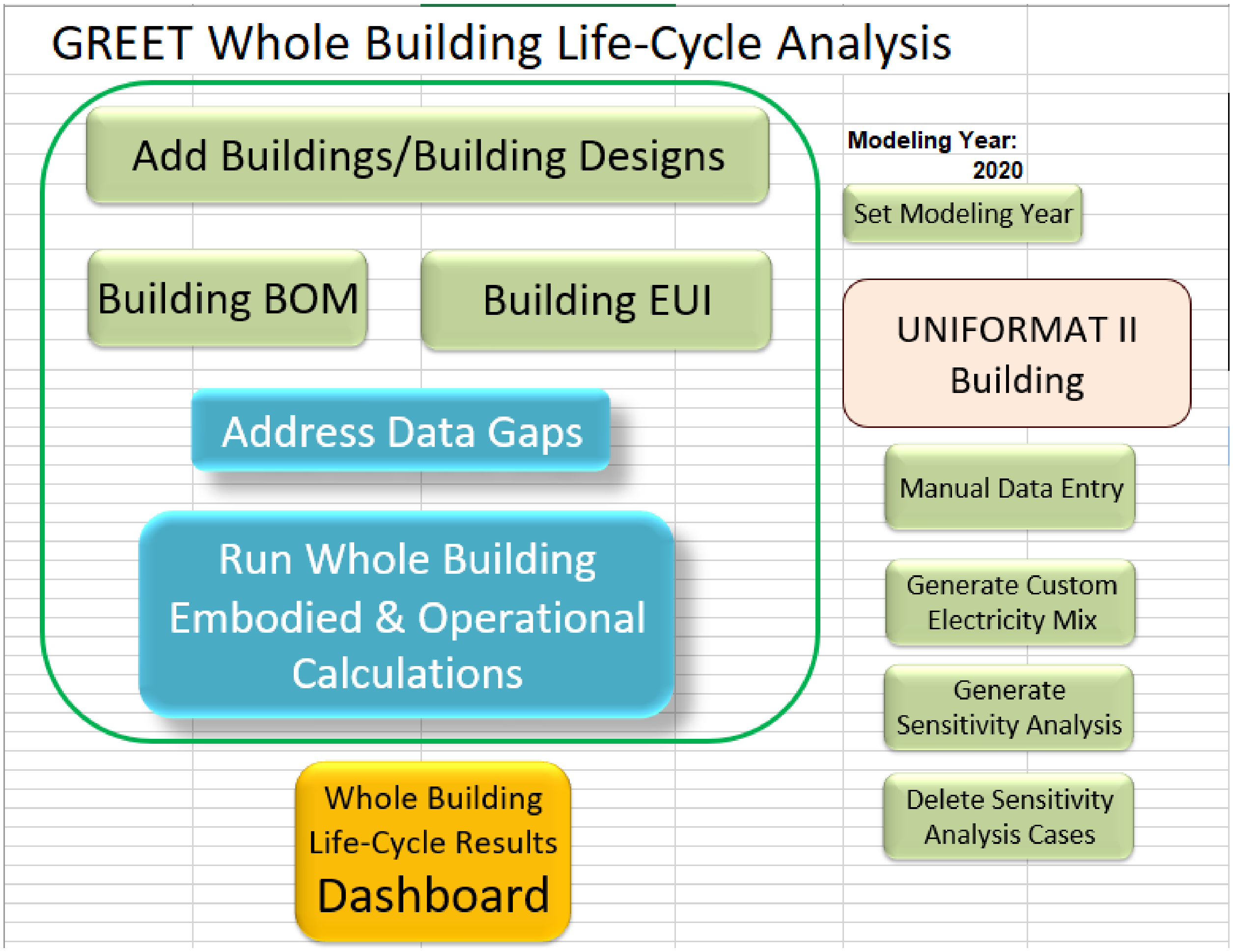


FIGURE B1: The whole building LCA modeling framework.

When the calculations are completed, the results are visualized in a Dashboard with pre-set charts that are dynamically linked to the modeling results, allowing for exploration, interpretation, and comparison of the results of selected buildings/building designs in a dynamic fashion. This dashboard can be found on the "Dashboard_WB" worksheet, accessed using the "Whole Building Life-Cycle Results" button on the Whole Building Modeling worksheet. This dashboard is described in section B7.

B2 ENTERING WHOLE BUILDING MODELING DATA

Data can be entered into the model in one of two ways. Users can enter data through a variety of user interface forms or enter data manually into the data worksheets. It is recommended for most users to interact with the user interface forms, as they simplify the process of data entry as well as properly format the data for the model. To access the user interface forms or manually enter data, use the buttons found on the Whole Building Dashboard, described in Section B1.

B2.1 Whole Building Analysis Data Aggregation and Time Series LCA

During Whole Building Analysis, the Bill of Materials data supports data aggregated to the system boundary, or to the life cycle stage. Material life cycle data for whole building analysis is stored in the Aggregated LCProfiles worksheet. This is discussed in section D3. Before running LCA, the user will be prompted to select the system boundary for the analysis, as well as the data aggregation type; aggregated to the system boundary, or disaggregated to the life cycle stage.

Additionally, the Whole Building Analysis module is equipped with time series functionality. A modeling year can be selected from the dashboard, to allow the user to model a building starting in any year. GREET1 and GREET2 data are present, including electricity generation mixes for each U.S State and a National Average, from 2020 to 2080 to support time series modeling. Additionally, when a material is entered into the bill of materials, a replacement period can be entered. Every time the replacement period elapses, the calculation of life cycle data will use data from the relevant year. For example, a material with a replacement period of 20 years in a building with a lifespan of 60 years starting in 2020 will be modeled in 2020, 2040, 2060, and 2080.

B22 Entering data through Building Info Interface

Data is entered through the user interface forms using the buttons located on the Whole Building Dashboard (Figure B1). To begin, users enter the building information into the Building Information Interface (Figure B2). This interface is accessed by clicking the “Add Building/Building Designs” button on the Whole Building Dashboard.

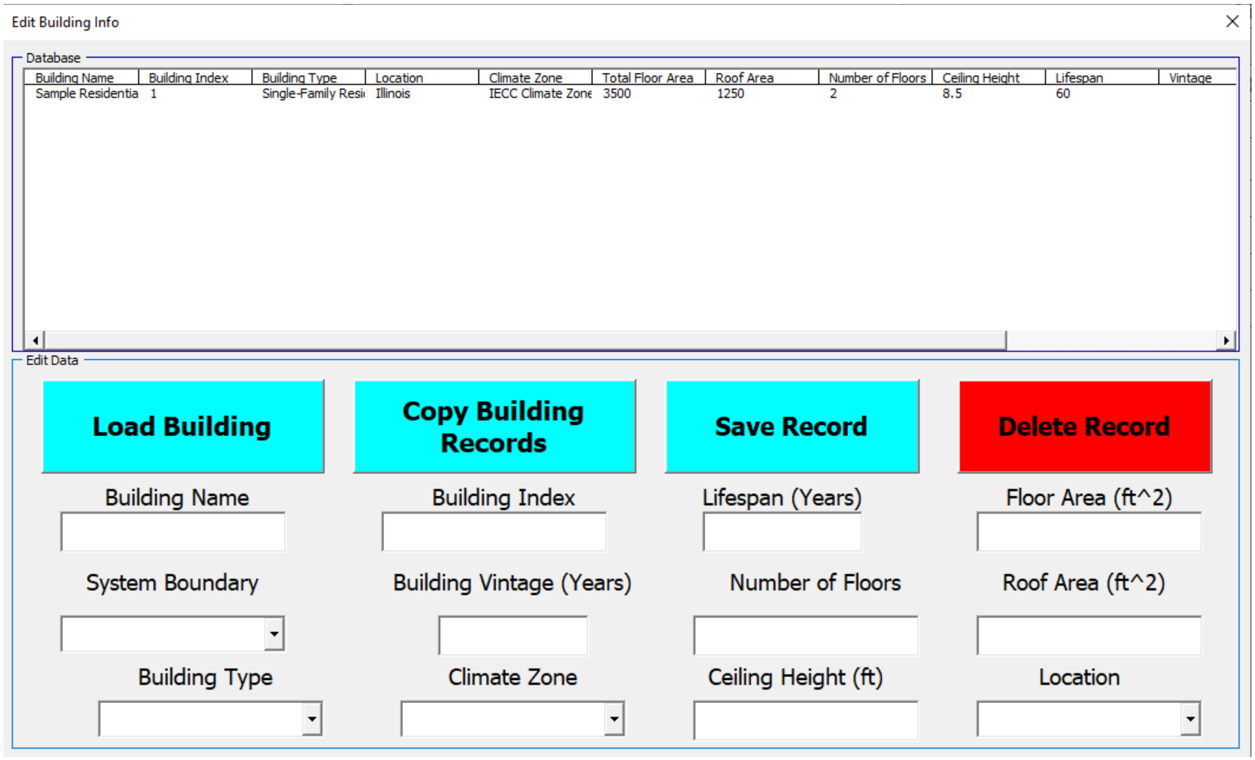


FIGURE B2: The Building Info Interface.

To begin entering building information, users enter data into the text boxes at the bottom of the form. The building name and building index serve as identifiers for this building. Separate building records can share the same name, or share the same index, but each building record must have a unique building name and index pairing. The lifespan of the building is entered in years and determines how many years of Energy Use Intensity information the building can have. The floor area, in square feet, is the total floor span of the building. The system boundary represents the boundary for both BOM data and EUI data. Choices range from Cradle to Gate all the way to Cradle to Cradle. The building vintage is used for retrofitting old buildings. It serves as a record of how many years the building has already been in operation. The number of floors is the total number of floors in the building. The roof area is entered in square feet and is the total roof space of the building. Building type represents the type of building entered. Users can enter their own entry or choose from a preset option. Preset options include Single-Family Residential Building, Multi-Family Residential Building, Low-Rise Commercial Building, and High-Rise Commercial Building. Climate Zone is the IECC Climate zone that the building is located in. Choices range from IECC Climate Zone 1 to Climate Zone 8. The ceiling height is the height of the ceilings within the building entered in feet. The location is the location of the building. The user can enter their own location or choose from a preset option. Preset options currently include the 50 U.S States.

To save a record, users click the "Save Record" button. If the entered information has a unique building name and index pairing, it will be saved as a new building entry. If it is not a unique building name and index pairing, users will be prompted if they want to save over a previous building entry. Additionally, users can click on a building entry in the database above and click the "Load Building" button to preload the selected building information into the textboxes at the bottom of the interface. The "Copy Building Records" button allows the user to duplicate the building record, including BOM and EUI data, of a selected building to a new building name and index. The "Delete Record" button allows the user to delete a building record, including BOM and EUI data associated with that building.

B2.3 Entering Data into the Bill of Materials Interface

The next step is to add data to the Bill of Materials for the building. This is done by accessing the Bill of Materials Interface through the "Building BOM" button on the Whole Building Dashboard (Figure B3)

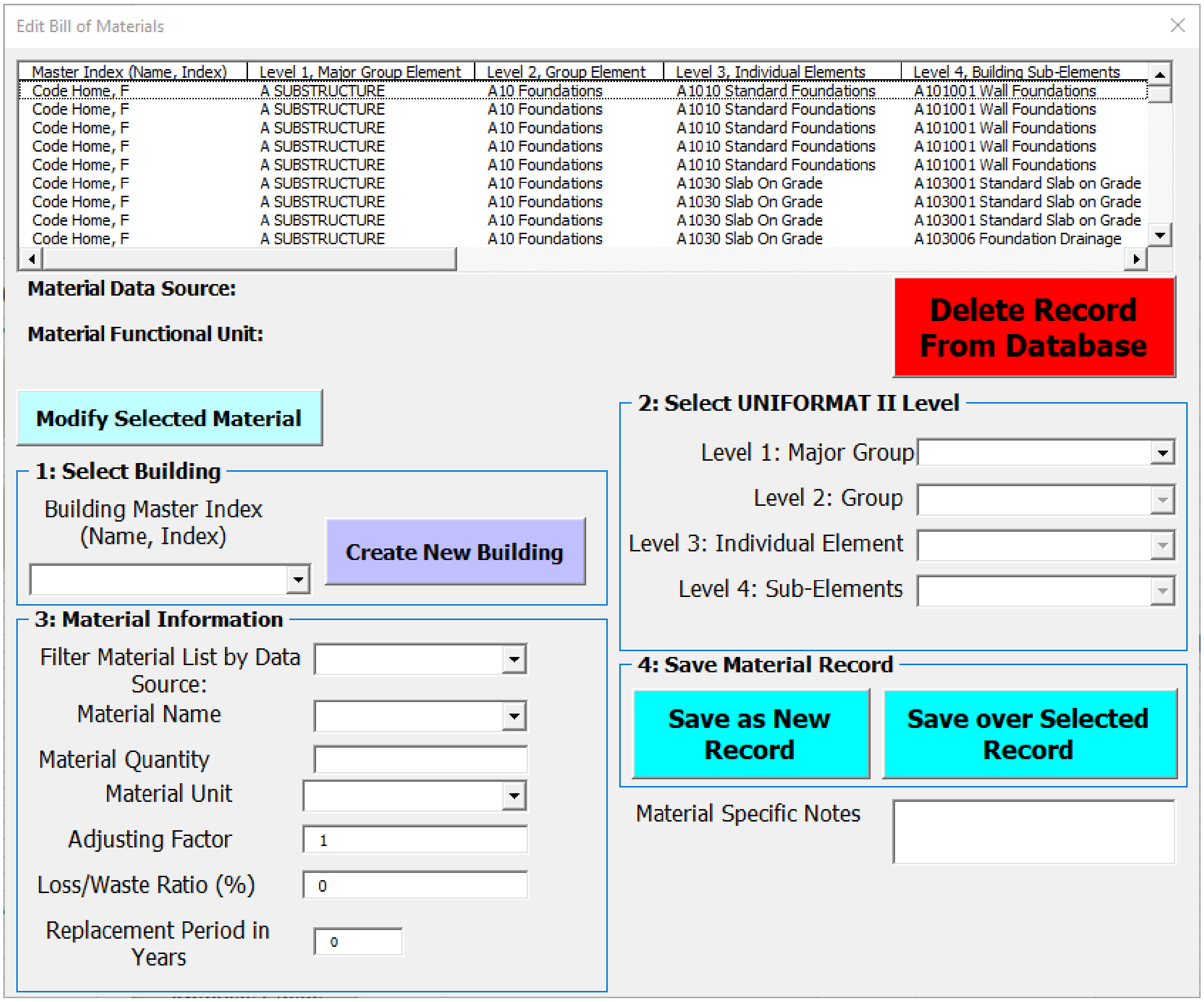


FIGURE B3: The Bill of Materials Interface for modifying the bill of materials for building records.

To enter BOM data, users first must choose a building name and index pair to pick a building record they wish to modify BOM data for. The user can also choose to create a building at this step; clicking the Create New Building button will load the Building Info user form to allow the user to create a building before entering BOM data. Next, to enter a material, users interact with the level 1 through level 6 text boxes at the bottom of the interface. Materials are organized within the BOM data through the UNIFORMAT II classification system (Figure B4).

ASTM Uniformat II Classification for Building Elements (E1557-97)

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations
		A1020 Special Foundations
		A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation
		A2020 Basement Walls
B SHELL	B10 Superstructure	B1010 Floor Construction
		B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls
		B2020 Exterior Windows
		B2030 Exterior Doors
	B30 Roofing	B3010 Roof Coverings
		B3020 Roof Openings
C INTERIORS	C10 Interior Construction	C1010 Partitions
		C1020 Interior Doors
		C1030 Fittings
	C20 Stairs	C2010 Stair Construction
		C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes
		C3020 Floor Finishes
		C3030 Ceiling Finishes
D SERVICES	D10 Conveying	D1010 Elevators & Lifts
		D1020 Escalators & Moving Walks
		D1090 Other Conveying Systems
	D20 Plumbing	D2010 Plumbing Fixtures
		D2020 Domestic Water Distribution
		D2030 Sanitary Waste
		D2040 Rain Water Drainage
		D2090 Other Plumbing Systems
	D30 HVAC	D3010 Energy Supply
		D3020 Heat Generating Systems
		D3030 Cooling Generating Systems
		D3040 Distribution Systems
		D3050 Terminal & Package Units
		D3060 Controls & Instrumentation
		D3070 Systems Testing & Balancing
		D3090 Other HVAC Systems & Equipment
	D40 Fire Protection	D4010 Sprinklers
		D4020 Standpipes
		D4030 Fire Protection Specialties
		D4090 Other Fire Protection Systems
	D50 Electrical	D5010 Electrical Service & Distribution
		D5020 Lighting and Branch Wiring
		D5030 Communications & Security
		D5090 Other Electrical Systems
E EQUIPMENT & FURNISHINGS	E10 Equipment	E1010 Commercial Equipment
		E1020 Institutional Equipment
		E1030 Vehicular Equipment
		E1090 Other Equipment
	E20 Furnishings	E2010 Fixed Furnishings
		E2020 Movable Furnishings
F SPECIAL CONSTRUCTION & DEMOLITION	F10 Special Construction	F1010 Special Structures
		F1020 Integrated Construction
		F1030 Special Construction Systems
		F1040 Special Facilities
		F1050 Special Controls and Instrumentation
	F20 Selective Building Demolition	F2010 Building Elements Demolition
		F2020 Hazardous Components Abatement

FIGURE B4: The UNIFORMAT II Classification system for Building Elements (Charette & Marshall, 1999).

The level 1 through level 3 data directly matches the UNIFORMAT II Classification system (Charette & Marshall, 1999). Level 4 further refines the individual element, to correspond to a specific part of an individual element.

Users next choose the name of the material being added. All materials are visible by default in the dropdown list in level 5, organized alphabetically. Users can additionally filter the list by data source, choosing to filter for data from GREET1 / GREET 2, user entered data, user modeled data, surrogate data, or any material. Level 6, specifics, is left for the user to add any additional information about the material for their own records. Users enter the material quantity, and the unit into the text boxes on the right. There are a variety of units available in the dropdown list, however the user can also type in their own custom unit. Users then enter the Adjustment factor and Loss/Waste Ratio. The Adjustment factor is a user defined value that directly increases the life cycle emissions of the material. An adjustment factor of 2.0 will multiply the life cycle results by 2.0. The Loss/Waste ratio represents a loss of material during the construction or use phase of the material, and is entered as a percentage from 0 to 100%. Next, users can either save the material as a new record or click on a record in the preview on the top of the interface and click on “Save over Selected Record” to overwrite a previous record. Finally, users can delete a record by selecting it in the preview and clicking “Delete Record”.

If the unit entered for a material does not match the unit used in the life cycle metrics data, the module will attempt to convert between the units. If unsuccessful, it will prompt the user to enter a unit conversion (Figure B5)

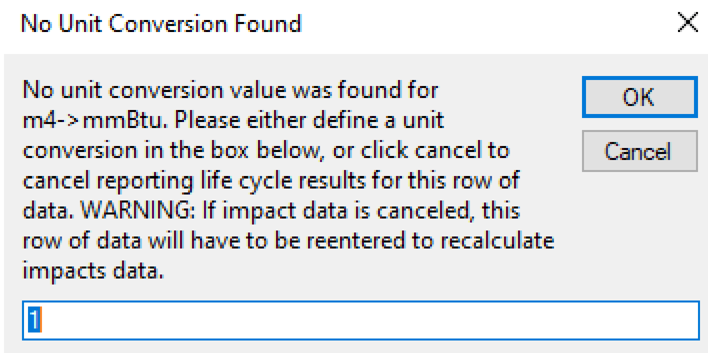


FIGURE B5: The warning that there is no appropriate unit conversion for this material.

B2.4 Entering Energy Use Intensity information through the EUI User Interface

After entering BOM data, the user next enters Energy Use Intensity information. This information handles the operational GHG emissions from a building. To access the interface, users click on the “Building EUI” button on the Whole Building Dashboard (Figure B6).

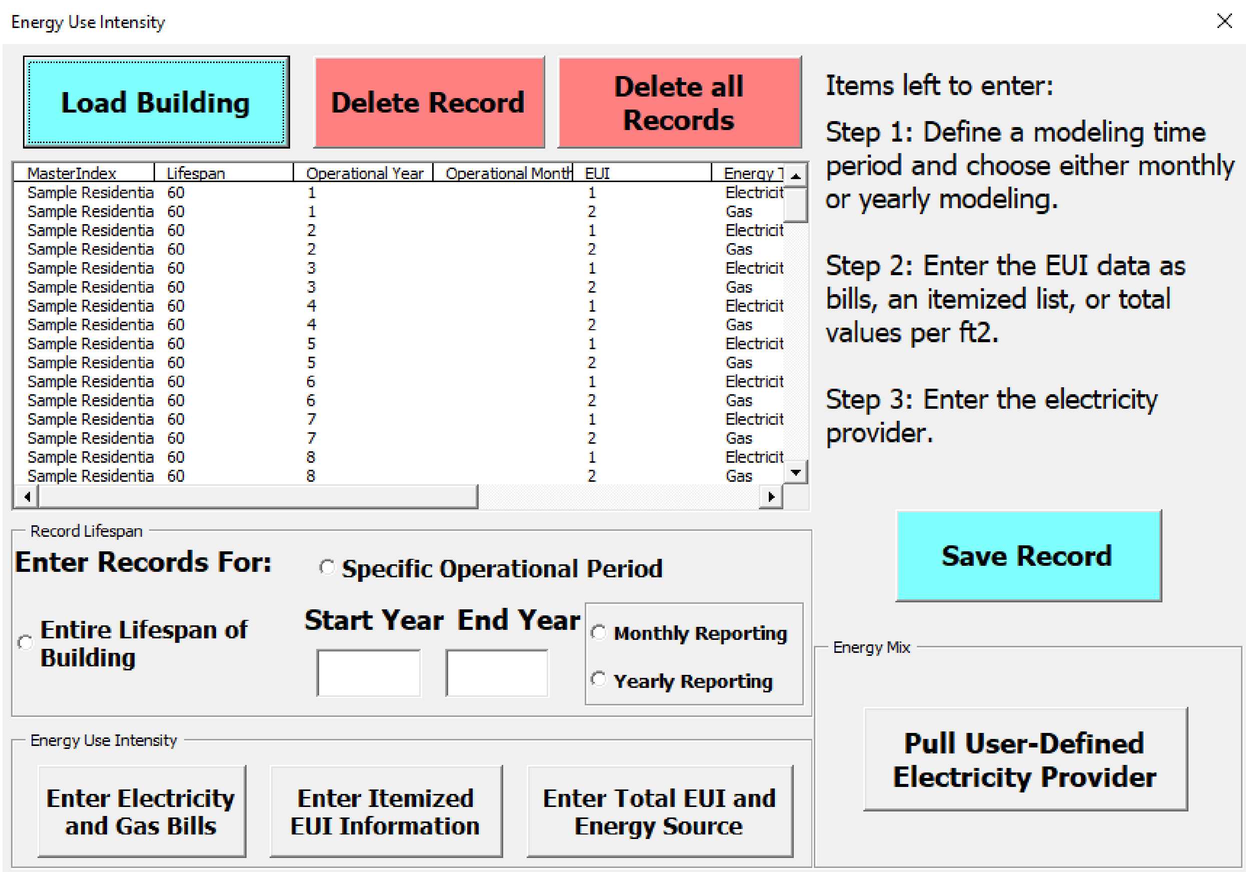


FIGURE B6: The EUI User Interface.

To begin entering EUI data, the user must first choose a building record by clicking on the Load Building button. This will open an interface to choose the building to load. Users then must click on the building they wish to load and click load building (Figure B7). With the building loaded, the user has three steps to complete to calculate EUI impacts. Firstly, the user must choose the timespan of the record, in the “Record Lifespan” box in the bottom right of the interface. The user can enter a specific operational period to model or model the entire lifespan of the building. If the user chooses to model the entire lifespan, the lifespan will be taking from the value entered in the Building Information Interface. Records can be modeled either with monthly reporting, or with yearly reporting.

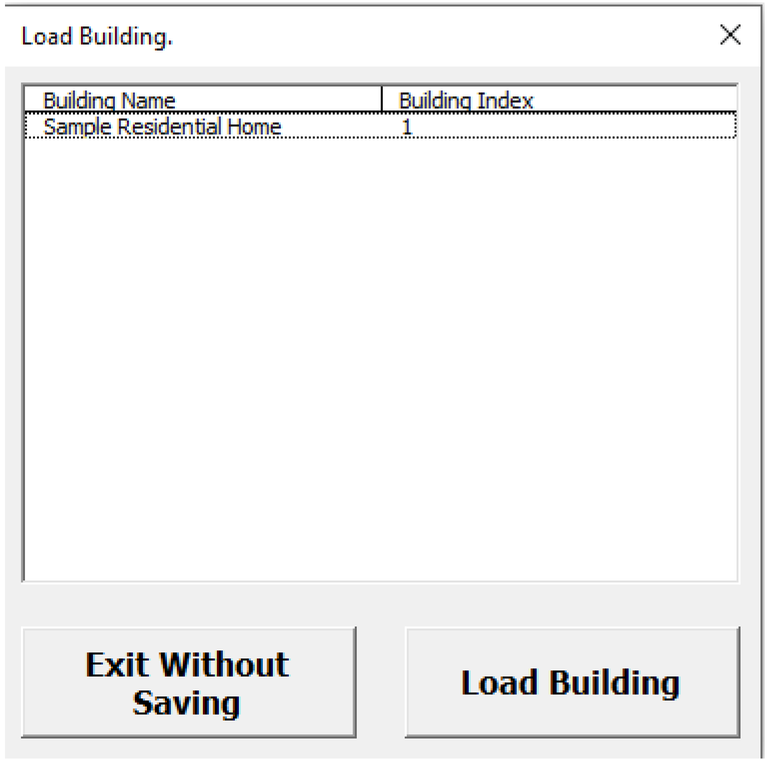


FIGURE B7: The form to load a building into the EUI interface.

Next, the user must load the Energy Use Intensity information. There are three options for reporting. First, the user can load in values from bills. Clicking the "Enter Gas and Electricity Bills" button opens a form for the user to input the gas bill of the building in therms, and the electricity bill of the building in kWh (Figure B8).

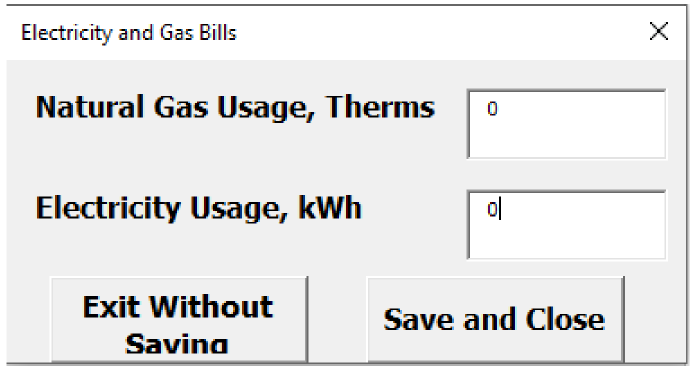


FIGURE B8: The form to enter Gas and Electricity bill information into the EUI interface.

The user can also choose to enter individual appliance usage information by clicking the “Enter Itemized EUI Information” button (Figure B9). Users enter the name of the appliance, the energy type, the energy use intensity, and the unit into the text boxes on the bottom of the form and click the “Save Item to EUI List” to add an appliance to the list. An item can be deleted from the list by selecting the item in the above list and clicking the “Delete Selected Item in EUI List” button. When the user has entered all appliances, the list is saved with the “Save EUI List and Close” button.

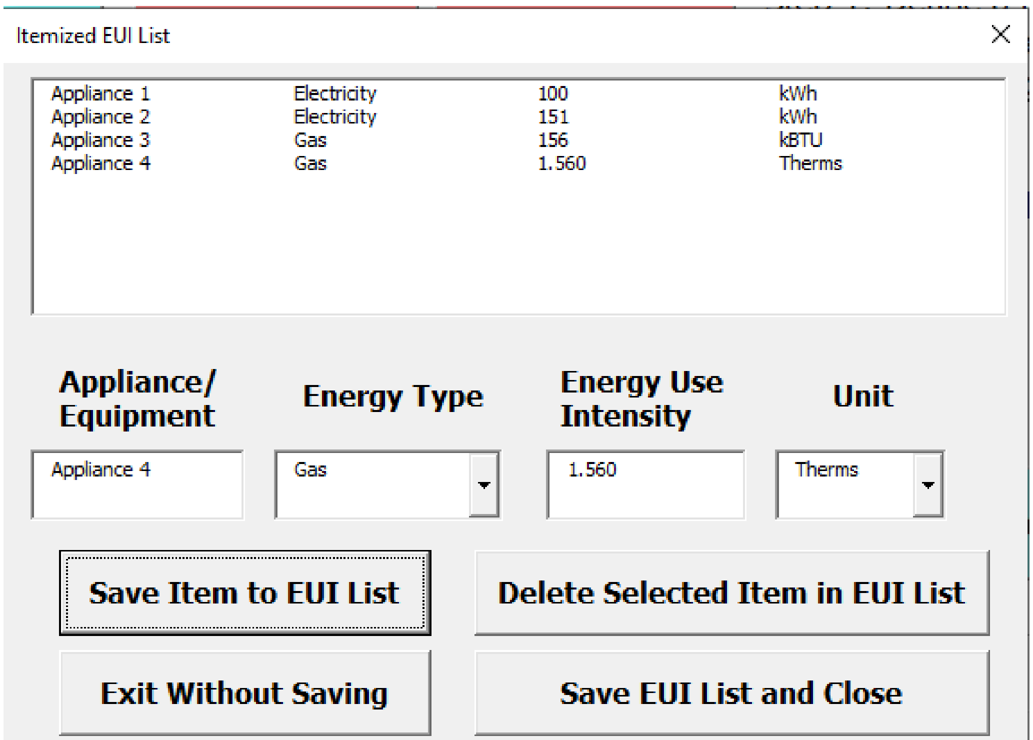


FIGURE B9: The interface to add an itemized EUI list to the EUI interface.

Finally, the user inputs the energy provider by clicking the “Pull User-Defined Electricity Provider” button to load the provider interface (Figure B10). In this interface, the user chooses the location, either the National US or an individual U.S. state, and then chooses the electricity provider in the text boxes. In the current version, only the national average and state averages are available by default in the system.

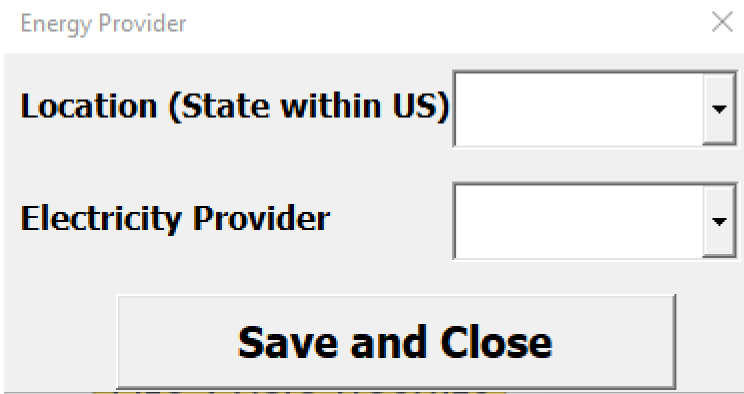


FIGURE B10: The Energy Provider Interface.

When the user has entered the modeling lifespan, the energy use intensity, and the energy provider, the EUI is ready to be saved. Clicking the “Save Record” button will save the EUI record to the database and calculate the operational GHG usage. Depending on the size of a record and the speed of the computer, saving can potentially take up to a couple minutes. In this time, excel will lock up, and appear frozen. The time can be shorted by closing other applications on the computer before saving. While EUI data is saving, please do not close excel.

B3 DATA GAPS AND UNIT CONVERSION ISSUES DURING WHOLE BUILDING LCA

Data gaps in the Whole Building Analysis section are resolved very similar to the methods in Building Component Analysis. The user begins by clicking the “Address Data Gaps” button located on the Whole Building LCA worksheet. This opens a user form for the user to specify the system boundary and data aggregation of each building, as well as select which buildings to check for data gaps and issues in unit conversion, shown in Figure B11.

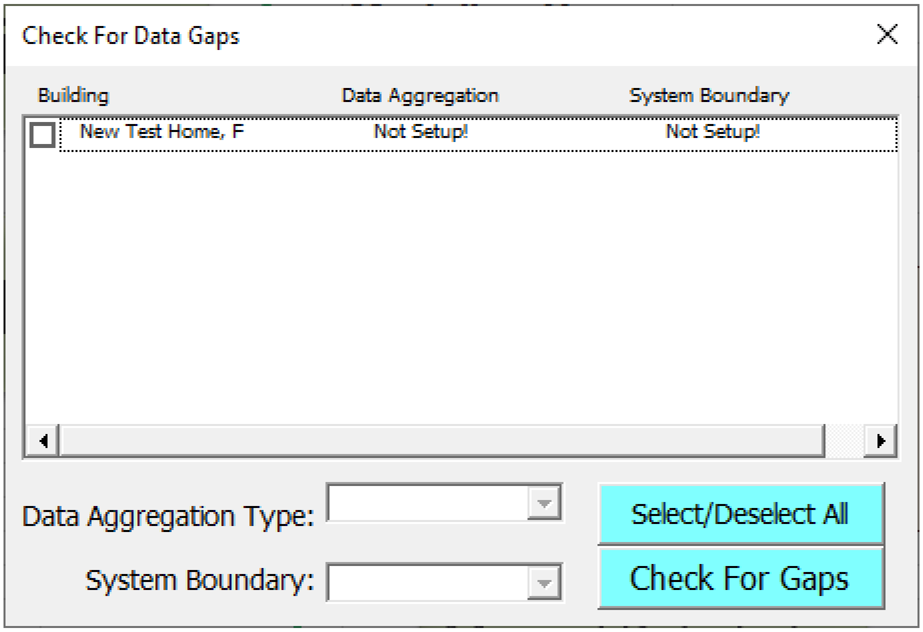


FIGURE B11: The form for selecting buildings to check for data gaps.

The user can select one or more buildings in the list of buildings on this user form. Then, the user sets the data aggregation type, either aggregated to the system boundary or disaggregated to the life cycle stage, and system boundary, and selects Check for Gaps. The selected buildings are then checked for data gaps; if any data gaps or unit conversion issues are found, a user form will appear to guide the user through the process of correcting these issues. The first user form, shown in Figure B12, displays the list of materials used in the selected buildings that are either data gaps, have unit conversion issues, or both.

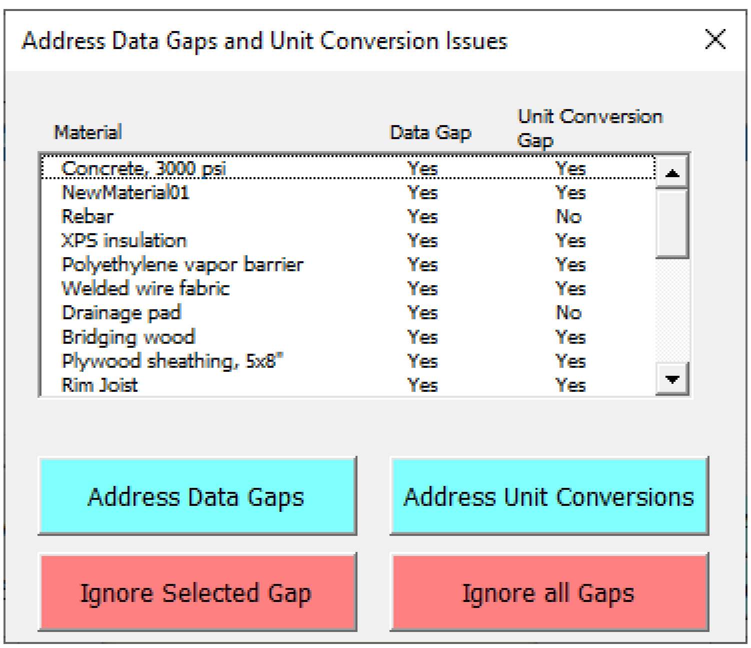


FIGURE B12: The window showing materials that are data gaps and/or need unit conversions applied to them.

B3.1 Resolving Data Gaps during Whole Building LCA

Clicking the address data gaps button will load the user forms for resolving data gaps. A user form will appear, showing a list of the data gaps, including the material, building, year, system boundary, and data aggregation level, shown in Figure B13. To address a data gap, the user needs to click on a data gap in the list, then click address gap. Additionally, the user can choose to ignore a data gap, or ignore all data gaps and continue the LCA. Note that ignoring a data gap will result in inaccurate data, as any data gaps will have no life cycle data associated with them.

Data gaps in Whole Building LCA process can be resolved in a similar fashion to data gaps in the Building Component LCA process. A data gap can be resolved by modeling the material in BC Analysis, inputting LC Metrics manually, or using a surrogate. Modeling a material in BC Analysis and inputting LC Metrics manually perform identically to the processes in modeling Building Component Analysis data gaps. The surrogate method is similar but offers additional information for Whole Building modeling. A list of surrogates is listed from the aggregated LCProfiles worksheet, including the year of data available, the system boundary of the material, and the data aggregation level. This allows the user to choose a surrogate while being aware of the surrogate's data aggregation level and system boundary. The user then chooses to load the surrogate, which will resolve the gap. When all gaps are resolved, the LCA can continue.

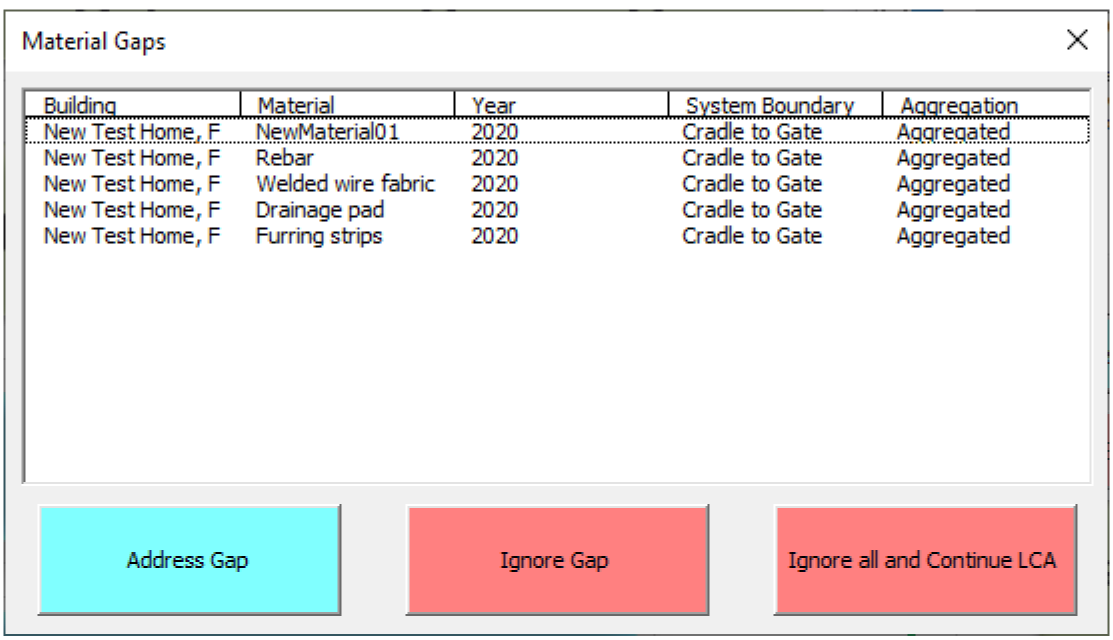


FIGURE B13: The list of data gaps detected during Whole Building Analysis.

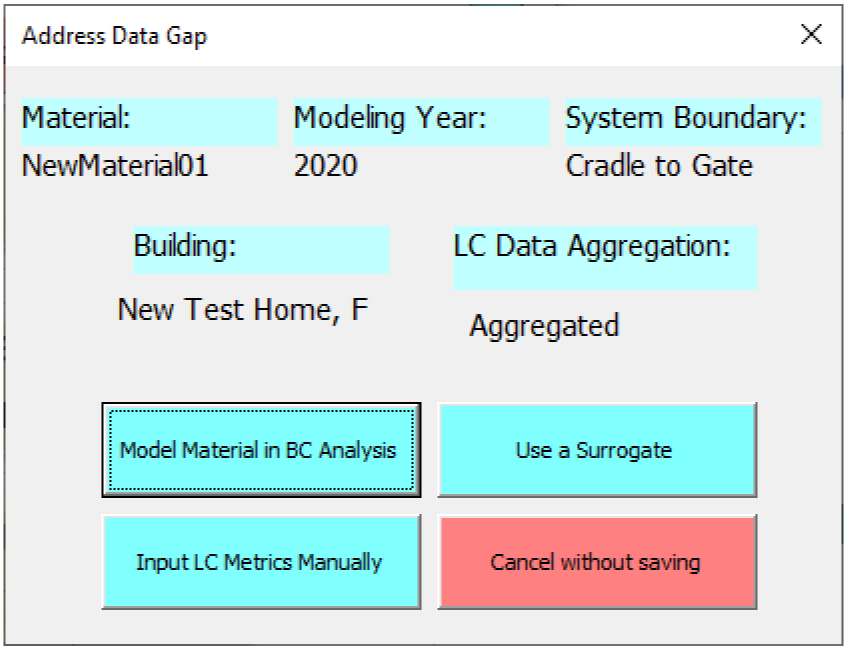


FIGURE B14: The userform designed to help the user address a data gap.

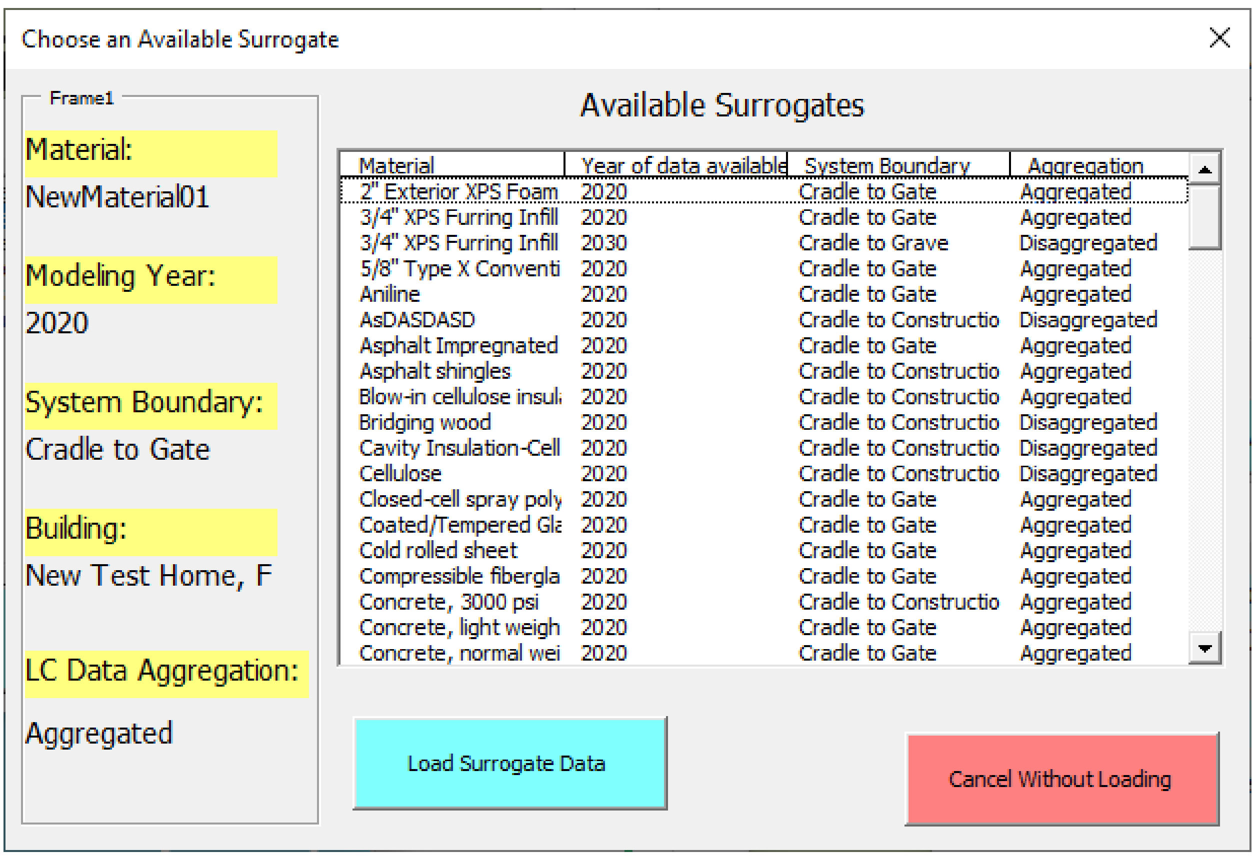


FIGURE B15: The user form for loading a surrogate to address a whole building modeling data gap.

B3.2 Resolving Unit Conversion Issues During Whole Building LCA

To address any unit conversion issues, click the appropriate button in the check gaps user form, shown in Figure B12. This will open a user form to aid the user in addressing unit conversion issues. The list box shows what materials have conversion issues, as well as what unit is specified in the bill of materials, the unit in the database, and the unit conversion found, as well as a notice to the user whether the gap has been resolved.

To resolve a gap, the user clicks on a material in the list, and types of the desired unit conversion into the text box. Note that if a material is listed as having No Unit Found in Database, that material is also a data gap; data gaps must be resolved before unit conversions can be addressed. The user then selects whether the unit conversion should be usable for all materials, or only the selected material. Finally, the user clicks Resolve Gap to save the unit conversion. Alternatively, the user can select Resolve all Gaps and Continue to set all unit conversions to a value of 1.0. Note that this is intended in a similar fashion to the ability to ignore data gaps and may result in inaccurate results if the unit conversions are not considered during analysis of the life cycle data.

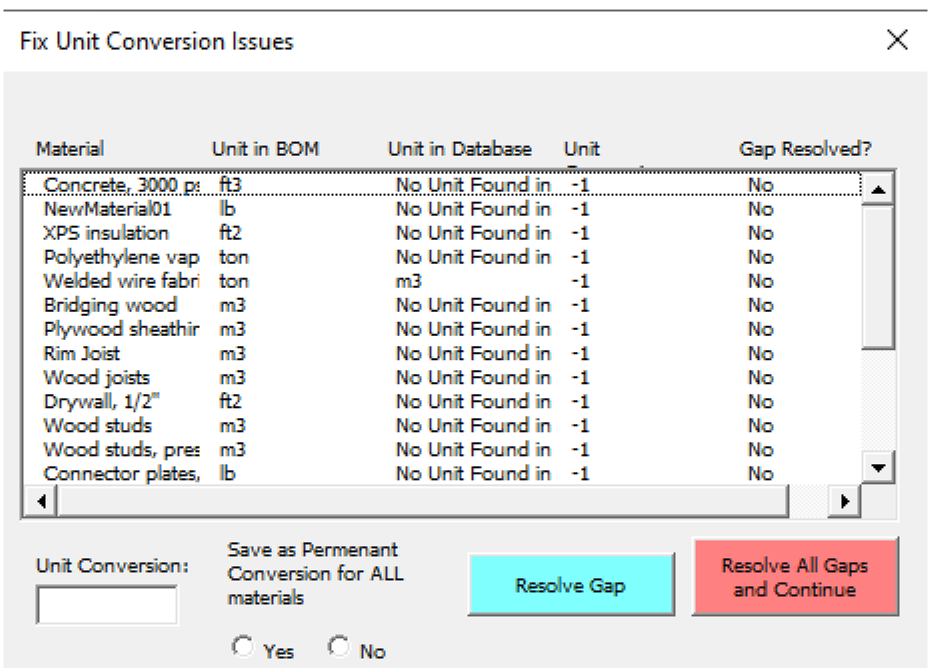


FIGURE B16: The User form for addressing data gaps.

B4 RUN EMBODIED AND OPERATIONAL LIFE CYCLE ANALYSIS

To calculate the embodied and operational life cycle results, click on the "Run Whole Building Embodied & Operational Calculations" button. This will calculate the embodied metrics for all BOM data, and the operational metrics for all EUI data. Depending on the amount of data, this could take several minutes. During this time, excel will appear frozen. To speed up the process, please close any background applications before running calculations. Please do not close excel during calculations, as this may result in unsaved data.

B5 WHOLE BUILDING SENSITIVITY ANALYSIS

In addition to Standard LCA, the Whole Building Analysis Module is equipped to configure sensitivity analysis, allowing for the analysis of a variety of changes to a singular base case. The sensitivity analysis functions can be accessed by selecting a building to run, as with standard LCA, by clicking the Configure Sensitivity Analysis button, shown in Figure B17. This will open the user interface for configuring sensitivity analysis. Note that multiple buildings can be selected for analysis at the same time; if multiple buildings are selected in the list prior to clicking on the Sensitivity Analysis button, then the bills of materials for all selected buildings will be available for configuration. This allows the user to configure multiple buildings for sensitivity analysis at the same time. Note that each sensitivity analysis case will be kept separate, and configuring multiple buildings at the same time will still result in separate sensitivity analysis per building being carried out.

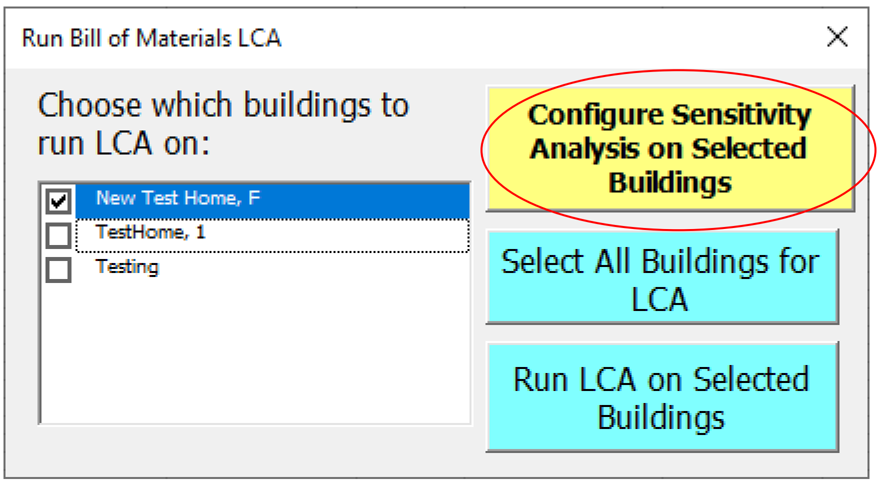


FIGURE B17: The button to access sensitivity analysis.

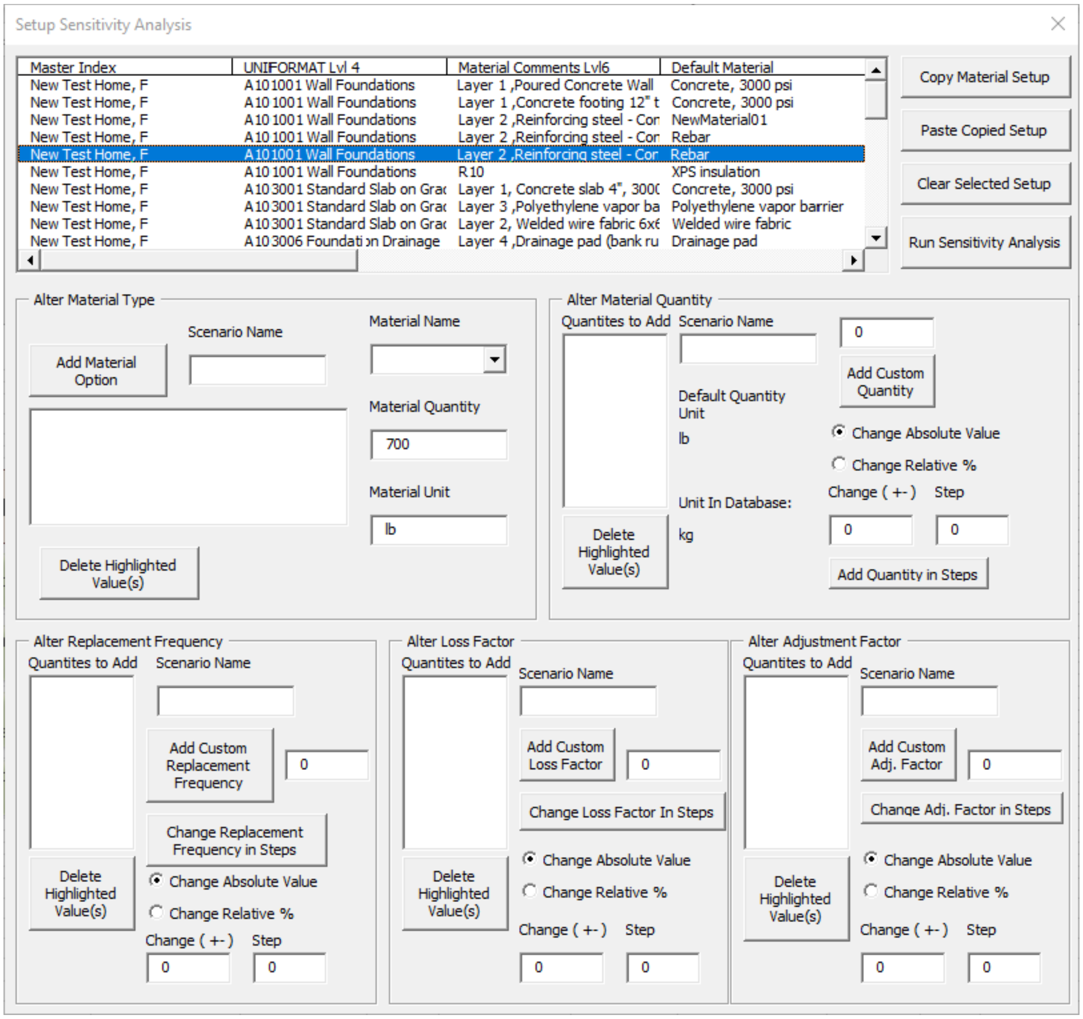


FIGURE B18 The user interface to configure sensitivity analysis.

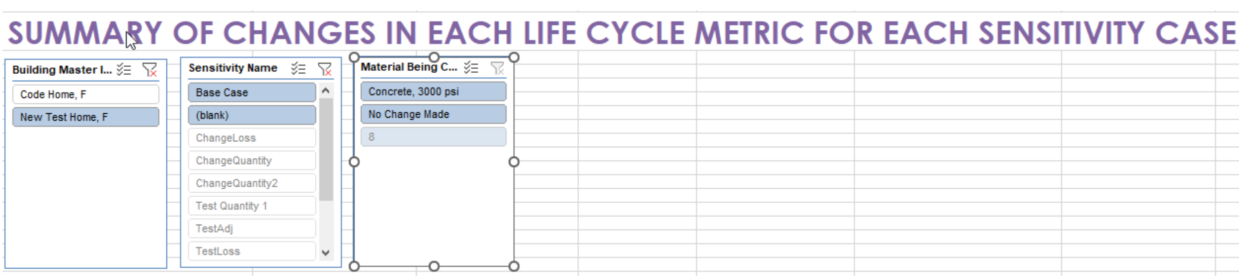
To configure a sensitivity analysis case, the user clicks on the desired material in the list at the top of the user form. Then, in the five sections below, the user can configure changes to the material, quantity, replacement frequency, loss factor, or adjustment factor. For each sensitivity type, a scenario name option is added to aid the user in creating meaningful names or descriptions for each sensitivity case. These scenario names will be used to set up the dynamic visuals in the Sensitivity Analysis Dashboard. For configuring the material type, the user can choose a material from the dropdown list at the top right of the section, choose the material quantity and unit, and then click Add Material Option to add the option. This will add the desired case to the list. A case can be deleted by clicking on it in the list, then clicking delete highlighted values.

To configure the quantity, replacement frequency, loss factor, and adjustment factor, a desired value can be added into the text box, then the Add button clicked. This will add the individual value as a sensitivity case. In addition, the user can choose to add changes in steps, either by absolute value or as a relative percentage of the base case. To do so, the user specifies a total change as a value +/- the base case, and the step value, as well as whether the change is absolute or as a relative percentage. For example, for a base case of 50, having a change of 10 with a step of 5 will result in the values {40, 45, 50, 55, 60} being added if the change is in absolute value, or {45,47.5,50,52.5,55} if the change is a relative percentage. Similar to the material option changes, the user can specify a scenario name, unique to each sensitivity analysis type, to aid in describing the cases, as well as delete values by clicking on them in the list of added values and clicking delete values.

Finally, the user can entirely copy a sensitivity analysis setup from one material to another. Starting from the material being copied, the user clicks the copy material setup button, then clicks on the desired material to be pasted on in the list at the top of the user form, before clicking paste material setup. This will copy all of the sensitivity analysis setup to the desired material(s). When the user has set up the desired sensitivity cases, clicking the Run Sensitivity Analysis button will run the analysis. If the user changes the material type or replacement period, then the data gaps feature will have to be re-run, as a data gap would affect the results from these changes. If this occurs, the data gap feature will occur, and the process will be the same as described in section B3. Please note that, depending on the number of cases added, this process could take multiple minutes, and Excel could be frozen during this time. Afterwards, a message box will appear notifying the user that the analysis is complete. Results can then be viewed in the sensitivity analysis Dashboard.

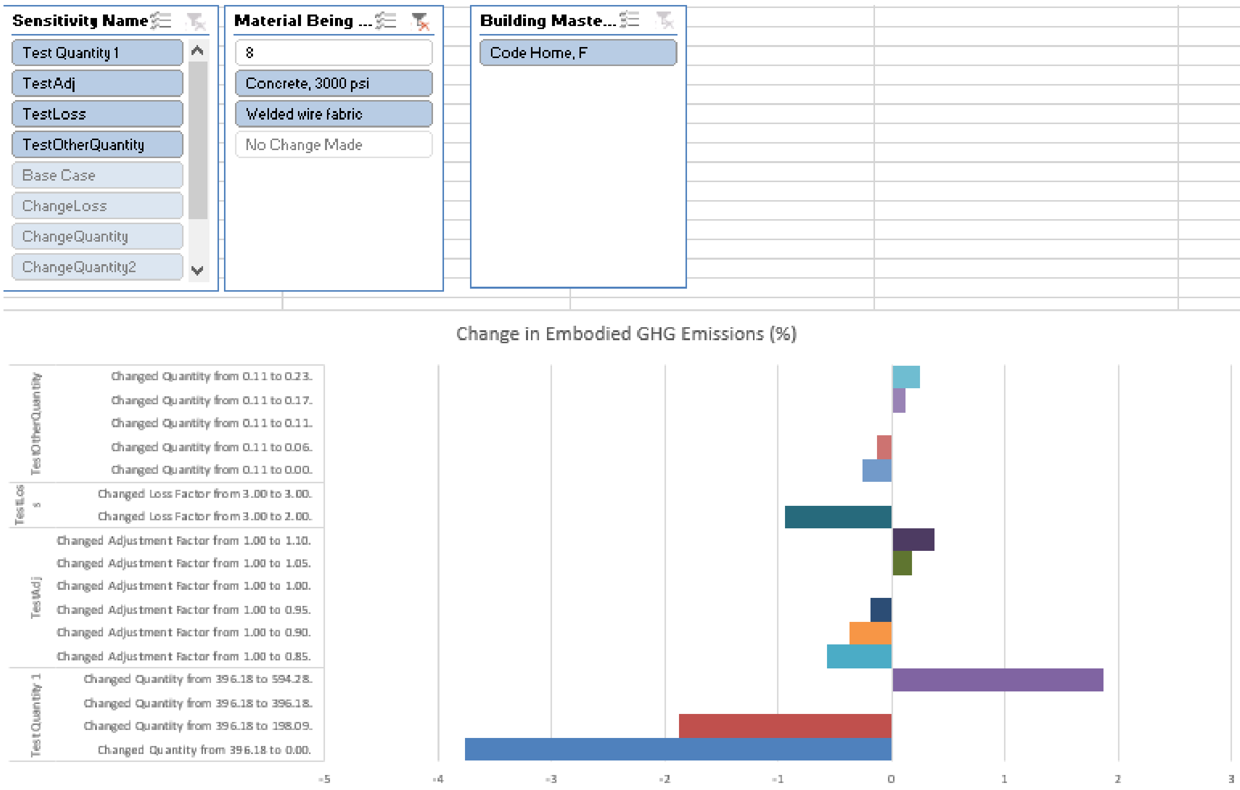
B5.1 Viewing Sensitivity Analysis Results

Results from the sensitivity analysis can be viewed in the Sensitivity Analysis Dashboard worksheet. This worksheet contains a tornado chart to view the changes in GHG emissions, viewed as a percentage change from the base case, as well as a table showing the absolute change in each LC Metric for each sensitivity case.



Row Labels	Sum of Total Energy Change	Sum of Fossil Fuels Change	Sum of Coal Change	Sum of Natural Gas Change	Sum of Water Consumption Change	Sum of Petroleum Change	Sum c
New Test Home, F	**37812644.28**	**33790822.3**	**13650899.77**	**9268396.086**	**5829.420445**	**10871526.44**	
Concrete, 3000 psi	**37812644.28**	**33790822.3**	**13650899.77**	**9268396.086**	**5829.420445**	**10871526.44**	
Changed Loss Factor from 3.00 to 10.00.	37812644.28	33790822.3	13650899.77	9268396.086	5829.420445	10871526.44	
No Change Made	**0**	**0**	**0**	**0**	**0**	**0**	
Unchanged Value	0	0	0	0	0	0	

Figure B18: The Sensitivity Analysis Table.



FigureB19: The tornado chart for the change in GHG emissions.

B6 MANUALLY ENTER DATA OUTSIDE OF USER INTERFACES

The GREET Building Module supports the user manually entering data into the data worksheets. To begin, click the “Manual Data Entry” button on the Whole Building Dashboard. This will open an interface to access the background worksheets for Building Information, BOM Information, and EUI Information (Figure B20). Clicking one of the three buttons will open the respective worksheet for entering data. It is highly recommended that the user enters Building Information first, following by Bill of Materials Information, and then Energy Use Intensity Information.

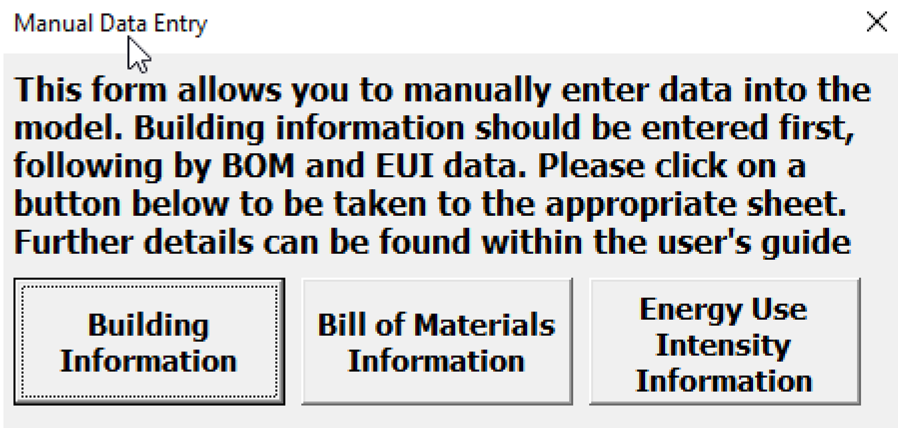


FIGURE B20: The User Interface to access background data worksheets for manual data entry

B7.1 Manually Enter Building Information

Building Name	Building Index	Building Type	Location	Climate Zone
Sample Residential Home	1	Single-Family Res	Illinois	IECC Climate Zone

FIGURE B21: A portion of the Building Info Worksheet

Clicking the “Building Information” in the manual data entry interface (Figure B19) will open the “Building Info” Worksheet (Figure B20). Each row corresponds to a building entry. Values can be manually entered into the form, following the format described below:

Columns A-B: The building name and index. Each row must have a unique name and index pair.

Column C: The Type of Building. Default values include Single-Family Residential Building, Multi-Family Residential Building, Low-Rise Commercial Building, and High-Rise Commercial Building; however, any value can be entered. This value is optional.

Column D: The location of the building. Default values include the U.S. states, although any value can be entered. This value is optional.

Column E: The climate zone of the building. It is highly recommended to follow the IECC Climate Zones. This value is optional.

Column F: The total floor area of the building. Values must be a positive number. This value is required.

Column G: The total roof area of the building. Values must be a positive number. This value is optional.

Column H: The number of floors present in the building. Values must be a positive whole number. This value is optional.

Column I: The height of the ceilings within the building. Values must be numerical. This value is optional.

Column J: The amount of years the building will remain in operation. Values must be a positive whole number. This value is required.

Column K: The amount of years a retrofitted building has already been in operation. Values must be a positive whole number. This value is optional.

Column L: The master index is used by the module to index for buildings. The format is "(Building Name from Column A), (Building Index from Column B)". This value is required, and the format must be strictly followed.

B7.2 Enter Bill of Materials Data Manually

R	S	T	U
Level 5, Building Materials	Level 6, Material Specification	Material Quantity	Material Unit
Gypsum wall board		100.0	m2
Concrete slab		151.0	m3
Flat Glass		10.0	kg
Copper		105	kg
Steel		3	kg
Steel		351	kg
Sand		500	ton

FIGURE B21: A portion of the Bill of Materials Data Table.

Clicking the "Bill of Materials Information" in the manual data entry interface (Figure B20) will open the "WB BOM & Results" Worksheet (Figure B22). Each row corresponds to a material entry. Values can be manually entered into the form, following the format described below:

Columns A-L: These values correspond to the building that the material is part of. Values match the values in the "Building Info" worksheet. Values should be identical between the desired building record in the "Building Info" worksheet and the desired material row. Please note that the master index is found in column C on the "WB BOM & Results" worksheet instead of column N. These values are required.

Columns M-P: These values represent the four UNIFORMAT II values used in material classification. Please refer to the "UNIFORMAT II" worksheet for accepted values, accessible by clicking the "UNIFORMAT II" button on the Whole Building Dashboard. These values are required, and the format must be followed.

Column Q: The name of the material. Any name can be entered. If a material is entered that is not present in the life cycle metrics data, it will be a data gap. Please check the data gaps feature (See Section B1.2) before calculating results. This value is required.

Column R: This column holds specific notes about a material. Any value is accepted. This value is optional.

Column S: The quantity of material. Values must be a positive number. This value is required.

Column T: The unit of the material being added. Any value is accepted. If the unit is not the same as the unit used in the life cycle metrics being calculated, the user will be prompted to add a unit conversion.

Column U: The replacement period of the material. Any positive value is accepted; the material for this row will be replaced every X years, where X is the value entered.

Column V: The % of material lost in calculation. Values are entered as a percentage, from 0 (inclusive) to 100 (exclusive). This value is required. No material loss is represented by 0.

Column W: The system boundary. Accepted values are Cradle to Gate, Cradle to Construction, Cradle to Use, Cradle to Grave, and Cradle to Cradle.

Column X: The data aggregation type. Accepted values are Aggregated for data aggregated to the system boundary, and Disaggregated for data aggregated to the life cycle stage. All values for a given building must match!

Column Y: The adjusting factor for the life cycle metrics. Provides a multiplier to the life cycle metrics data. Any positive numerical value is accepted. This value is required and unless needed should be set to 1.

Columns Z-AZ: These columns are used by the module to hold life cycle metrics. These will be filled in when the user calculates embodied carbon results (See Section B1.3) or when the user enters a material through the BOM Interface (See Section B1.1.2). Users should not manually enter data into these columns. Any data entered will be overwritten when calculations are run.

B7.3 Enter EUI Information Manually

MasterIndex	Lifespan	Operational Year	Operational Month	EUI	Energy Type	Unit
Sample Reside	60	1		1	Electricity	kWh/ft2
Sample Reside	60	1		2	Gas	kBTU/ft2
Sample Reside	60	2		1	Electricity	kWh/ft2
Sample Reside	60	2		2	Gas	kBTU/ft2
Sample Reside	60	3		1	Electricity	kWh/ft2
Sample Reside	60	3		2	Gas	kBTU/ft2
Sample Reside	60	4		1	Electricity	kWh/ft2
Sample Reside	60	4		2	Gas	kBTU/ft2

FIGURE B22: A portion of the EUI Info data table.

Clicking the “Energy Use Intensity Information” button in the manual data entry interface (Figure B19) will open the “EUI Info & Modeling Results” (Figure B22). Each row corresponds to a year or month entry. Values can be manually entered into the form, following the format described below:

Column A: Holds whether the column holds Gas or Electricity data. Must be either Gas or Electricity.

Column B: The energy source. Value must match the desired electricity generation mix, or “Natural gas for space heating, per mmBtu input”

Column C: The master index of the building record being used. The format is “(Building Name), (Building Index)”. This must match a building record present in the “Building Info” worksheet and is required.

Column D: This is the lifespan of the building record being used. This must match the lifespan of the building record chosen in column A. This value is required.

Column E: This is the year represented by the EUI record being inputted. Accepted values are positive whole integers from one to the lifespan of the building. This value is required.

Column F: This column allows for monthly reporting. This value is optional. Values include 1 – 12, to correspond with January – December respectively. If unused, the model will be yearly values, and should be left blank.

Column G: The Energy Use Intensity being reported. Accepted values are positive numbers. This value is required.

Column H: The Unit of the EUI being reported. Accepted values are dependent on the reporting type; please see column J. This value is required.

Column I: This is the EUI value from column G, converted to mmBTU/reporting period. This value is required.

Column J: This column is the name of the appliance or equipment being modeled, if the modeling is done on an appliance basis as defined by Column J. If the user is not modeling on an itemized level, this column should be left blank.

Column K: This column is the electricity provider. Acceptable values are "(State) State Average", where (State) is the name of a U.S. State, or "U.S. National Average". This value is required.

Column L: This column represents the reporting method for the EUI data. Accepted values are "Bills", "Totals", or "Items". If the reporting method chosen is "Bills", there must be two rows per year/month, depending on the reporting period; one row with the electricity energy type, reported in kWh, and one row with the gas energy type reported in therms. If the reporting method chosen is "Totals", there must be two rows per year/month, depending on the reporting period; one row with the electricity energy type, reported in kWh/ft^2, and one row with the gas energy type reported in kBTU/ft^2. If the reporting method chosen is "Items" then there must be one row per appliance per year/month. The appliance name must be entered into column H. Accepted units in column G are kWh for electricity, and kBTU or therms for gas.

B7 VIEWING AND INTERPRETING LIFE CYCLE RESULTS

The results of the embodied and operational life cycle calculations can be viewed on the Whole Building Results Dashboard, found on the "Dashboard_WB" Worksheet. This worksheet can be accessed with a button on the "Whole Building Modeling" Worksheet. Results are broken into three categories. First, the embodied GHG emissions. Second, the operational GHG emissions. Thirdly, the summary of the Bill of Materials.

B6.1 View and Explore Embodied GHG Results

The embodied GHG results are displayed as a series of PivotCharts on the Whole Building Results Dashboard (Figure B23). **It is necessary to click the "Refresh Data" button after running Whole Building LCA to refresh the results.** There are four PivotCharts displayed. The farthest left pivot chart shows the total embodied GHG emissions of each building record. The middle-left pivot chart shows a pie chart displaying the portion of GHG emissions reported by each Level 2 group element. The middle pivot chart shows the GHG emissions by each level 2 group element. The middle right pivot chart displays the GHG emissions by each level 3 individual element. The furthest right pivot chart shows the GHG emissions for each material. Additionally, users can choose to select only specific materials through a variety of buttons to control the pivot table (Figure B24). Selecting a button will enable only that option to be shown on the pivot table. Holding left shift and clicking multiple buttons will display all clicked options in the results.

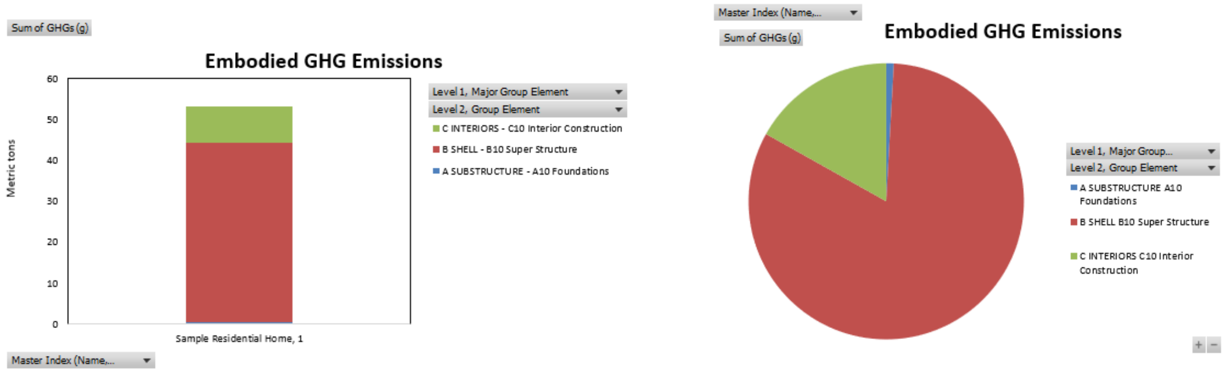


FIGURE B23: The first two PivotCharts displaying Embodied GHG Emissions results.

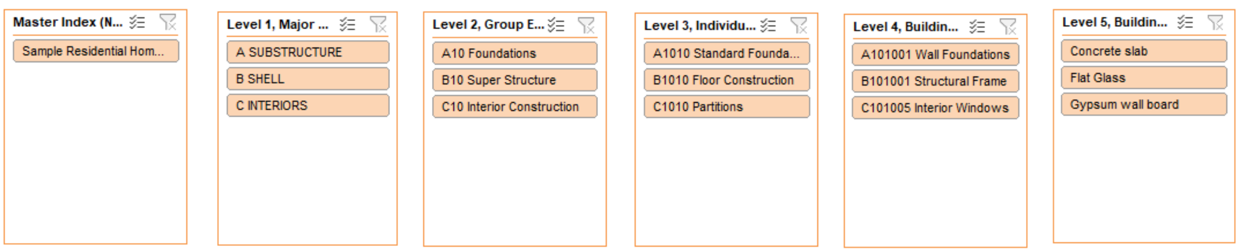


FIGURE B24: The buttons for selecting/deselecting results to be displayed in the PivotCharts for embodied GHG emissions.

B6.2 View and Explore Operational GHG Emissions

The operational GHG results are displayed as a series of PivotCharts on the Whole Building Results Dashboard (Figure B25).). **It is necessary to click the "Refresh Data" button after running Whole Building LCA to refresh the results.** The pivot chart displays the operational GHG emissions by year for the selected building. To display results for a desired building, click the building name desired in the right most list in the Operational GHG options (Figure B26). To display multiple buildings at once, hold the left shift key and click on the desired building names. Additionally, the user can select to only view one time of energy type (Gas or Electric), filter by energy source, operational year, or appliance/equipment.

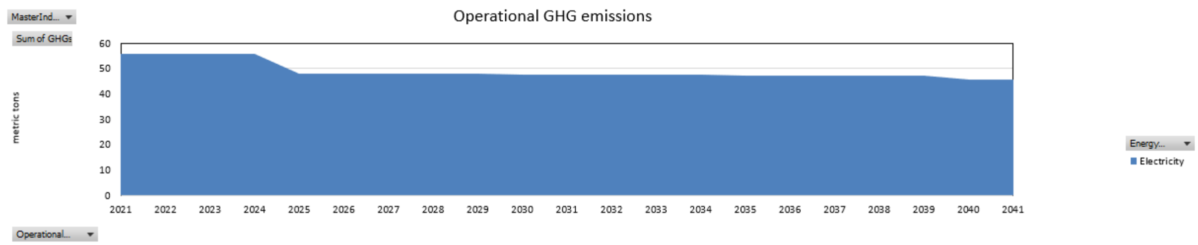


FIGURE B25: The PivotCharts displaying the operational GHG emissions from a selected building record.

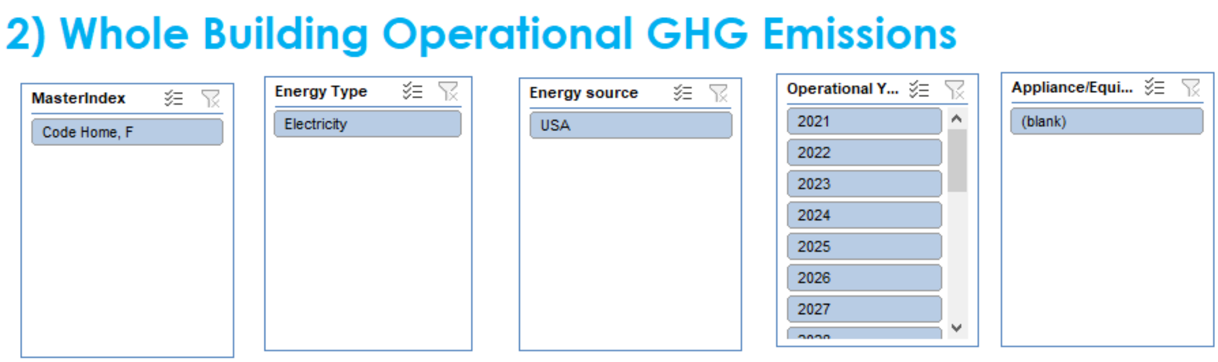


FIGURE B26: The controls for the operational GHG emissions pivot tables.

B6.3 View the Bill of Materials

Below the Embodied and Operational GHG emissions displays is the summary of Building Bill of Materials. This allows the user to see the total quantity of materials in the bill of materials for a selected building (Figure B27). The table can be filtered for a desired building time, or to display the bill of materials for a single building (Figure B28).

Sum of Material Quantity	Column Labels			
	A SUBSTRUCTURE			A SUBSTRUCTURE Total
	A10 Foundations		A10 Foundations Total	
	A1010 Standard Foundations	A1010 Standard Foundations Total		
Row Labels	A101001 Wall Foundations			
Concrete slab				
Gypsum wall board	100.0	100.0	100.0	100.0
Flat Glass				
Grand Total	**100.0**	**100.0**	**100.0**	**100.0**

FIGURE B27: A portion of the Bill of Materials Summary Table.

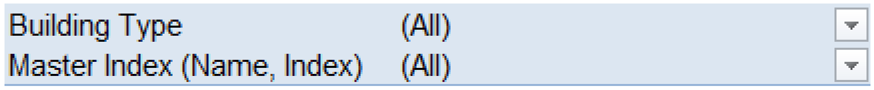


FIGURE B28: The controls for the Bill of Materials Summary Table.

C BACKGROUND DATA WORKSHEETS

The GREET Building Module is designed to enhance transparency and consistency, which are key to reliability and comparability of the modeling results. To achieve this goal, we make the background database accessible to the user for view, modification, update, and expansion, which is an important feature to remedy some of the gaps in the LCA models we reviewed (Cai et al., 2021).

Several background datasheets are available to be viewed and are accessible through the "Building Module" worksheet, via buttons on the bottom of the sheet (Figure C1). Note that these buttons are dual functional, which open and hide the worksheet with one click and another. See below an introduction to what is included in each background worksheet.

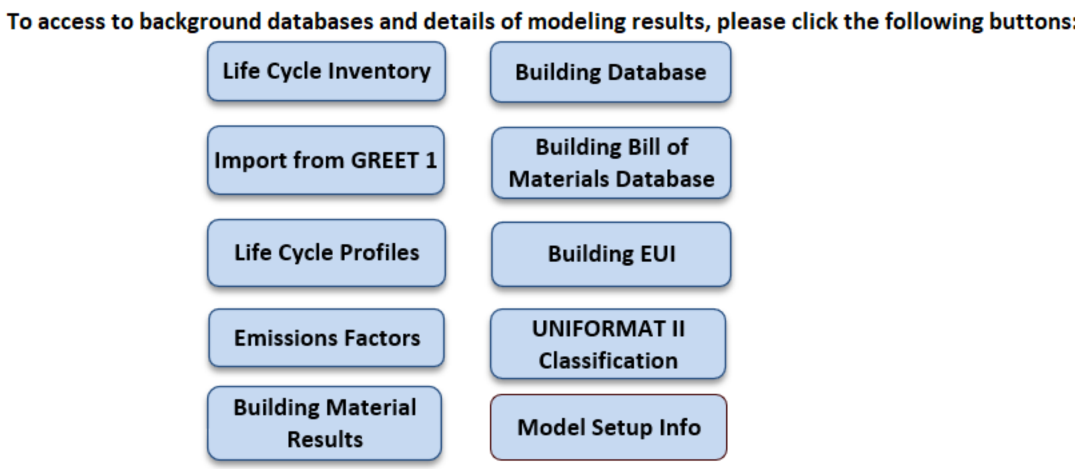


FIGURE C1: The background databases and detailed model results.

C1 LIFE CYCLE INVENTORY

This worksheet contains the life cycle inventory, such as material and energy requirements, along the supply chain of building materials based on the user inputs from the GUI available in the BC Analysis worksheet. This worksheet serves as an LCI repository of all building materials that are currently being modeled with the Module.

C2 LIFE CYCLE PROFILES

This worksheet contains the life cycle profiles for each material that are that imported from the GREET Fuel Cycle model (known as GREET 1), GREET Vehicle Cycle model (known as GREET 2), open literature such as EPDs, or generated through simulation with the Module. For a given material, its life cycle profile includes 27 life cycle metrics and associated information such as unit, functional unit, representative year, comment, and source of the data.

Life cycle profiles are stored for each material for every year from 2020 to 2080. Table C1 shows the life cycle profile of coal as an example., This worksheet forms the background database of common materials, process fuels, chemicals, etc., as well as newly added and/or generated data that may be involved in modeling new building materials. This worksheet is only used for building material LCA, and as such, the life cycle profiles in this database all have a Cradle to Gate system boundary.

TABLE C1. Life cycle profile of coal as an example. Data continues for every year until 2020.

	Raw_Material	Input_Type	LC Metric	Metric Unit	Functional Unit	Calculations Metrics	2020 LCMetrics	2020 Comment	2020 Data Source	2021 LCMetrics	2021 Comment	2021 Data Source
1973	Coal	Energy	Total Energy	Btu	mmBtu	19526.70929	19,526.709	Data taken from GREE	GREET1	20091.407	Data taken from GREE	GREET1
1974	Coal	Energy	Fossil Fuels	Btu	mmBtu	18380.42503	18,380.425	Data taken from GREE	GREET1	19195.02561	Data taken from GREE	GREET1
1975	Coal	Energy	Coal	Btu	mmBtu	1489.077356	1,489.077	Data taken from GREE	GREET1	1886.247929	Data taken from GREE	GREET1
1976	Coal	Energy	Natural Gas	Btu	mmBtu	3158.710101	3,158.710	Data taken from GREE	GREET1	3471.328533	Data taken from GREE	GREET1
1977	Coal	Energy	Petroleum	Btu	mmBtu	13732.63757	13,732.638	Data taken from GREE	GREET1	13837.44915	Data taken from GREE	GREET1
1978	Coal	Energy	Water Consumption	Gal	mmBtu	3.818428425	3.818	Data taken from GREE	GREET1	3.876863018	Data taken from GREE	GREET1
1979	Coal	Energy	VOC: Total	g	mmBtu	7.319125193	7.319	Data taken from GREE	GREET1	7.320726089	Data taken from GREE	GREET1
1980	Coal	Energy	CO: Total	g	mmBtu	1.716499946	1.716	Data taken from GREE	GREET1	1.743629872	Data taken from GREE	GREET1
1981	Coal	Energy	NOx: Total	g	mmBtu	4.7862567	4.786	Data taken from GREE	GREET1	4.836796716	Data taken from GREE	GREET1
1982	Coal	Energy	PM10: Total	g	mmBtu	8.50008736	8.500	Data taken from GREE	GREET1	8.5076574	Data taken from GREE	GREET1
1983	Coal	Energy	PM2.5: Total	g	mmBtu	1.180808069	1.181	Data taken from GREE	GREET1	1.184789604	Data taken from GREE	GREET1
1984	Coal	Energy	SOx: Total	g	mmBtu	6.793846817	6.794	Data taken from GREE	GREET1	6.800335903	Data taken from GREE	GREET1
1985	Coal	Energy	BC: Total	g	mmBtu	0.034573313	0.035	Data taken from GREE	GREET1	0.034788914	Data taken from GREE	GREET1
1986	Coal	Energy	OC: Total	g	mmBtu	0.070018566	0.070	Data taken from GREE	GREET1	0.070773176	Data taken from GREE	GREET1
1987	Coal	Energy	CH4	g	mmBtu	147.5481782	147.548	Data taken from GREE	GREET1	147.6793481	Data taken from GREE	GREET1
1988	Coal	Energy	N2O	g	mmBtu	0.028177403	0.028	Data taken from GREE	GREET1	0.02947556	Data taken from GREE	GREET1
1989	Coal	Energy	CO2	g	mmBtu	1426.467546	1,426.468	Data taken from GREE	GREET1	1493.166849	Data taken from GREE	GREET1
1990	Coal	Energy	CO2 (w/ C in VOC & C	g	mmBtu	1451.976176	1,451.976	Data taken from GREE	GREET1	1518.723101	Data taken from GREE	GREET1
1991	Coal	Energy	GHGs	g	mmBtu	5885.888534	5,885.889	Data taken from GREE	GREET1	5956.914568	Data taken from GREE	GREET1
1992	Coal	Energy	VOC: Urban	g	mmBtu	0.04014617	0.040	Data taken from GREE	GREET1	0.040774604	Data taken from GREE	GREET1
1993	Coal	Energy	CO: Urban	g	mmBtu	0.03952552	0.040	Data taken from GREE	GREET1	0.045475624	Data taken from GREE	GREET1
1994	Coal	Energy	NOx: Urban	g	mmBtu	0.067966586	0.068	Data taken from GREE	GREET1	0.080831445	Data taken from GREE	GREET1
1995	Coal	Energy	PM10: Urban	g	mmBtu	0.010108459	0.010	Data taken from GREE	GREET1	0.011531882	Data taken from GREE	GREET1
1996	Coal	Energy	PM2.5: Urban	g	mmBtu	0.008667218	0.009	Data taken from GREE	GREET1	0.009822476	Data taken from GREE	GREET1
1997	Coal	Energy	SOx: Urban	g	mmBtu	0.04136784	0.041	Data taken from GREE	GREET1	0.055887505	Data taken from GREE	GREET1
1998	Coal	Energy	BC: Urban	g	mmBtu	0.000855419	0.001	Data taken from GREE	GREET1	0.000909584	Data taken from GREE	GREET1
1999	Coal	Energy	OC: Urban	g	mmBtu	0.0019676	0.002	Data taken from GREE	GREET1	0.002182581	Data taken from GREE	GREET1
2000	Coated/Tempered Gla:	Energy	Total Energy	BTU	m2		110976552.3	User Modeled Data Da	GREET1	20091.4	Data taken from GREE	GREET1

C3 DISAGGREGATED LIFE CYCLE PROFILES

This worksheet contains the life cycle profiles for each material that are that imported from the GREET 1, GREET 2, open literature such as EPDs, or generated through simulation with the Module. For a given material, its life cycle profile includes 27 life cycle metrics and associated information such as unit, functional unit, representative year, comment, and source of the data. Life cycle data is stored at the life cycle stage level, as well as aggregated to the system boundary. Life cycle profiles are stored for each material on an individual year basis. Table C2 shows the life cycle profile of Aniline as an example.

This worksheet forms the background database of common materials, process fuels, chemicals, etc., as well as newly added and/or generated data that may be involved in modeling new buildings. This worksheet is only used for whole building LCA.

TABLE C2. Disaggregated Life cycle profile of Aniline as an example.

A	B	C	D	E	F	G	H	I	J	K	R	S	T	U	V	W	X	Y	Z	AA	AB
Material	Year	Metric	Unit	Functional Unit	Data source & Note	A1	A2	A3	A4	A5	B Grou	C1	C2	C3	C4	D	Cradle-to-Gate	Cradle-to-Consti	Cradle-to-Use	Cradle-to-Grave	Cradle-to-Cradle
Aniline	2020	Total Energ	BTU	kg	User Modeled Data. Mate	64776.05	350.7351	4836.56	0	0	0	0	0	0	0	0	69963.34281	69963.34281	69963.34281	69963.34281	69963.34281
Aniline	2020	Fossil Fuel	BTU	kg	User Modeled Data. Mate	64488.65	348.9908	3832.065	0	0	0	0	0	0	0	0	68669.70101	68669.70101	68669.70101	68669.70101	68669.70101
Aniline	2020	Coal	BTU	kg	User Modeled Data. Mate	211.503	2.354773	1603.967	0	0	0	0	0	0	0	0	1817.824563	1817.824563	1817.824563	1817.824563	1817.824563
Aniline	2020	Natural Ga	BTU	kg	User Modeled Data. Mate	49770.13	36.26263	2157.836	0	0	0	0	0	0	0	0	51964.22767	51964.22767	51964.22767	51964.22767	51964.22767
Aniline	2020	Petroleum	BTU	kg	User Modeled Data. Mate	14507.01	310.3734	70.26187	0	0	0	0	0	0	0	0	14887.64878	14887.64878	14887.64878	14887.64878	14887.64878
Aniline	2020	Water Con	Gal	kg	User Modeled Data. Mate	1.148425	0.006757	0.742533	0	0	0	0	0	0	0	0	1.897714528	1.897714528	1.897714528	1.897714528	1.897714528
Aniline	2020	VOC: Tota	g	kg	User Modeled Data. Mate	2.044379	0.004107	0.054796	0	0	0	0	0	0	0	0	2.103281636	2.103281636	2.103281636	2.103281636	2.103281636
Aniline	2020	CO: Total	g	kg	User Modeled Data. Mate	1.976237	0.056977	0.241618	0	0	0	0	0	0	0	0	2.274832649	2.274832649	2.274832649	2.274832649	2.274832649
Aniline	2020	NOx: Total	g	kg	User Modeled Data. Mate	1.663181	0.03887	0.40857	0	0	0	0	0	0	0	0	2.110621653	2.110621653	2.110621653	2.110621653	2.110621653
Aniline	2020	PM10: Tota	g	kg	User Modeled Data. Mate	0.120156	0.002186	0.047969	0	0	0	0	0	0	0	0	0.170310724	0.170310724	0.170310724	0.170310724	0.170310724
Aniline	2020	PM2.5: Tot	g	kg	User Modeled Data. Mate	0.101894	0.000635	0.033148	0	0	0	0	0	0	0	0	0.135677095	0.135677095	0.135677095	0.135677095	0.135677095
Aniline	2020	SOx: Total	g	kg	User Modeled Data. Mate	0.729834	0.001571	0.207635	0	0	0	0	0	0	0	0	0.939041013	0.939041013	0.939041013	0.939041013	0.939041013
Aniline	2020	BC: Total	g	kg	User Modeled Data. Mate	0.011868	6.1E-05	0.003472	0	0	0	0	0	0	0	0	0.015401279	0.015401279	0.015401279	0.015401279	0.015401279
Aniline	2020	OC: Total	g	kg	User Modeled Data. Mate	0.026547	0.000108	0.01118	0	0	0	0	0	0	0	0	0.037834478	0.037834478	0.037834478	0.037834478	0.037834478
Aniline	2020	CH4	g	kg	User Modeled Data. Mate	8.707598	0.032737	0.753082	0	0	0	0	0	0	0	0	9.49341657	9.49341657	9.49341657	9.49341657	9.49341657
Aniline	2020	N2O	g	kg	User Modeled Data. Mate	0.025101	0.000101	0.010434	0	0	0	0	0	0	0	0	0.035637165	0.035637165	0.035637165	0.035637165	0.035637165
Aniline	2020	CO2	g	kg	User Modeled Data. Mate	1562.625	26.93874	532.5146	0	0	0	0	0	0	0	0	2122.078468	2122.078468	2122.078468	2122.078468	2122.078468
Aniline	2020	CO2 (w/ C	g	kg	User Modeled Data. Mate	1572.102	27.04107	533.0651	0	0	0	0	0	0	0	0	2132.208433	2132.208433	2132.208433	2132.208433	2132.208433
Aniline	2020	GHGs	g	kg	User Modeled Data. Mate	1839.982	28.05	558.4226	0	0	0	0	0	0	0	0	2426.454779	2426.454779	2426.454779	2426.454779	2426.454779
Aniline	2020	VOC: Urba	g	kg	User Modeled Data. Mate	0.475657	0.00082	0.003013	0	0	0	0	0	0	0	0	0.479490156	0.479490156	0.479490156	0.479490156	0.479490156
Aniline	2020	CO: Urban	g	kg	User Modeled Data. Mate	0.18431	0.000552	0.030386	0	0	0	0	0	0	0	0	0.215248473	0.215248473	0.215248473	0.215248473	0.215248473
Aniline	2020	NOx: Urba	g	kg	User Modeled Data. Mate	0.27463	0.000844	0.061563	0	0	0	0	0	0	0	0	0.337038347	0.337038347	0.337038347	0.337038347	0.337038347
Aniline	2020	PM10: Urb	g	kg	User Modeled Data. Mate	0.029326	0.000148	0.006521	0	0	0	0	0	0	0	0	0.035995019	0.035995019	0.035995019	0.035995019	0.035995019
Aniline	2020	PM2.5: Urb	g	kg	User Modeled Data. Mate	0.026607	0.000127	0.005424	0	0	0	0	0	0	0	0	0.03215758	0.03215758	0.03215758	0.03215758	0.03215758
Aniline	2020	SOx: Urba	g	kg	User Modeled Data. Mate	0.041913	0.000302	0.059157	0	0	0	0	0	0	0	0	0.101372174	0.101372174	0.101372174	0.101372174	0.101372174
Aniline	2020	BC: Urban	g	kg	User Modeled Data. Mate	0.002285	1.62E-05	0.000253	0	0	0	0	0	0	0	0	0.002554713	0.002554713	0.002554713	0.002554713	0.002554713
Aniline	2020	OC: Urban	g	kg	User Modeled Data. Mate	0.007315	2.29E-05	0.001409	0	0	0	0	0	0	0	0	0.008746677	0.008746677	0.008746677	0.008746677	0.008746677

C4 EMISSIONS FACTORS

This worksheet contains emission factors of GHGs, which include carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (N_2O) and criteria air pollutants, which include nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter with a diameter of less than 2.5 and 10 micrometers, respectively ($PM_{2.5}$ and PM_{10}), sulfur oxides (SO_x), and volatile organic compounds (VOCs), that are related to combustion of process fuels, such as natural gas, coal, residual oil, etc., with specific combustion technologies, such as a boiler, a kiln, etc. These emission factors come from GREET 1.

C5 BUILDING COMPONENTS RESULTS

This worksheet contains detailed life cycle results of building materials that are modeled. The embodied energy consumption, GHG emissions, water consumption, and criteria air pollutant emissions associated with each input of process energy or material along the life cycle stages of the defined system boundary applied in the modeling are itemized. This is the results dataset used to visualize the details in the dynamic Dashboard for building materials, building components, and building technologies.

C6 IMPORTS FROM GREET 1

This worksheet contains imports of emission factors related to transportation and electricity generation at the national and state level from GREET 1. These values are taken directly from GREET 1. It is recommended to work with GREET 1 instead of modifying the values on this worksheet.

C7 UNIFORMAT II CLASSIFICATION

This worksheet holds the UNIFORMAT II Classification for building elements and construction work used in the Bill of Materials database. The structure conforms to the ASTM E1557 Standard.

C8 BUILDING DATABASE

Please see section B5.1 for information on the building database.

C9 BILL OF MATERIALS DATABASE

Please see section B5.2 for information on the bill of materials database.

C10 EUI DATABASE

Please see section B5.3 for information on the EUI database.

C11 MODELSETUPINFO

This worksheet contains general model setup information that is used primarily by dropdown lists, such as the list of default functional units available, in the graphical user interface for building material modeling. The user can access to this worksheet to expand the default options available for the dropdown lists to serve unique modeling needs.

REFERENCES

Cai, H., Han, J., Wang, M., Davis, R., Biddy, M., & Tan, E. (2018). Life-cycle analysis of integrated biorefineries with co-production of biofuels and bio-based chemicals: co-product handling methods and implications. Biofuels, Bioproducts and Biorefining, 12(5), 815-833.

Cai, H., Wang, X., Kelly, J., & Wang, M. (2021a). GREET Building Life-Cycle Analysis: Methodologies, Data, and Case Studies. Argonne National Laboratory. Technical Report: ANL/ESD-21/13.

Cai, H., Wang, X., Kelly, J., & Wang, M. (2021b). Building Life-Cycle Analysis with the GREET Building Module: A User Guide. Argonne National Laboratory. Technical Report: ANL/ESD-21/14.

Charette, R. and Marshall, H. (1999). UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating and Cost Analysis, NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology, Gaithersburg, MD (Accessed September 27, 2021)

Wang, M., Hong, H., & Arora, S. (2011). Methods of dealing with co-products of biofuels in life-cycle analysis and consequent results within the U.S. context. Energy Policy 39, 5726–5736.

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