User's Guide for California PATHWAYS model version 2.3.2

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Energy+Environmental Economics

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1. Intro to California PATHWAYS

1.1 Purpose

California PATHWAYS (CA PATHWAYS) was designed by Energy & Environmental Economics with support from Lawrence Berkeley National Labs (LBNL). The purpose of the model is to evaluate the feasibility and cost of a range of GHG reduction cases in California within the context of complying with California's 2050 goal of 80% GHG emissions reduction from 1990 levels.

This work was supported by a collaboration between the California Air and Resources Board (CARB), California Independent System Operator (CAISO), California Public Utilities Commission (CPUC), and California Energy Commission (CEC).

This user's guide is designed to provide a basic overview of how to open the model and run and evaluate cases using the Analytica-based California PATHWAYS tool. For a description of the model structure, please see the supporting model documentation. For more information about how to use the Analytica platform generally, please see the online tutorials developed by Lumina, as described in Section 2.5.

1.2 Version

Version 2.3.2 is the current version of the CA PATHWAYS model. This model replaces the prior version 2.3.1 which is not compatible with Analytica version 4.6 and should no longer be used.

1.3 Modeling Approach

CA PATHWAYS is a California-wide, economy-wide infrastructure-based GHG and cost analysis tool. Components include:

- Equipment stock turn-over for many sectors, with rates based on lifetime of equipment; energy use determined as service demand is met by the stock of equipment in each year
- Tracking of energy and energy infrastructure costs
- Bottom up forecast of service demand by end use, driven by variables including population, residential and commercial square footage, space heating/cooling, water heating, lighting, etc.
- Hourly electricity demand and supply detail, simulating required planning, system operation, and cost
- CA PATHWAYS is not an optimization model: the user is in full control of the outcomes

2. Installation of California PATHWAYS and Analytica

2.1 Installing Analytica

The software platform Analytica by Lumina Systems is required to run CA PATHWAYS. Once Analytica is installed on your computer, opening CA PATHWAYS does not require any further installation steps. This chapter is designed to guide the user through the download and installation of Analytica and CA PATHWAYS.

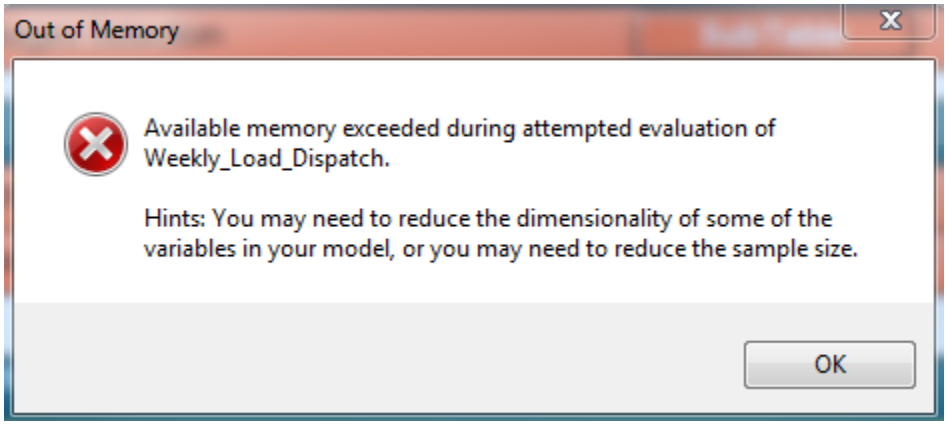
System Requirements

To use Analytica for CA PATHWAYS, the following minimum system requirements apply:

- Minimum 8GB of RAM
- Windows 7 or 8, dual core 64 bit processor

Running 1-2 cases on a computer meeting the minimum requirements above can take 10-30 minutes.

In general, a faster CPU and more RAM will lead to CA PATHWAYS cases running more quickly. With the minimum requirements listed above it is not recommended to run more than two cases simultaneously. Running too many cases simultaneously or not meeting system requirements may lead to an Out of Memory error or computer crash. An example of the Out of Memory error is displayed below:



2.2 Recommended Versions of Analytica

Free 101 edition of Analytica: For users who would like to run existing cases, obtain results from the CA PATHWAYS model, or create and save new cases using the pre-existing model structure. This version of the software can be downloaded as described below.

The purchase of a Professional Analytica license is required to edit variables in the code and an Enterprise or Optimizer license in required to read and write data files into or out of the Analytica platform.

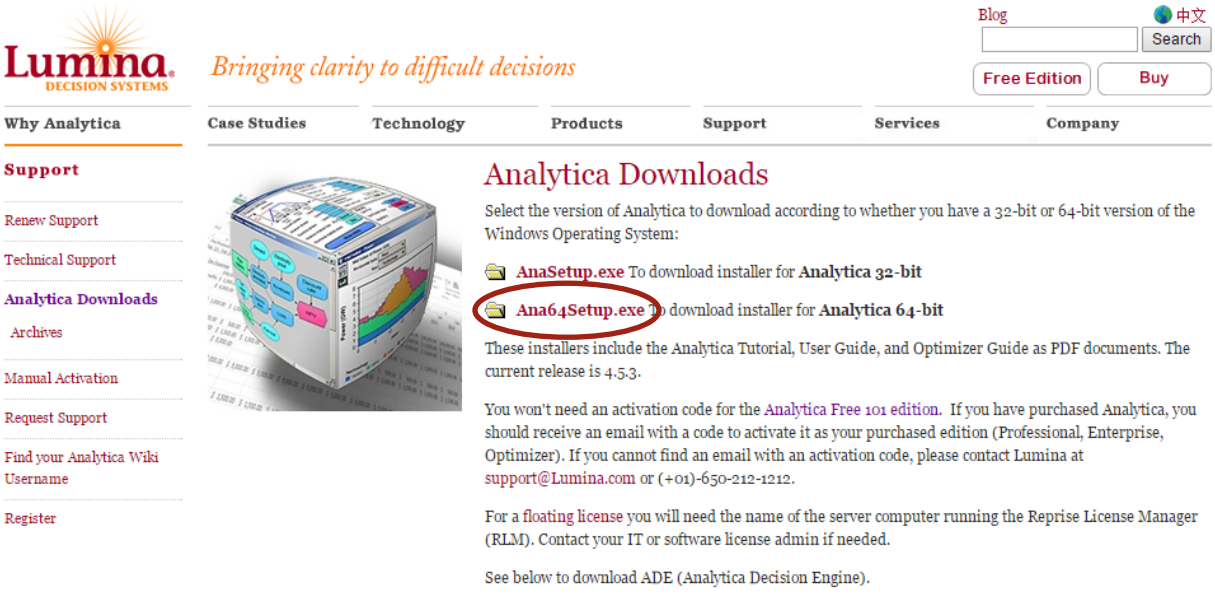
Currently, the latest version of Analytica is 4.6. Lumina issues periodic updates to its software. PATHWAYS version 2.3.2 is compatible with Analytica version 4.6. The prior version of PATHWAYS (version 2.3.1) should no longer be used, even with Analytica version 4.5, as it produces errors (See section 5 for more details). For future Analytica software updates, there are no guarantees that the new software will be compatible with PATHWAYS 2.3.2 and in some cases updates may result in new errors. It is recommended that users do not use new updates unless notified by E3 that the new update is compatible with CA PATHWAYS version 2.3.2.

2.3 Licenses

A license is needed to use Analytica. The Analytica Free Player is automatically included when the software is downloaded, and can be used by anyone.

2.4 Downloading Analytica Free Player

Step 1. Go to Lumina's website and download the Analytica free player at:
http://www.lumina.com/support/downloads/



Click on "Ana64Setup.exe" to being downloading the 64-bit version of Analytica. The 32-bit version of the software is not compatible with CA PATHWAYS. After downloading, double click on the file to begin the installation process. Once installed you do not need an activation key to run the free version of Analytica.

Step 2. Follow Instructions on the Lumina website to download and Install Analytica software.

2.5 User Guide & Tutorials

Details about how to use the Analytica software are available in the Analytica User Guide, available at:

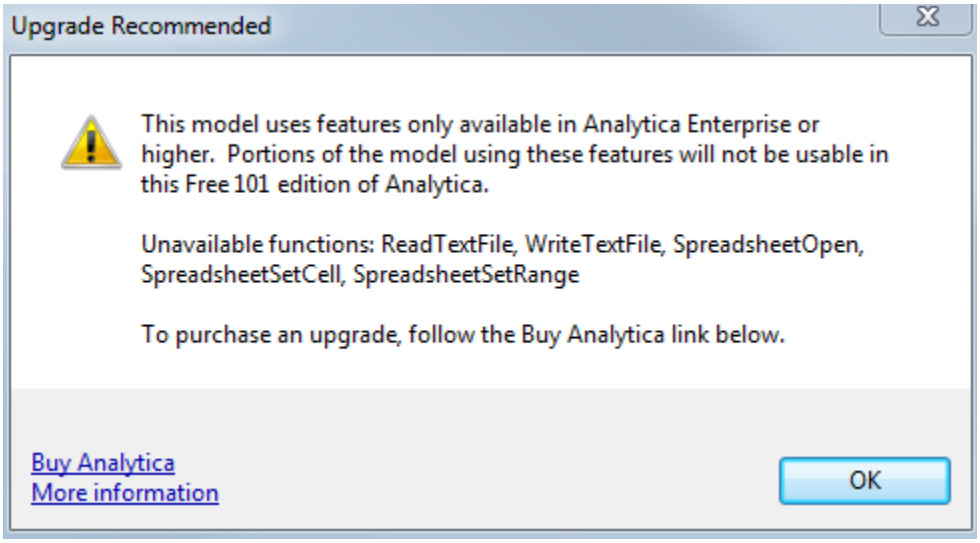
http://www.lumina.com/support/downloads/

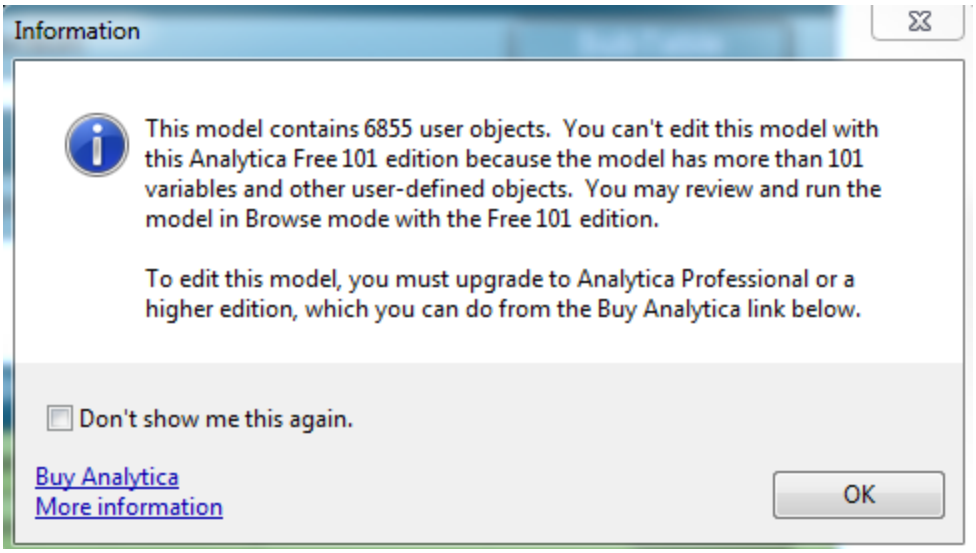
Lumina also provides tutorials in written and video versions. Tutorials contain further information about installing Analytica (pg. 4-6) and information on creating and editing models in Analytica, available at the same link as above.

3. Running & Evaluating Pre-Defined Cases

3.1 Opening CA PATHWAYS in the Free Player Version of Analytica

Once Analytica is downloaded a user can open CA PATHWAYS. Opening the model in the Free Player version of Analytica will result in the following two messages after the model loads:

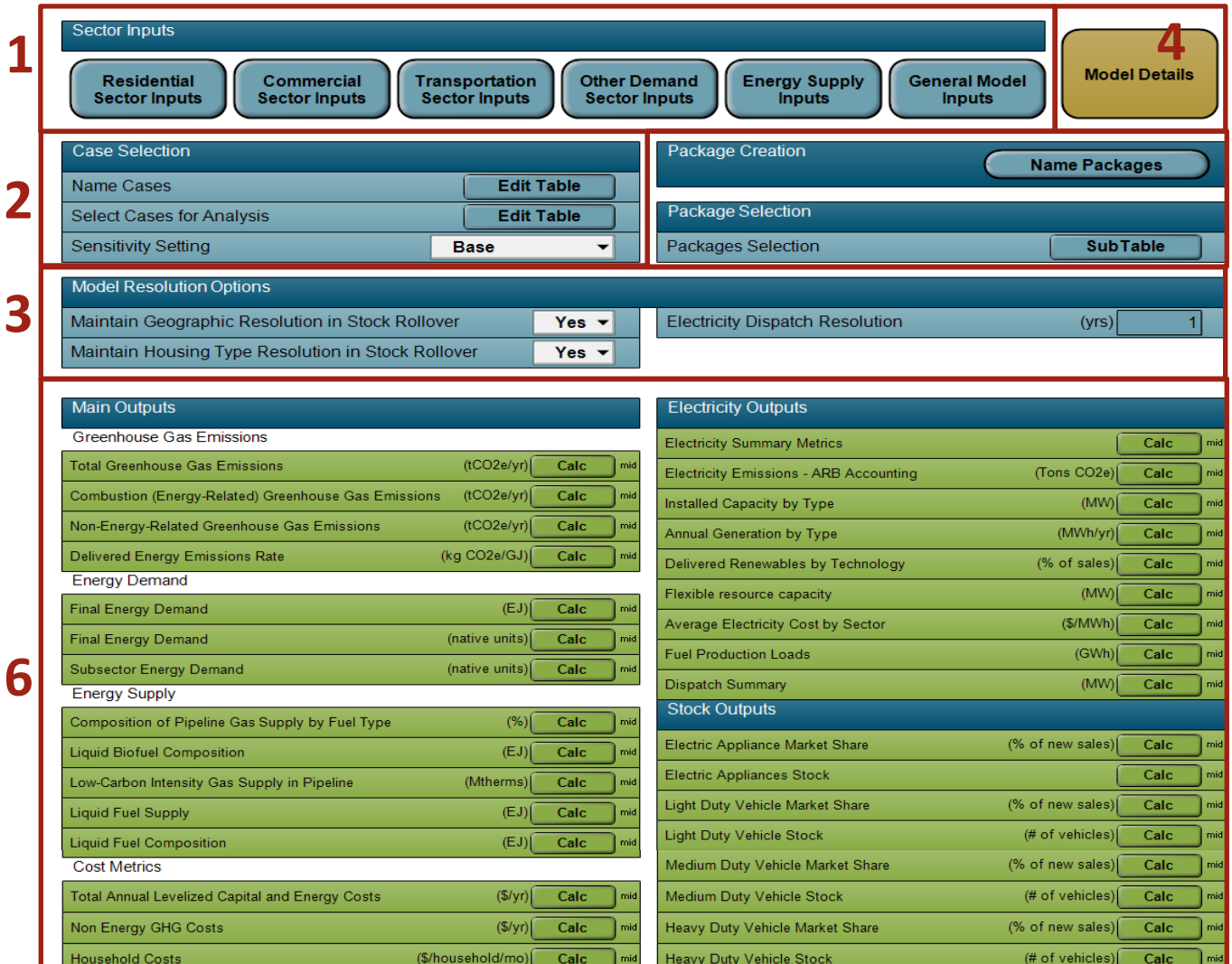




Unless you wish to purchase an upgraded version of Analytica, click "OK" on both of these screens.

3.2 User Interface

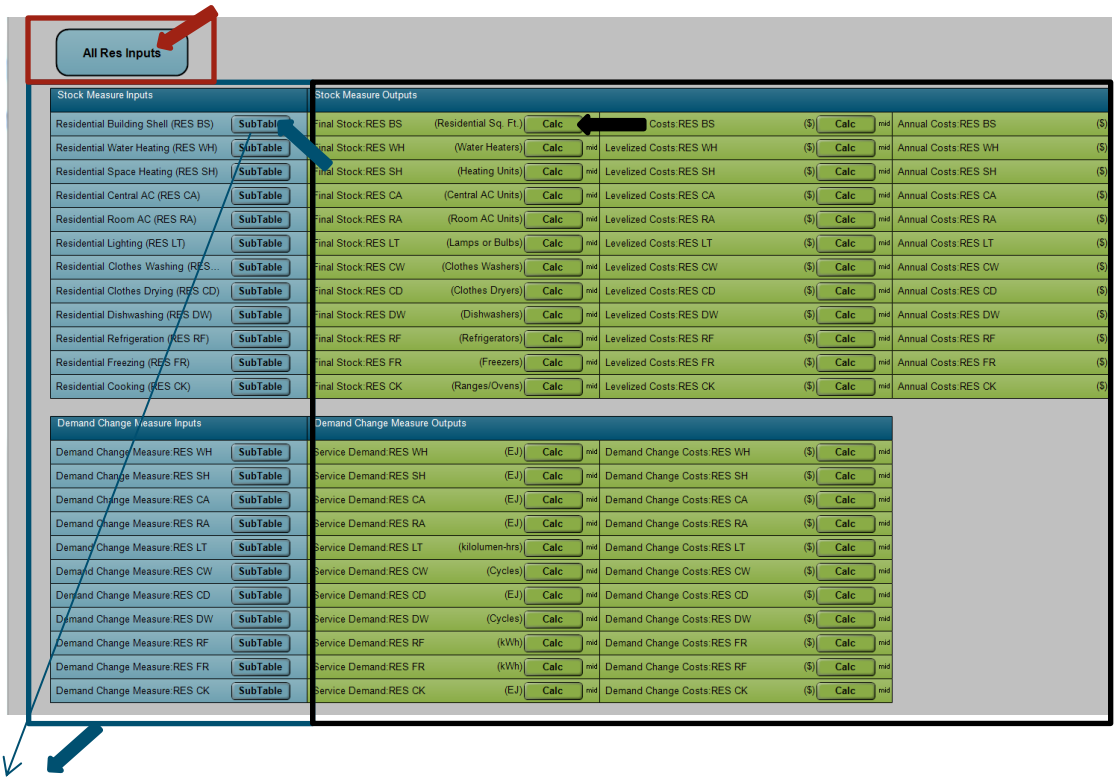
The main user interface for CA PATHWAYS is pictured below. Sections of the model are highlighted with numbers, explained below.

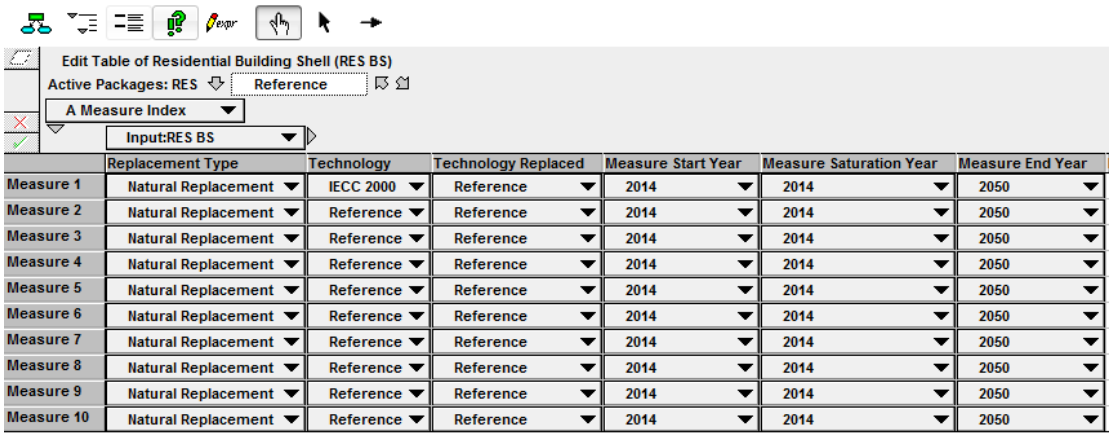


7

1. **Sector Inputs:** Double clicking on any of the six input tabs displays a list of inputs and some outputs associated with that sector. From that view, further detail is available for some sectors by clicking "All [Sector] Inputs." Subtables display model inputs, which may also be represented graphically (see Section 3.4) or as diagrams by clicking the "Diagram Window" button once viewing a subtable.

   An example of this process is shown below for the Residential Sector Inputs button. Double clicking the button where the **red** box and arrow are shown displays all Residential Inputs. Clicking any of the subtable buttons (**blue** box and arrow) will display input sub-tables as shown below. Clicking any of the "Calc" buttons in **black** will run all calculations in the model necessary to provide that value, but will not run the full model.





Edit Table of Residential Building Shell (RES BS)

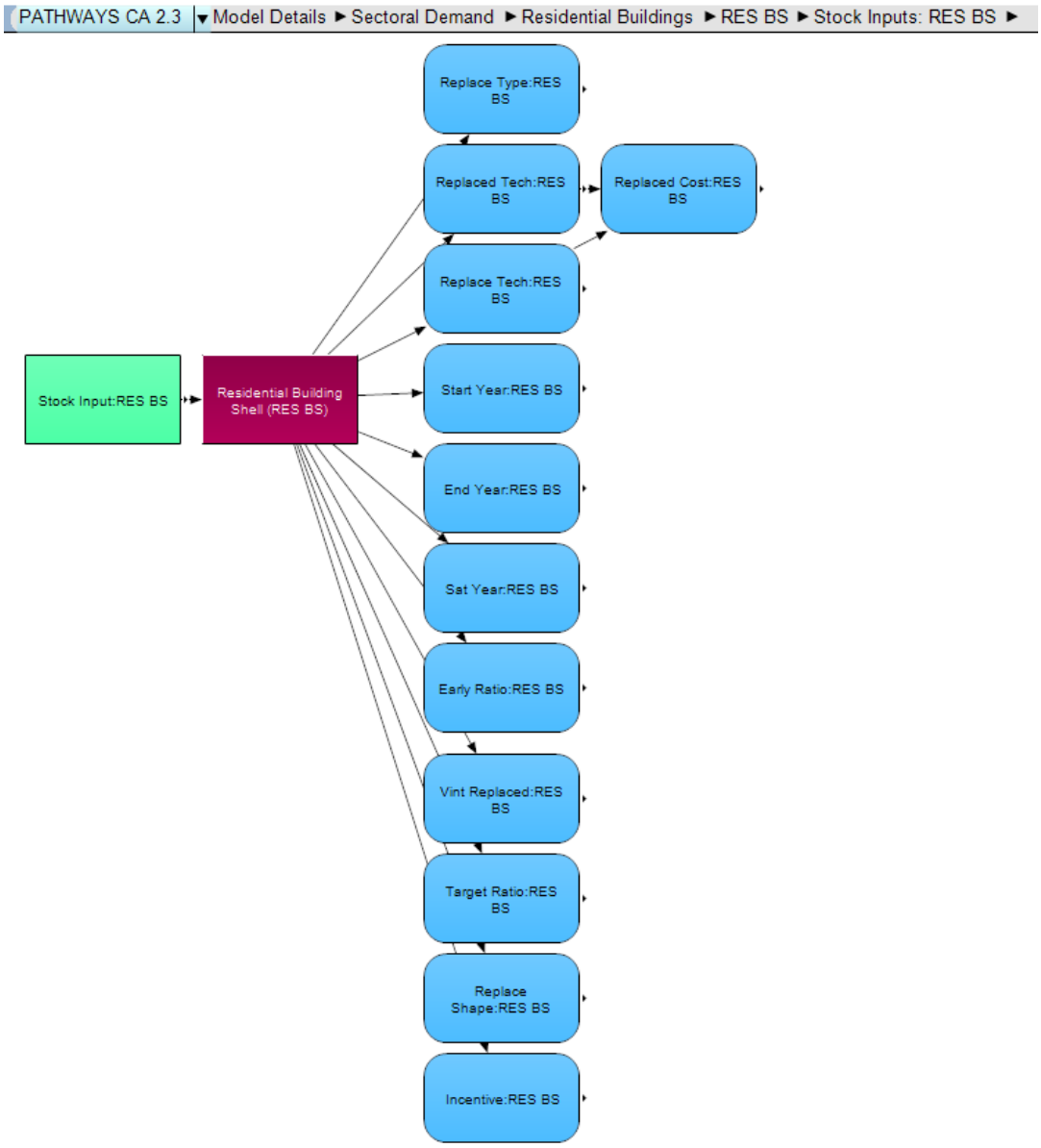
Active Packages: RES | Reference

A Measure Index

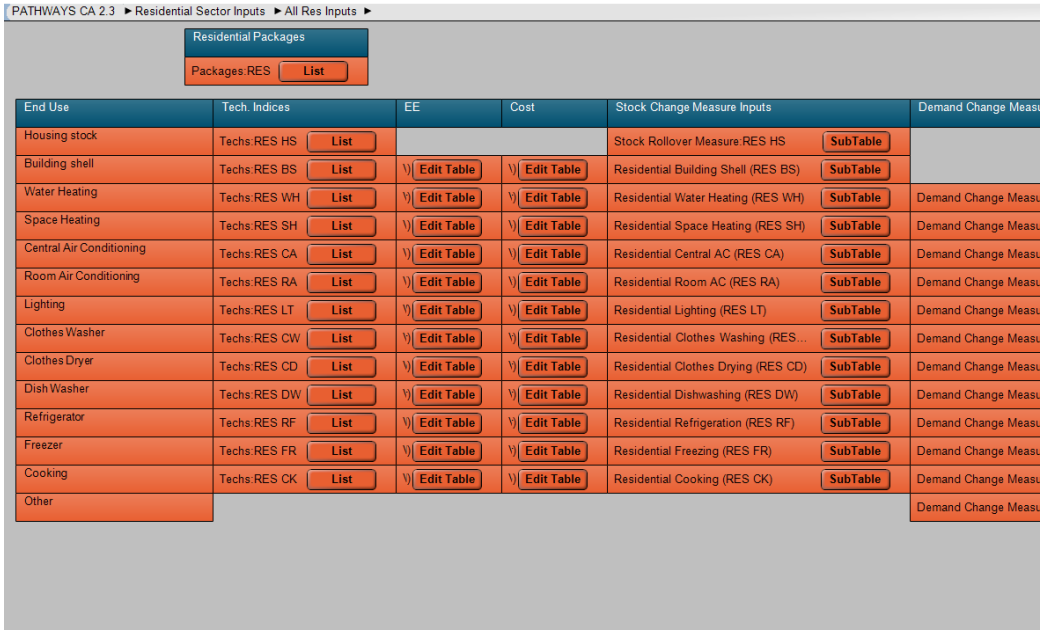
Input:RES BS

	Replacement Type	Technology	Technology Replaced	Measure Start Year	Measure Saturation Year	Measure End Year
Measure 1	Natural Replacement	IECC 2000	Reference	2014	2014	2050
Measure 2	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 3	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 4	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 5	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 6	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 7	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 8	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 9	Natural Replacement	Reference	Reference	2014	2014	2050
Measure 10	Natural Replacement	Reference	Reference	2014	2014	2050

Clicking the Diagram window (**blue** arrow above) button then displays the influence diagram for the selected input. An example is shown below for Residential Building Shell.



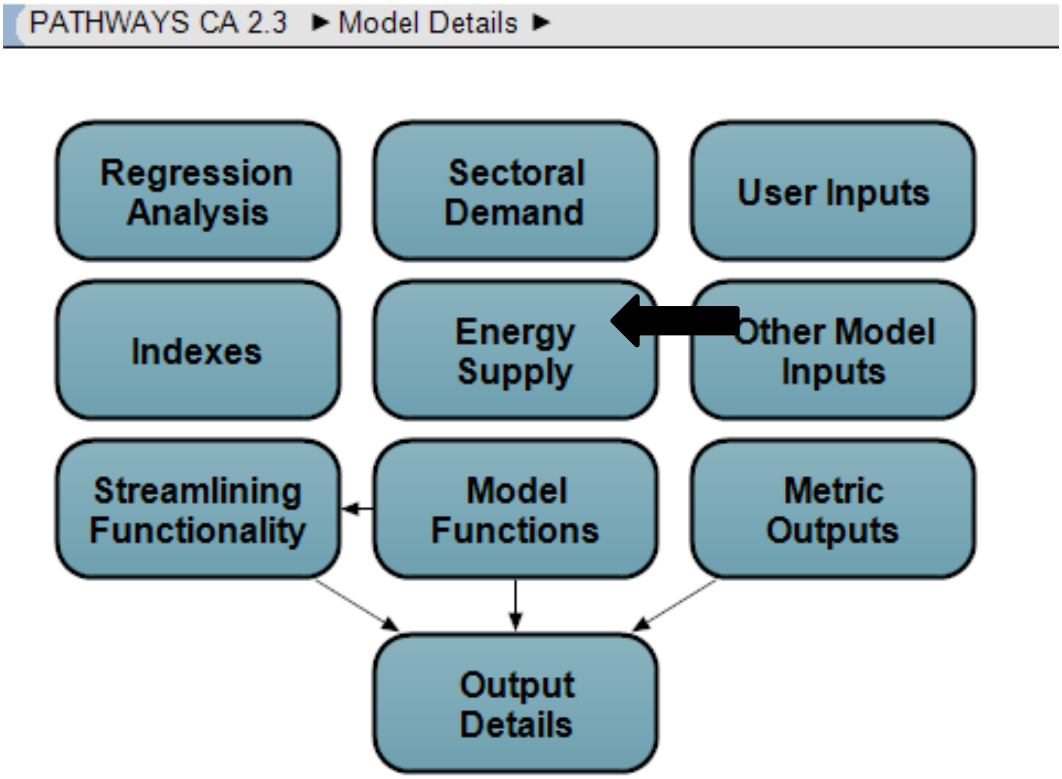
Alternatively, clicking “All Res Inputs” on the first subtable screen above (**red** arrow) brings up the screen below, from which the user may then double click a desired list or table of Residential data.

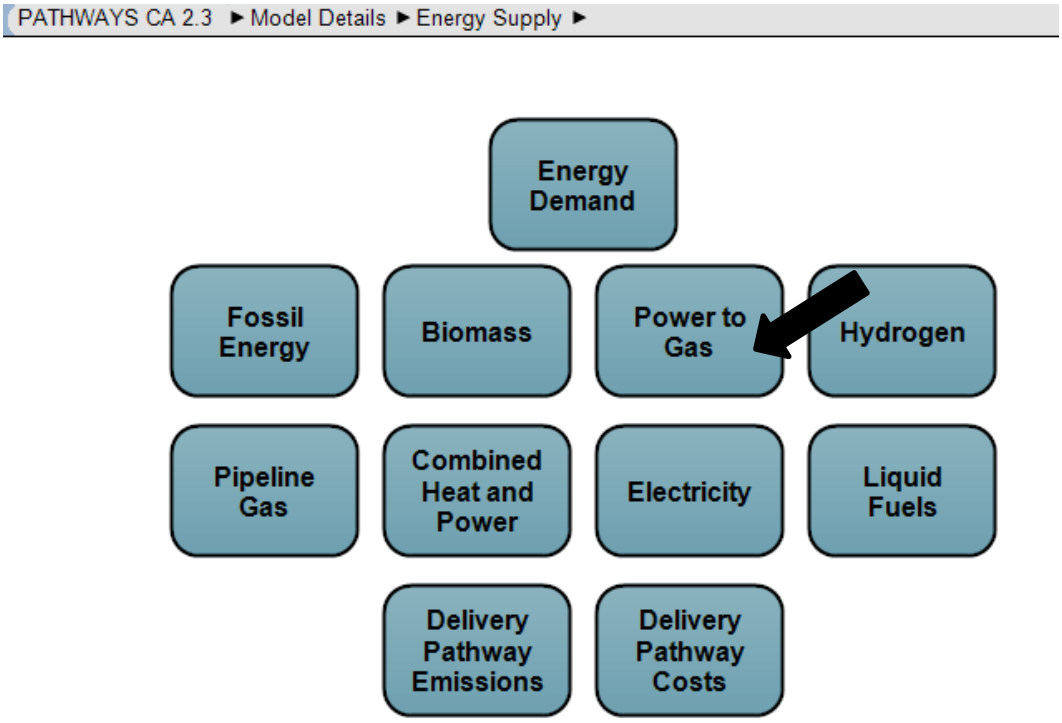


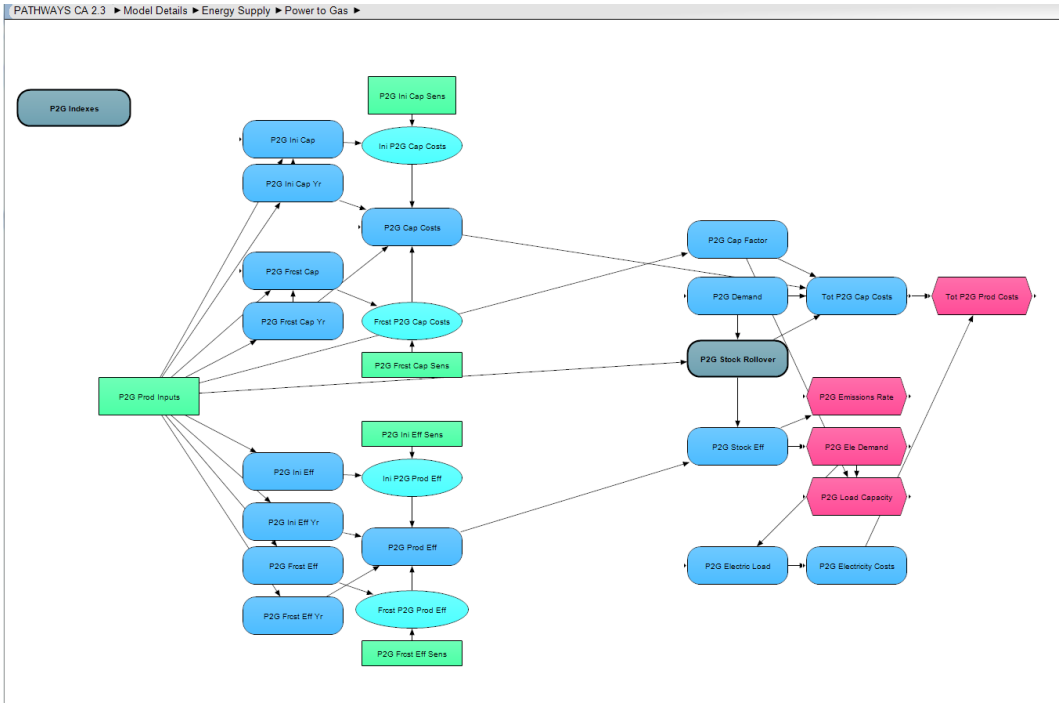
2. **Case Selection:** Choose which cases to run (Active Cases) and sensitivity settings. See sections 3.3 and 3.5 of this guide for more information.
3. **Model Resolution Options:** Several end uses in PATHWAYS are modeled with geographic resolution within the state. For example, light duty vehicle stocks are tracked by Air Quality Management District. This resolution can be turned off (i.e. all energy demand and stocks are tracked state-wide) with some loss of precision sacrificed in order to reduce runtimes. Some stocks are also tracked by Housing Type, which can also be turned off at the expense of precision in order to reduce runtimes. To reduce the resolution with respect to geography or housing type, set the corresponding "Maintain Geographic Resolution" settings to "No." By default, the electricity module calculates electricity system dispatch in every year until 2050, but this can be changed with the "Electricity Dispatch Resolution" setting to improve runtimes (for example to calculate dispatch only 10 years set this parameter to 10). Electricity system results are linearly interpolated between the dispatch years if this parameter is set to a value larger than 1.
4. **Model Details:** Brings up the main diagram window for the model. The user may then double click to display sectoral and sub-sectoral diagrams. Subsectoral diagrams (e.g. Model Details → Sectoral Demand →Transportation, Communication, and Utilities, or Model Details → Energy Supply → Fossil Energy) displays influence diagrams.[1] Clicking on variables within influence diagrams displays information about the variable. The variable can also be represented as a table or graph, see 3.4.

[1] For more on the shapes (variables) and functionalities of influence diagrams, see the Analytica tutorial on using influence diagrams, https://www.youtube.com/watch?v=dSzvuMGJTlk

An example of this process is shown below for the Power to Gas (P2G) influence diagram. Double Clicking the buttons highlighted with the black arrows allows the user to access the P2G influence diagram. Clicking other buttons allows access of other influence diagrams.





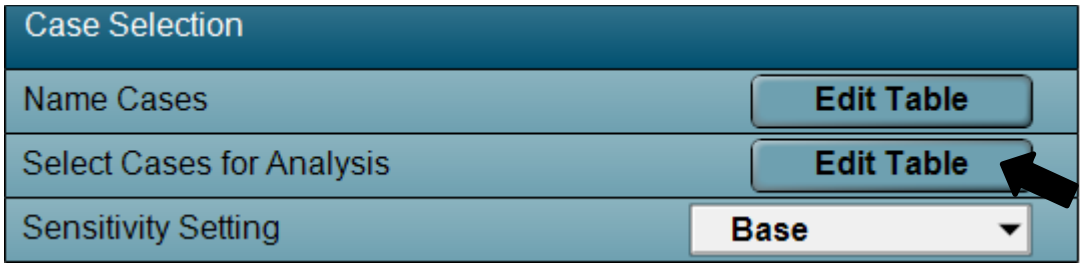


Once at the influence diagram level, double clicking on any variable allows the user to see how that variable is defined.

5. **Packages:** Packages define the set of input assumptions associated with a particular sector. Combinations of different packages are used to create economy-wide cases. This section of the model on package naming and selection is to create user-defined cases, see Section 4.
6. **Outputs:** Clicking "Calc" will run selected cases (see 3.3 on Selecting Cases). See Evaluating Results (3.4) for more information.
7. **Export CSV Files:** Exports categories of pre-defined results into csv files that can be viewed in Excel. Requires professional or higher version of Analytica.

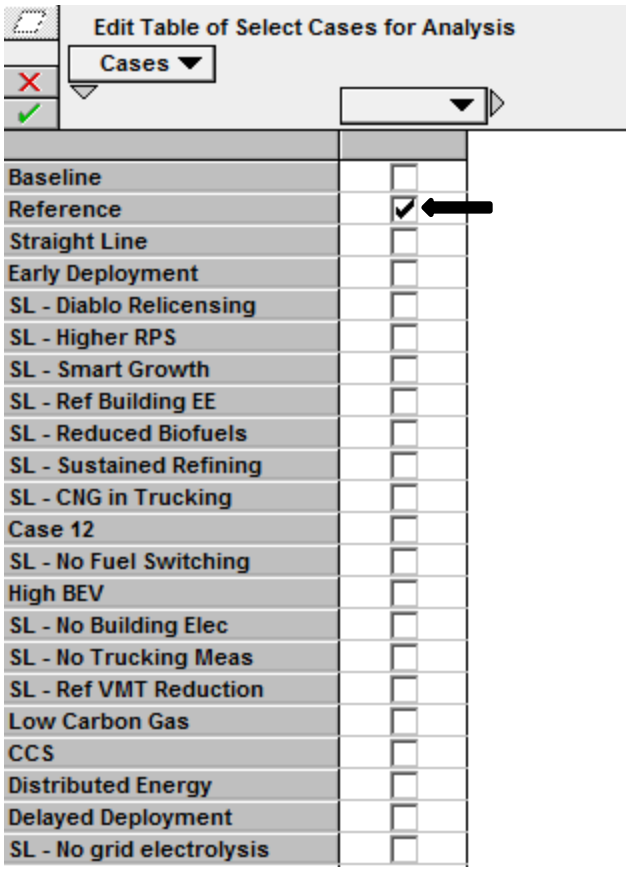
3.3 Selecting Cases

CA PATHWAYS contains 33 pre-set cases, with the option for creating further user-defined cases (see Section 4). Cases are accessed by clicking on the "Edit Table" button next to "Select Cases for Analysis," toward the top left of the opening model interface screen.



Analytica will then bring up the case selection screen, where the user can check boxes for the cases they wish to run – these will become the Active Cases. After checking the desired boxes, the user may return to the main screen of the model to run the selected cases by exiting this screen using the "x" in the upper right corner of the dialogue box.[2] It is not advisable to run more than two or three cases simultaneously with a computer meeting the minimum system requirements.

[2] Note that clicking the green checkmark box has been occasionally observed to result in the model hanging up for an extended period of time so is not recommended.



Users may then assign a "Sensitivity Setting" (see 3.5 for more information), Model Resolution Options, Electricity Dispatch Detail & Resolution, and Packages on the main model interface screen. Note that reassigning packages will result in different results from the pre-defined cases.

3.4 Evaluating Results

3.4.1 Calculating Results

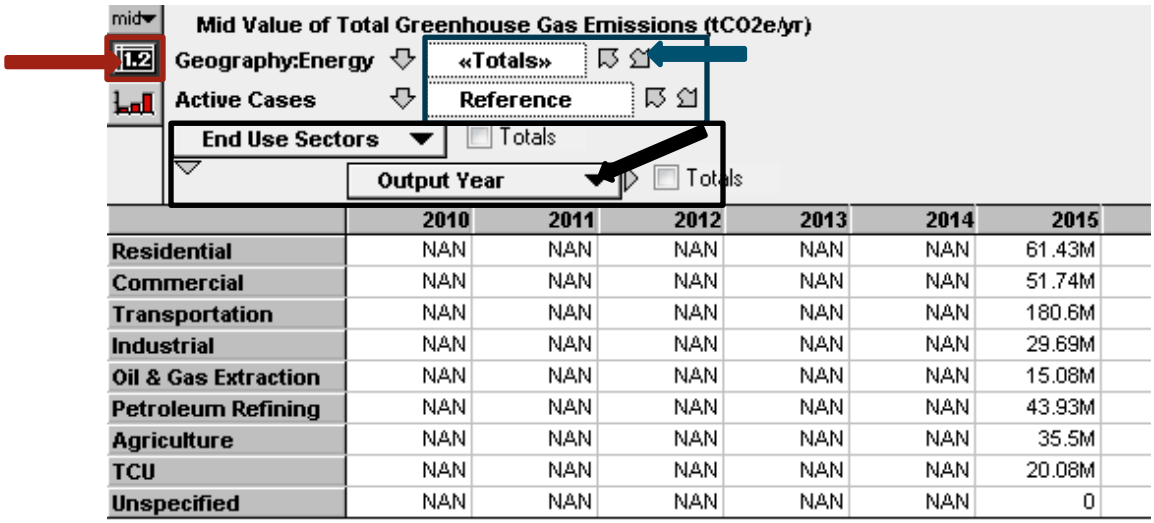
The model is run by clicking any of the green "Calc" buttons on the screen associated with every computed variable. Clicking "Calc" once will run the model through to the point in the model at which the result is available. Allow 10-30 minutes for the model to run 1-2 complete cases for the first time, for example by clicking on "calc" for final CA wide GHG emissions. Subsequent calculations will generally require less evaluation time since the model will not need to recalculate all modules.

Model calculations can be stopped at any time by clicking the red "x" in the top dialogue box, shown below. The red X button appears once the user starts running the model.

To check memory usage and to ensure that the model is still calculating, click on "window" → "show memory usage" to view your computer's computational statistics.

3.4.2 Results Tables

After the model has finished calculating, the "Calc" button will change to a "Result" button. By double clicking on results, a data table of results will generally be displayed. If not, the data table can be viewed by clicking on the table icon, shown by the **red** box and **red** arrow below.

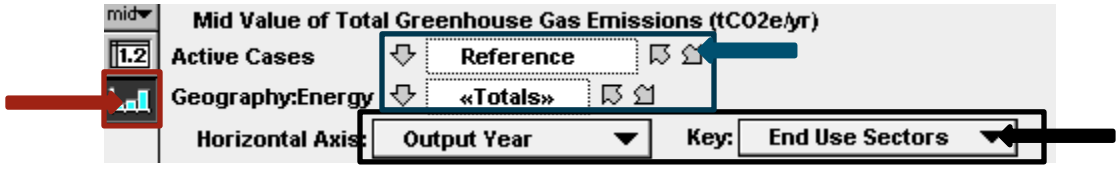


	2010	2011	2012	2013	2014	2015
Residential	NAN	NAN	NAN	NAN	NAN	61.43M
Commercial	NAN	NAN	NAN	NAN	NAN	51.74M
Transportation	NAN	NAN	NAN	NAN	NAN	180.6M
Industrial	NAN	NAN	NAN	NAN	NAN	29.69M
Oil & Gas Extraction	NAN	NAN	NAN	NAN	NAN	15.08M
Petroleum Refining	NAN	NAN	NAN	NAN	NAN	43.93M
Agriculture	NAN	NAN	NAN	NAN	NAN	35.5M
TCU	NAN	NAN	NAN	NAN	NAN	20.08M
Unspecified	NAN	NAN	NAN	NAN	NAN	0

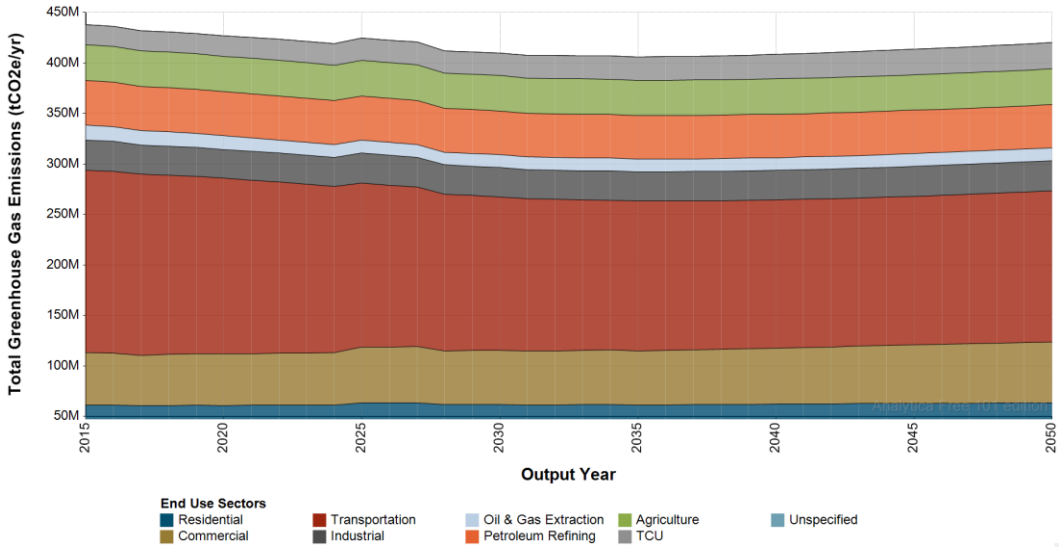
Different table axes are displayed by using the drop down lists on the buttons enclosed in **black** boxes and arrow above. The user may then toggle through what to display on the axes in by toggling through the boxes enclosed in **blue** boxes and arrow above (e.g. "Active Cases" will give options to look at any cases that have been run). This allows the user to choose what to display in the table.

3.4.3 Results Graphs

After clicking into case results, a graph of the result can be displayed by clicking on the graph button, highlighted above in the red box and arrow. As was the case for tables, the black box and arrow above shows where drop-down menus allow the user to choose what will define the x axis and key labeling for the graph. The blue box and arrow then determine what data will be displayed on the graph, e.g. from which case (Reference, Baseline, Low Carbon Gas, etc.) data will be displayed.



An example graph for GHG emissions by output year for the Reference case is displayed below.



3.5 Sensitivities

CA PATHWAYS offers five sensitivities that can be run on any pre-defined or user-defined case. When selected, the sensitivities are applied to all Active Cases. The sensitivities are:

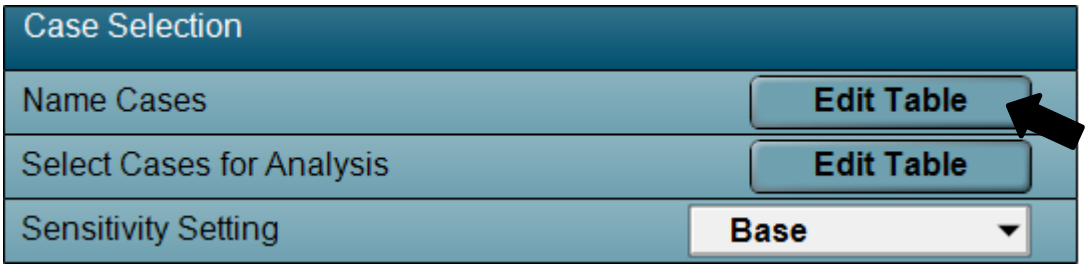
- Base Case: Default standard assumptions
- Low Cost
    - Reduces Solar and Power-to-Gas installed costs by 50% in 2050 relative to base case (with exponential escalation of the multiplier between 2010 and 2050)
    - Reduces Heat Pump, LED, and Grid Electrolysis costs by 20% in 2050 relative to the base case (with exponential escalation of the multiplier between 2010 and 2050)
    - Reduces Wind, Plug-In Hybrid, Battery Electric Vehicle, Fuel Cell Vehicle, and Electric Boiler costs by 5% in 2050 relative to the base case (with exponential escalation of the multiplier between 2010 and 2050)
    - Reduces model discount rates by 50% relative to the base case
    - Increases natural gas and petroleum prices by 50% in 2050 relative to base case (with linear escalation of the multiplier between 2010 and 2050)
- High Cost
    - Reduces natural gas and petroleum prices by 50% in 2050 relative to the base case (with linear escalation of the multiplier between 2010 and 2050)
    - Uses base case technology costs and discount rates

- Climate Change
    - Reduces Heating Degree Days by 5% in 2020 and 20% in 2050 (linear interpolation between 2020 and 2050)
    - Increases Cooling Degree Days by 5% in 2020 and 30% in 2050 (linear interpolation between 2020 and 2050)
    - Reduces Hydropower availability by 30% in 2050 (linear interpolation between 2020 and 2050)
- Population Growth
    - Increases both Population and Commercial Square Footage by 10% in 2050 relative to the base case (with linear escalation of the multiplier between 2010 and 2050)

4. User-Defined Cases

4.1 Naming a User-Defined Case

To create a new case, first give your case a new name. The user should begin by clicking "Edit Table" next to the "Name Cases" label on the main user interface.



This will bring up the table of pre-defined and available case names. Any cases with a 0 in the name box are available to be named by the user. Existing cases can also be re-named if desired.

Case 1	'Baseline'
Case 2	'Reference'
Case 3	'Straight Line'
Case 4	'Early Deployment'
Case 5	'SL - Diablo Relicensing'
Case 6	'SL - Higher RPS'
Case 7	'SL - Smart Growth'
Case 8	'SL - Ref Building EE'
Case 9	'SL - Reduced Biofuels'
Case 10	'SL - Sustained Refining'
Case 11	'SL - CNG in Trucking'
Case 12	0
Case 13	'SL - No Fuel Switching'
Case 14	'High BEV'
Case 15	'SL - No Building Elec'
Case 16	'SL - No Trucking Meas'
Case 17	'SL - Ref VMT Reduction'
Case 18	'Low Carbon Gas'
Case 19	'CCS'
Case 20	'Distributed Energy'
Case 21	'Delayed Deployment'
Case 22	'SL - No grid electrolysis'
Case 23	'LCG - No trucking meas'
Case 24	'SL - No heat pumps'
Case 25	'SL - Reference biofuels'
Case 26	'LCG - Reference biofuels'
Case 27	'SL - No WP chargers'
Case 28	'LCG - No WP chargers'
Case 29	'SL - Reference trans'
Case 30	'LCG - Reference trans'
Case 31	'SL - Reference industry'
Case 32	'LCG - Reference industry'
Case 33	0
Case 34	'High BEV - No WP chargers'
Case 35	'High BEV - No fuel switching'
Case 36	0
Case 37	0
Case 38	0
Case 39	0
Case 40	0
Case 41	0
Case 42	0
Case 43	0
Case 44	0
Case 45	0
Case 46	0
Case 47	0
Case 48	0
Case 49	0
Case 50	0

Double clicking in these boxes allows the user to edit the name of the case. Any new case will have Reference packages assigned to it by default, the user may change this assignment by creating new packages or selecting different packages (see 4.2 and 4.3).

4.2 Selecting Packages

Once the user has selected their newly named case for analysis, the packages associated with that case may be changed from the default of all Reference packages by double clicking the "Subtable" label next to Packages Selection.

The user may then select which package to associate with each sector (Residential, Commercial, Transportation, Industrial, Oil & Gas Extraction, Petroleum Refining, Agriculture, TCU, Non-Energy, Hydrogen, Pipeline Gas, Biomass, Electricity) using drop-down menus. This functionality allows the user to combine packages in ways that are not covered by pre-defined cases.

Below, the packages associated with the Reference, Straight Line, Low Carbon Gas, and two BEV cases are shown (Case listed across top row, Sectors in far left column).

Edit Table of Packages Selection

Package Key ▼ | Active Cases ▼

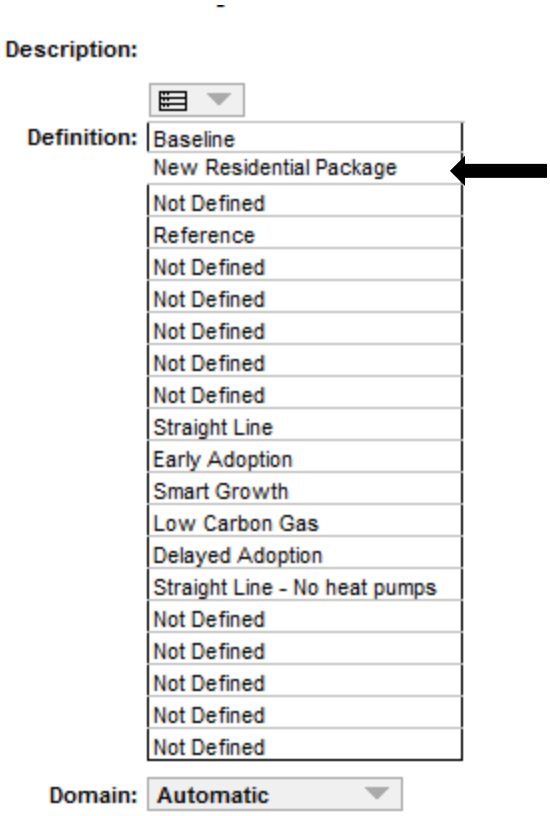
	Reference	Straight Line	Low Carbon Gas	High BEV - No WP chargers	High BEV - No fuel switching
Residential	Reference	Straight Line	Low Carbon Gas	Straight Line	Not Defined
Commercial	Reference	Straight Line	Low Carbon Gas	Straight Line	Straight Line - No Electrificat
Transportation	Reference	Straight Line	Low Carbon Gas	High BEV	High BEV
Industrial	Reference	Straight Line	Low Carbon Gas	Straight Line	Straight Line - No fuel switcl
Oil & Gas Extraction	Reference	Straight Line	Straight Line	Straight Line	Straight Line
Petroleum Refining	Reference	Straight Line	Straight Line	Straight Line	Straight Line
Agriculture	Reference	Straight Line	Straight Line	Straight Line	Straight Line
TCU	Reference	Straight Line	Straight Line	Straight Line	Straight Line
Non-Energy	Baseline	Straight Line	Straight Line	Straight Line	Straight Line
Hydrogen	Baseline	Straight Line	Low Carbon Gas	Straight Line	Straight Line
Pipeline Gas	Baseline	Straight Line	Low Carbon Gas	Straight Line	Straight Line
Biomass	Reference	Straight Line	Low Carbon Gas	Straight Line	Straight Line
Electricity	Reference	Straight Line	Low Carbon Gas	High BEV - No workplace charging	High BEV

4.3 Creating New Packages

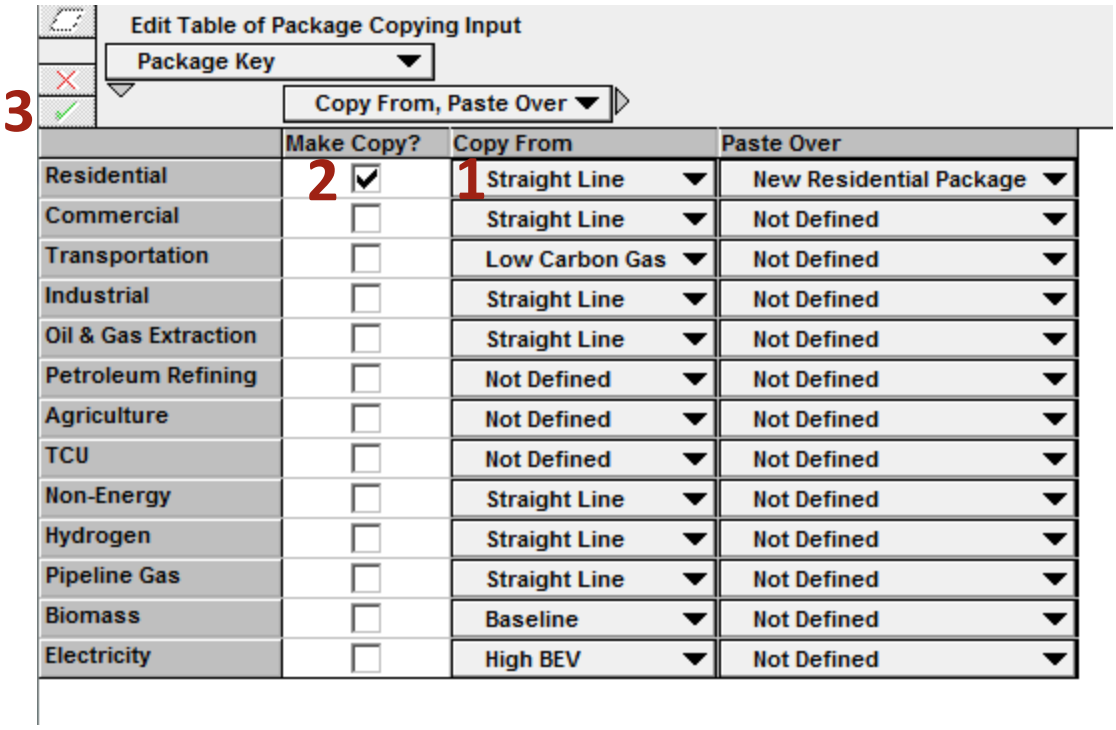
To begin the process of creating a new package, click the "Name Packages" button shown below on the opening CA PATHWAYS screen.

The user may then select which sector they would like to create a new package for. The **black** arrow below on the Main Package Screen points to the Residential Sector packages as an example.

The user may then name their new package by retitling any of the “Not Defined” Definitions.

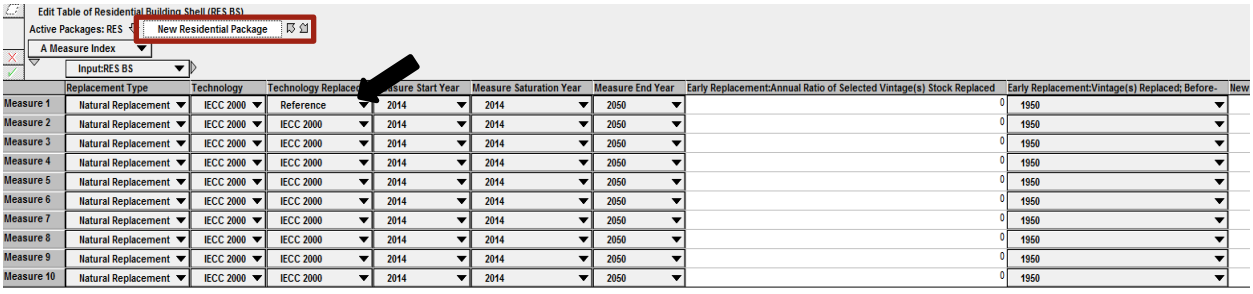


Next, the user can copy over data from one of the pre-existing packages to this new package by clicking "Package copying input: edit table" where the **blue** arrows is shown two figures above on the Main Package Screen. Then, on the screen displayed below, the user (1) chooses which package to copy from to their new package, (2) checks the box, and (3) hits the green check mark. It is very important that the user ensure they **DO NOT** choose to copy from one pre-existing package over another, as that **WILL** change the contents of the other package, leaving it mislabeled. Please ensure you have checked only the boxes to copy over your newly created package.



The user can then finish the new package copying process by clicking “Copy New Package” on the Main Package Screen, as pointed two four figures above by the **red** arrow.

The user may now edit this new package by changing any of its underlying measures, equations, etc. For example, for the “New Residential Package” created above, the user may select this case as one to be evaluated (see Section 3.3), then change e.g. measures associated with that package by entering one of the associated sectoral tables, as shown below. The user should ensure they change the correct package by toggling to the name of their newly created package on the “Active Packages” list in the red box below. By selecting any of the drop down menus (example pointed to by black arrow), the user can then change the package’s measures.



Finally, the user can associate this package with a scenario by creating a new scenario (see 4.1) and selecting this package as one of the packages associated with that scenario (see 4.2).

4.4 Evaluating Results

Results of a user-defined case are obtained and evaluated in the same way as results of a pre-defined case. See section 3.3-3.5.

5. Model changes in version 2.3.2

The following model updates and fixes were made in the California PATHWAYS release version 2.3.2. These changes from the prior version 2.3.1 fix small bugs in the code and allow the tool to be compatible with the most recent version of Analytica (version 4.6 at the time of this writing). These changes do not substantively change the model results. The only change to the model results is a small (less than 1%) reduction in the Reference scenario industrial sector technology stock cost results. The changes are described below:

1. Froze "Current_Year" variable to 2014, rather than allowing "Current_Year" variable to update based on actual calendar year date.
2. Updated Normalized Market Share variables to avoid a "divide by zero" error by checking to see if the denominator is 0 and returning zero if that is the case

- Normalized_market_s1
- Normalized_market_sh

3. Updated trajectory years used for linear interpolation to ensure that they are increasing across the entire index (previous code defined years for which there was no data entered as "max(Year) + 1", we have updated this to be "max(Year)+RPS_dummy_index"

- Market_Share_Years2
- Market_Share_Years1

While the linear interpolation function calculated the correct endpoint value in 2050 in v4.5, it was returning an error in v4.6. We were able to fix this by replacing the years outside of the interpolation window with increasing values and converting the NANs to zero.

4. VARIABLE NAME: Cost_Sens_IND. Problem: Misindexed table. Active_Cases=ActivePack2Case_IND was returning a single dimensional list rather than an array. Code is now fixed.
5. VARIABLE NAME: Electric_Appliance_M. Problem: Null values (from efficiency options that were available in the reference scenario but not in other scenarios) preventing calculation of electric appliance market share for Com Space Heating. Code is now fixed.
6. Code that exports data to .CSV files is updated to eliminate rounding values of exported data