HOMER® Pro Version 3.7
User Manual

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HOMER® Energy
1790 30th St Suite 100
Boulder CO 80301 USA
+1-720-565-4046
www.homerenergy.com

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1. Welcome to HOMER

What is HOMER?

HOMER (Hybrid Optimization of Multiple Electric Renewables), the micropower optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. When you design a power system, you must make many decisions about the configuration of the system: what components does it make sense to include in the system design? How many and what size of each component should you use? The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.

How do I use HOMER?

To use HOMER, you provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that you can view as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help you compare configurations and evaluate them on their economic and technical merits. You can export the tables and graphs for use in reports and presentations.

When you want to explore the effect that changes in factors such as resource availability and economic conditions might have on the cost-effectiveness of different system configurations, you can use the model to perform sensitivity analyses. To perform a sensitivity analysis, you provide HOMER with sensitivity values that describe a range of resource availability and component costs. HOMER simulates each system configuration over the range of values. You can use the results of a sensitivity analysis to identify the factors that have the greatest impact on the design and operation of a power system. You can also use HOMER sensitivity analysis results to answer general questions about technology options to inform planning and policy decisions.

How does HOMER work?

Simulation

HOMER simulates the operation of a system by making energy balance calculations in each time step of the year. For each time step, HOMER compares the electric and thermal demand in that time step to the energy that the system can supply in that time step, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides in each time step how to operate the generators and whether to charge or discharge the batteries.

HOMER performs these energy balance calculations for each system configuration that you want to consider. It then determines whether a configuration is feasible, (i.e. whether it can meet the electric demand under the conditions that you specify), and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest.

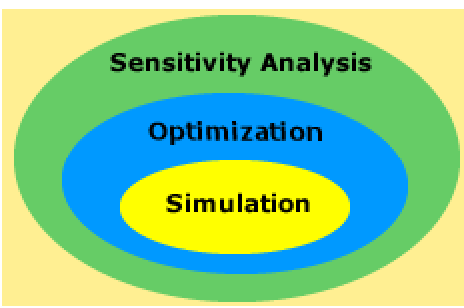
Optimization

HOMER Pro has two optimization algorithms. The original grid search algorithm simulates all of the feasible system configurations defined by the Search Space. The new HOMER Optimizer? uses a proprietary derivative free algorithm to search for the least cost system. HOMER then displays a list of configurations, sorted by net present cost (sometimes called lifecycle cost), that you can use to compare system design options.

Sensitivity Analysis

When you define sensitivity variables as inputs, HOMER repeats the optimization process for each sensitivity variable that you specify. For example, if you define wind speed as a sensitivity variable, HOMER will simulate system configurations for the range of wind speeds that you specify.

1.1 Solving Problems with HOMER



HOMER simplifies the task of designing distributed generation (DG) systems - both on and off-grid. HOMER's optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs and energy resource availability.

Working effectively with HOMER requires understanding of its three core capabilities - *simulation*, *optimization*, and *sensitivity analysis* - and how they interact.

Simulation**,** Optimization**,** Sensitivity Analysis

Simulation: At its core, HOMER is a simulation model. It will attempt to simulate a viable system for all possible combinations of the equipment that you wish to consider. Depending on how you set up your problem, HOMER may simulate hundreds or even thousands of systems.

Optimization: The optimization step follows all simulations. The simulated systems are sorted and filtered according to criteria that you define, so that you can see the best possible fits. Although HOMER fundamentally is an economic optimization model, you may also choose to minimize fuel usage.

Sensitivity analysis: This is an optional step that allows you to model the impact of variables that are beyond your control, such as wind speed, fuel costs, etc, and see how the optimal system changes with these variations.

HOMER models both conventional and renewable energy technologies:

Power sources in HOMER:
. solar photovoltaic (PV)
. wind turbine
. generator: diesel
. electric utility grid
. traditional hydro
. run-of-river hydro power
. biomass power
. generator: gasoline, biogas, alternative and custom fuels, cofired
. microturbine
. fuel cell

Storage in HOMER:
. flywheels
. customizable batteries
. flow batteries
. hydrogen

Loads in HOMER:
. get started quickly with the HOMER Quick Load Builder and built-in profiles
. daily profiles with seasonal variation
. deferrable (water pumping, refrigeration)
. thermal (space heating, crop drying)
. efficiency measures

See also:
3.1 Simulation Results
3.2 Optimization Results
3.3 Sensitivity Results

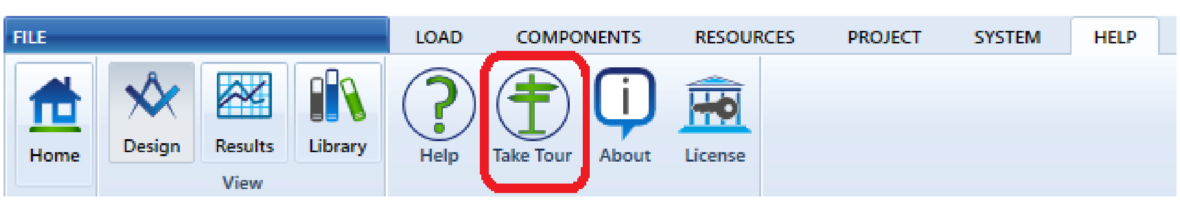
1.2 The HOMER Knowledgebase

The Knowledgebase is a searchable database of questions from HOMER users concerning system modeling, training, downloads and licensing. Questions are addressed by HOMER support experts.

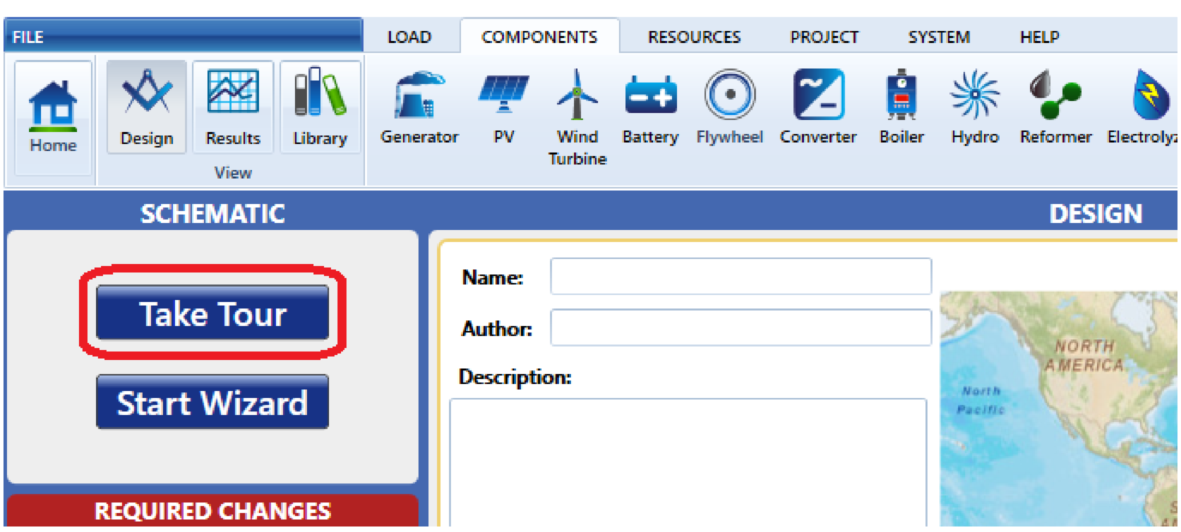
The Knowledgebase can be accessed online at **http://support.homerenergy.com/index.php?/Knowledgebase/List**

1.3 Tour

HOMER® Pro can help you design the best micropower system to suit your needs. This tour is intended to help you get started quickly with the software.



The tour is available from the Help toolbar any time (above) or via a large button on the schematic when you first start a new project (below).



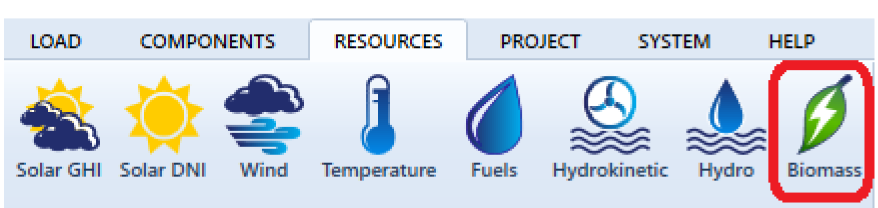
The tour is intended to get you started in HOMER Pro quickly by walking through one way to run an analysis. It is not intended to replace the study of how power systems operate or to cover all areas of HOMER. It should provide you with basic familiarity of the interface.

1.4 Add-on Modules

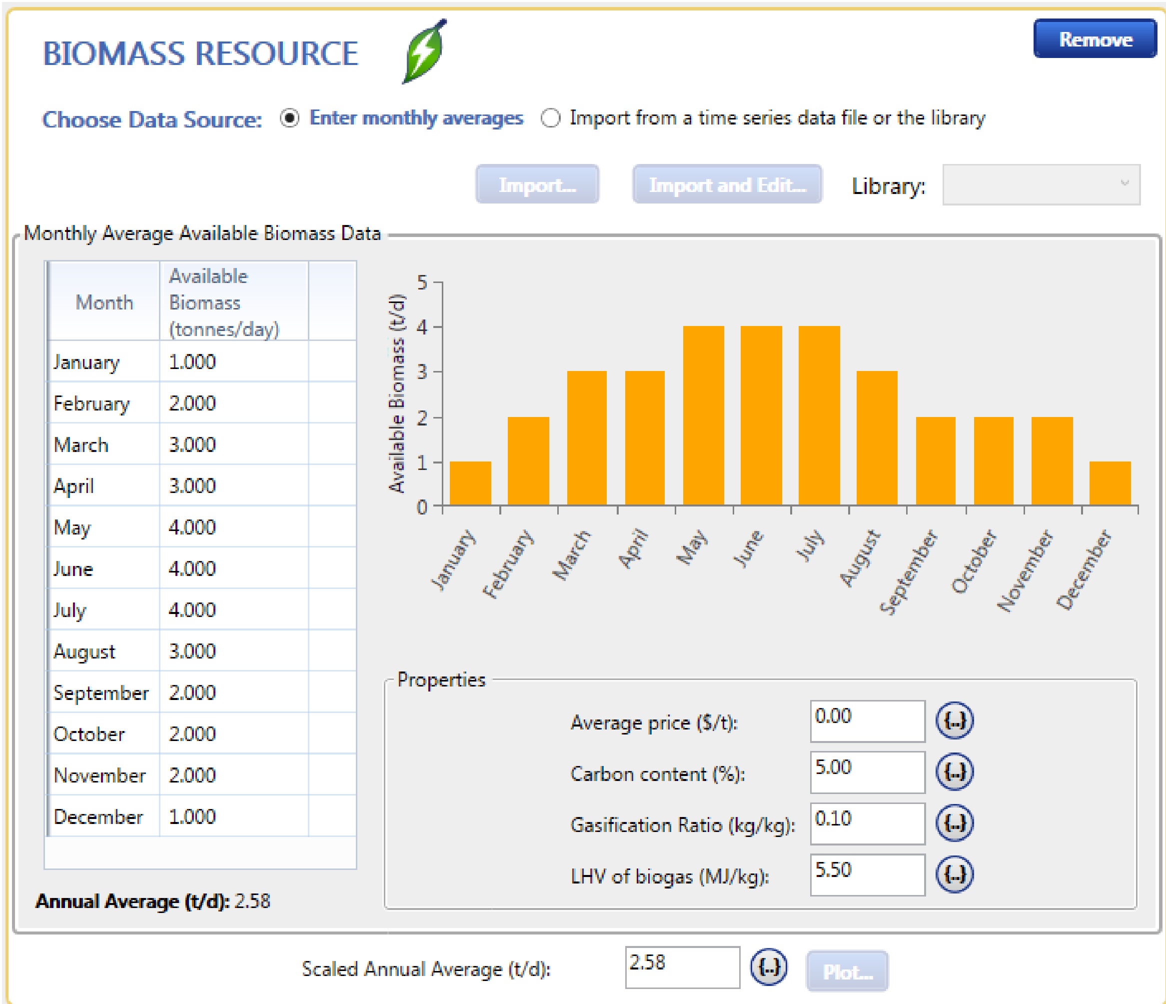
Several add-on modules are available that add advanced functionality to HOMER Pro. New modules will become available as they are developed. The table below lists the currently available modules.

Module	Features
Biomass	**Biomass resource**, bio-gas fuel, bio-gas and co-fired generator.
Hydro	**Hydro component** and **hydro resource**.
Combined Heat and Power	**Thermal load**, **boiler**, **thermal load controller**, and generator heat recovery ratio.
Advanced Load	Additional **electric load** and **deferrable load**.
Advanced Grid	**Real time rates**, time of use pricing (called **scheduled rates** in HOMER), **grid extension** models, and demand charges.
Hydrogen	Includes the **reformer**, **electrolyzer**, **hydrogen tank**, and fuel cell (**generator** fueled by stored hydrogen) components, as well as the **hydrogen load**.
Advanced Storage	Unlocks the **Modified Kinetic Battery Model** with rate dependent losses, temperature effects on capacity, degradation due to cycling, and temperature effects on degradation. Battery degradation effects are best modeled with the **Multi-Year Module**.
Multi-Year	Model price escalation or variation of the grid or fuel, load growth, changing economic incentives, battery degradation, and PV degradation.

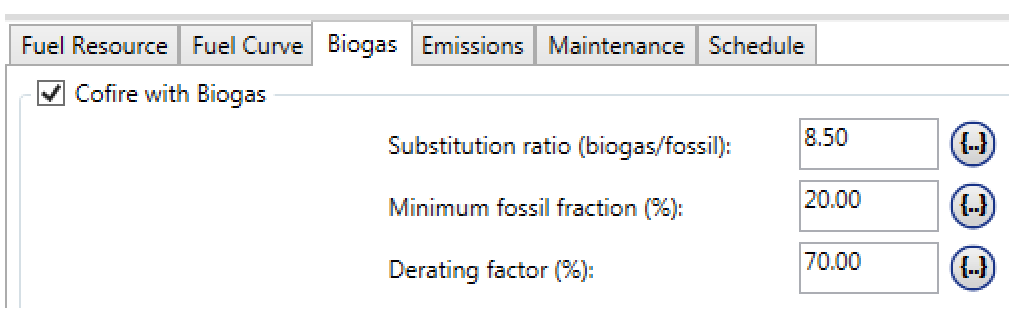
1.4.1 Biomass Module



The Biomass module allows you to model biomass gasification and biogas fueled or cofired generators. It adds the biomass resource, the biogas fuel, and the biogas fueled or biogas co-fired generator. The Biomass module can support users who model systems running on most types of biomass feedstock and gasification process.



You can specify the availability and cost of the biomass feedstock in the Biomass Resource menu. Since raw biomass generally can't be used in a generator, it is first converted to biogas through a process called gasification. The parameters of this process can be specified here. The biogas can be burned in a biogas or co-fired generator like any other fuel.

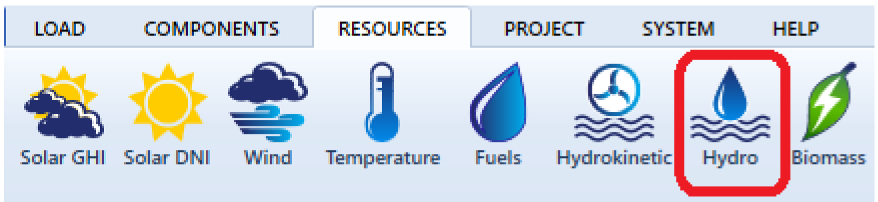


A cofired generator can operate on a mixture of traditional fuel and biogas. You can specify a cofired generator in the "Biogas" tab of the generator menu by checking the option for "Cofire with Biogas".

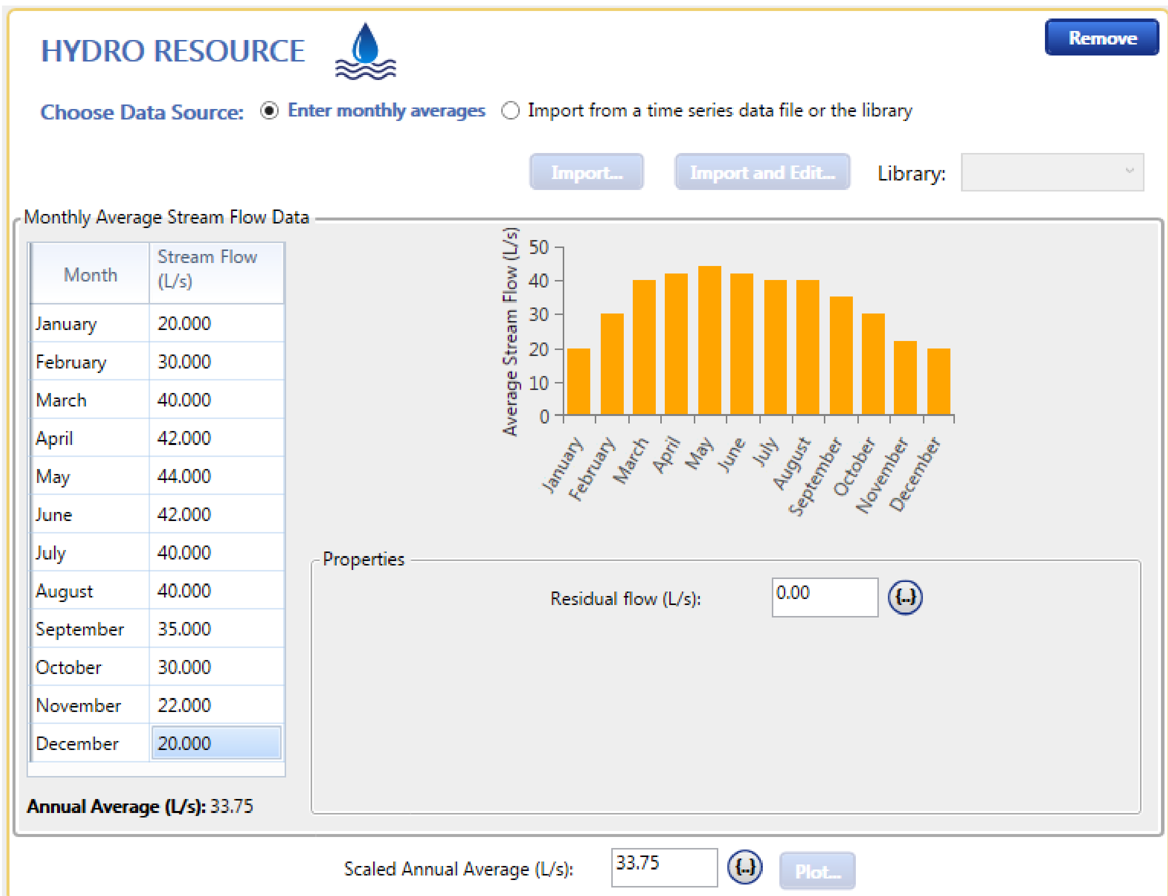
See also:

2.2.1 Generator
2.3.8 Biomass Resource
7.20 Biogas

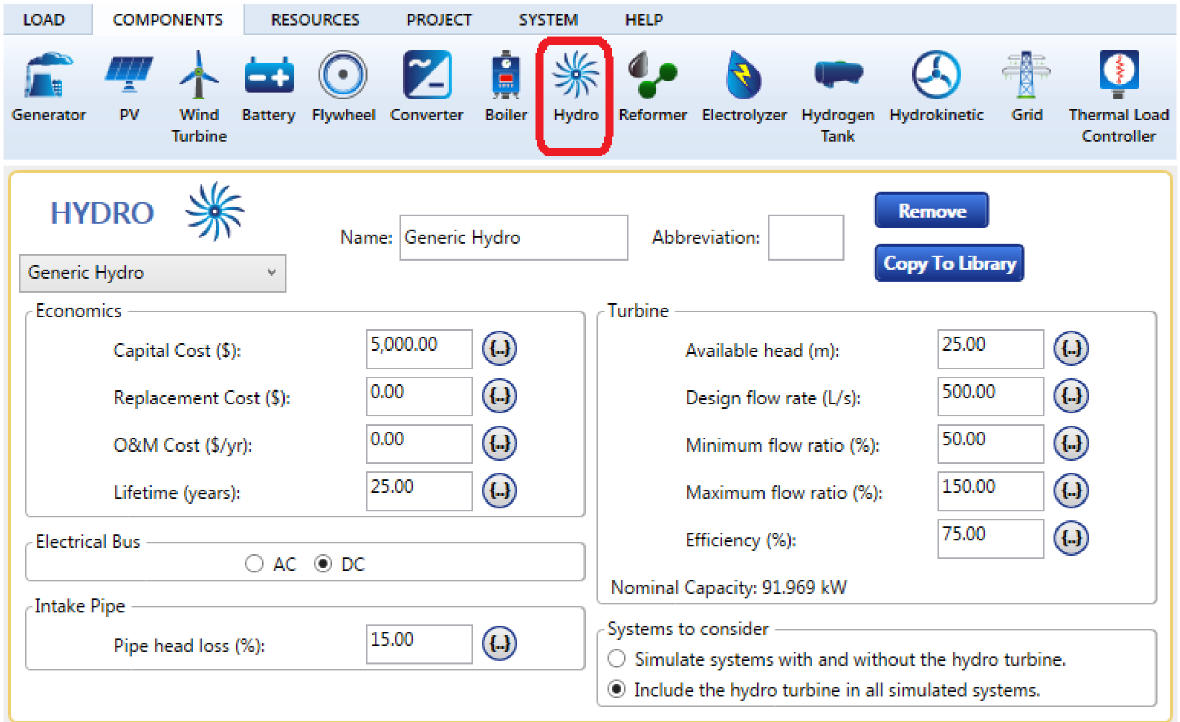
1.4.2 Hydro Module



The Hydro module adds the hydro resource and the hydro component. You can specify the stream flow in the Hydro resource, either as twelve monthly values, or as an imported time series. The Hydro module is ideal for users who model systems that include conventional, small, or micro hydroelectricity generation. For run-of-river hydroelectricity, see the **Hydrokinetic** component.



You can specify the cost, available head, design flow rate, operating range, and losses of your hydro system in the hydro component menu.

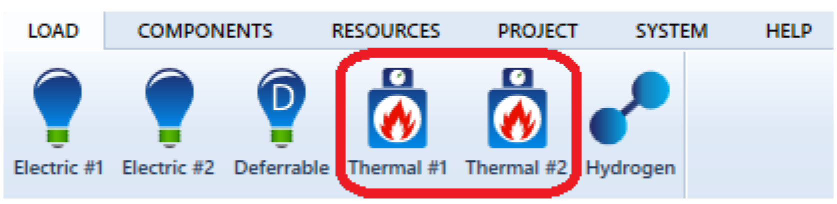


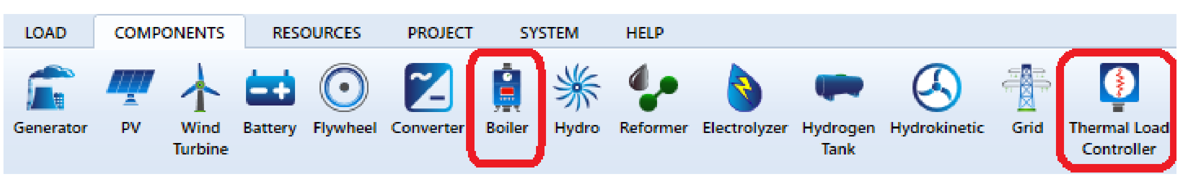
See also:

2.2.7 Hydro
2.3.5 Hydro Resource

1.4.3 Combined Heat and Power Module

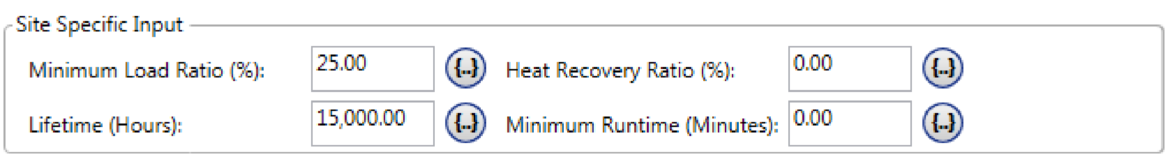
Users who model building heating, boilers, cogeneration and heat recovery, and any system that demands and/or supplies heat energy will need the Combined Heat and Power module.



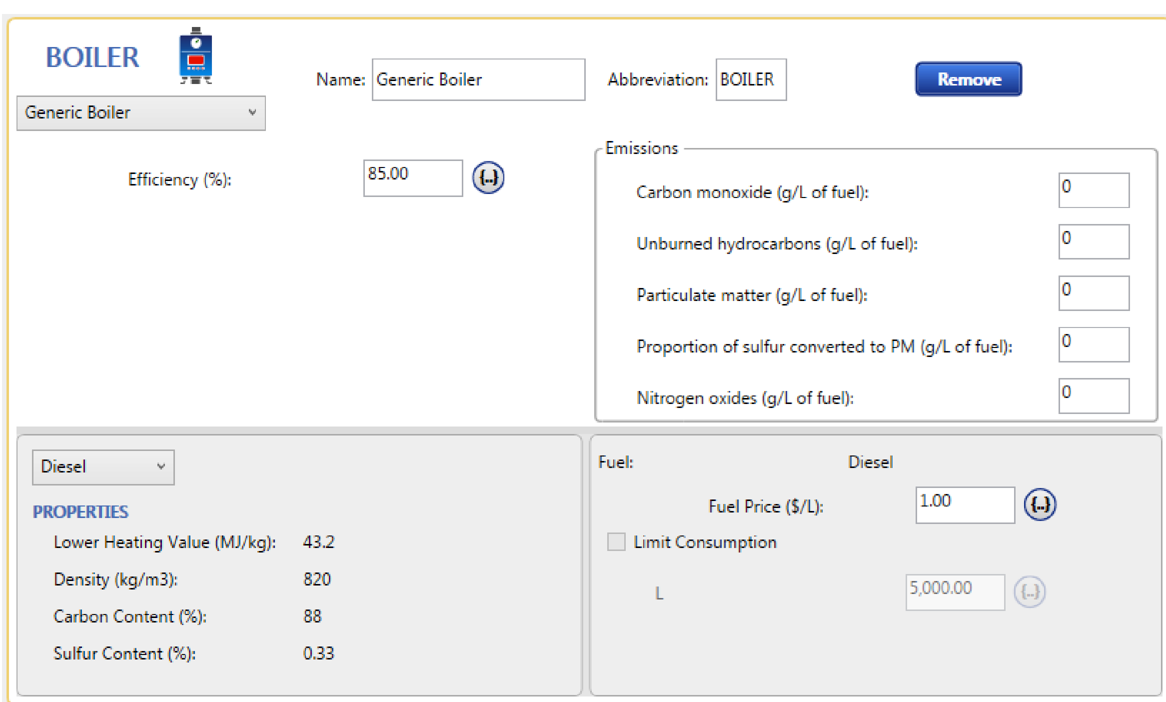


The Combined Heat and Power module adds two thermal loads, the thermal load controller, the boiler component, and the heat recovery ratio parameter in the generator menu.

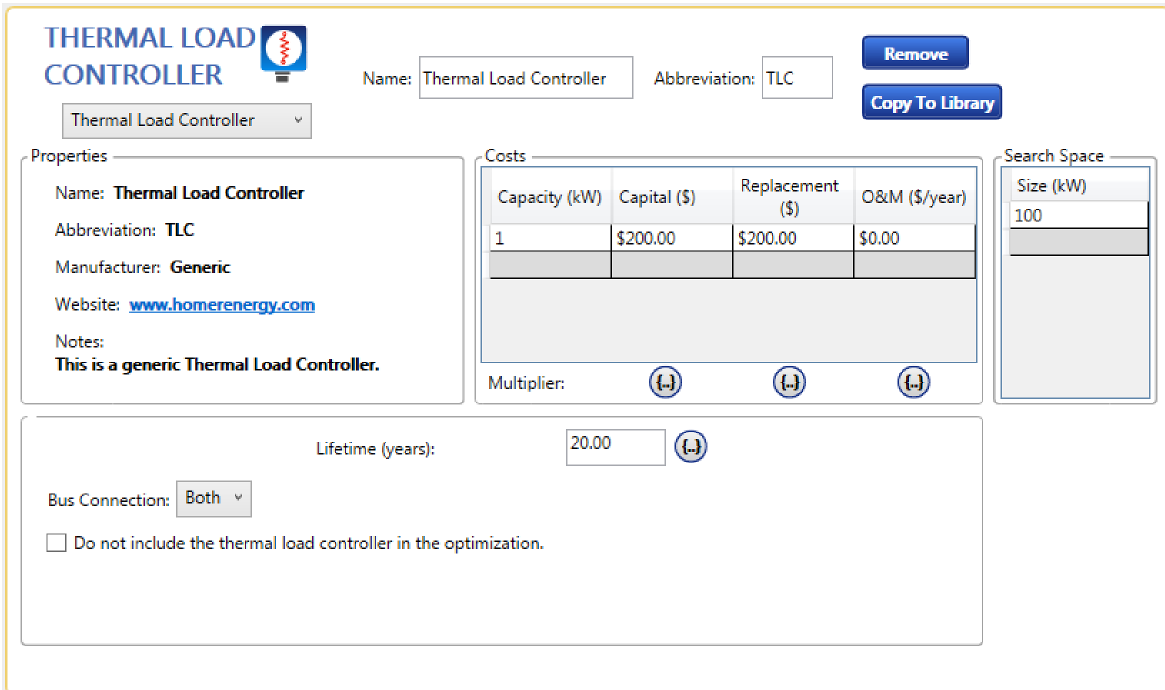
A thermal load can model a building, an industrial process, equipment such as a thermal absorption chiller, and any other system that consumes heat energy. The combined heat and power module adds the parameter "Heat Recovery Ratio" to the generator menu. To set up a combined heat and power system, set this parameter to a number greater than zero.



If you have a thermal load, you must add a boiler. HOMER does not account for capacity shortage of the thermal load, and so any portion not met will be supplied by the boiler. This is also why the capacity of the boiler is unlimited.



The thermal load controller converts extra electricity into heat. The option "do not include thermal load controller in the optimization" will ignore the costs of the thermal load controller and will allow unlimited capacity.

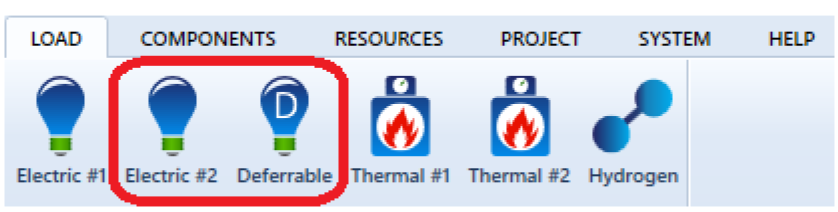


See also:

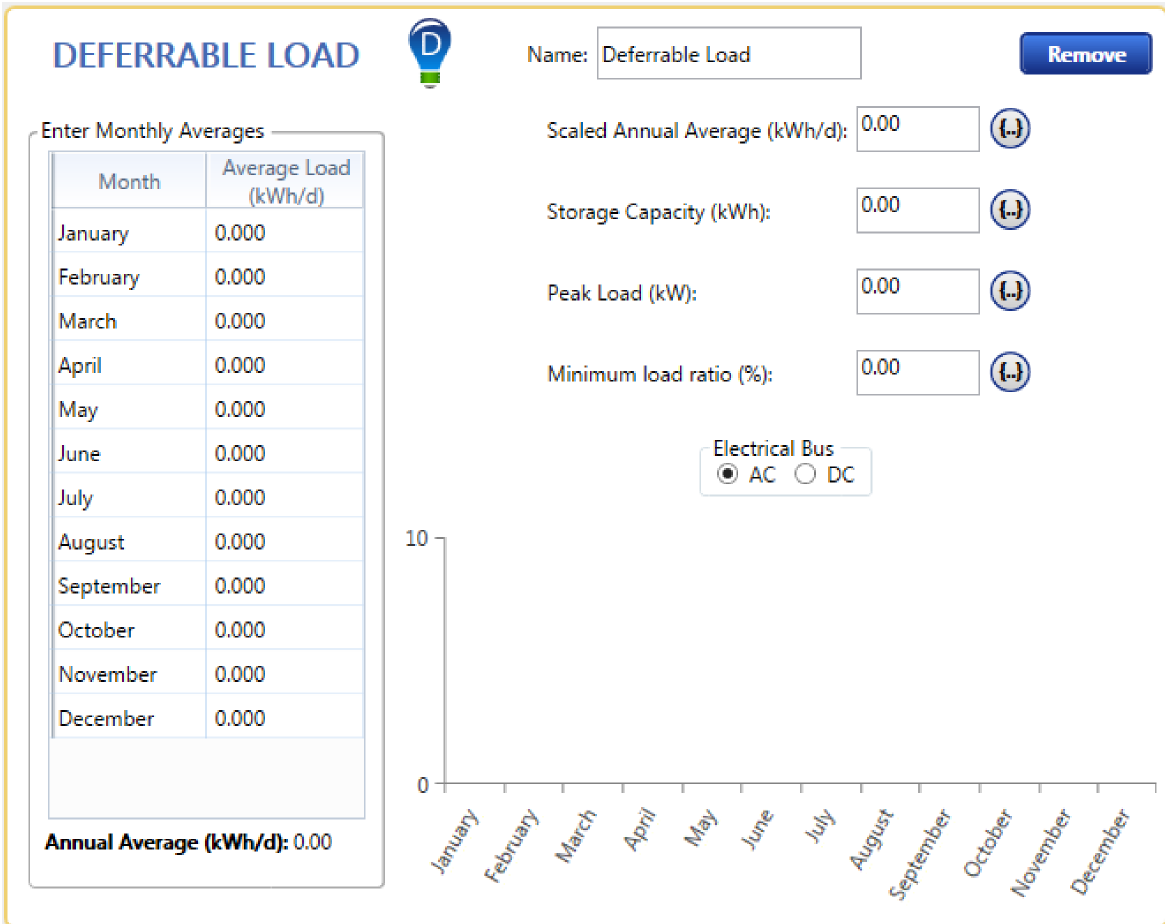
2.1.4 Thermal Load
2.2.1 Generator
2.2.6 Boiler
2.2.9 Thermal Load Controller

1.4.4 Advanced Load Module

Users who create models with both AC and DC loads, or who want to model deferrable loads such as pumping or HVAC should use the Advanced Load module.



The Advanced load module adds a second electric load and the deferrable load. Deferrable loads are loads that need a certain amount of energy supplied, but can wait until power is available and don't need to be supplied at any specific moment.

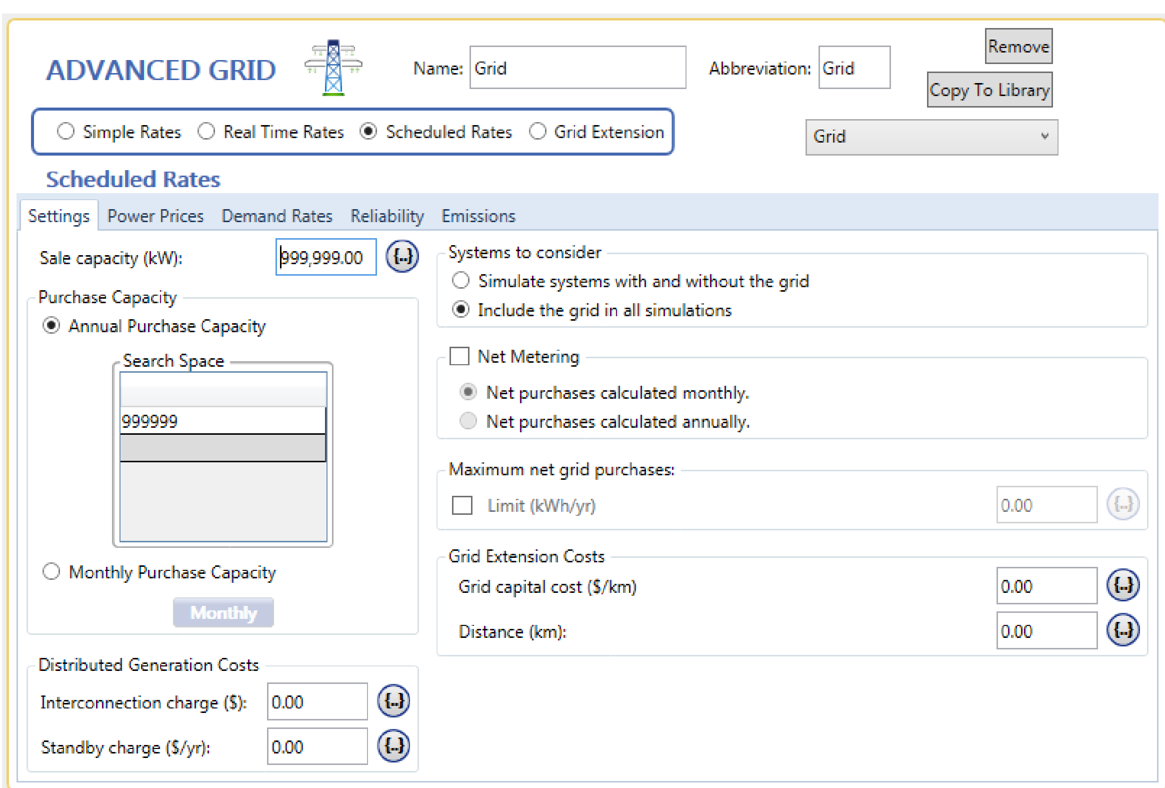


See also:

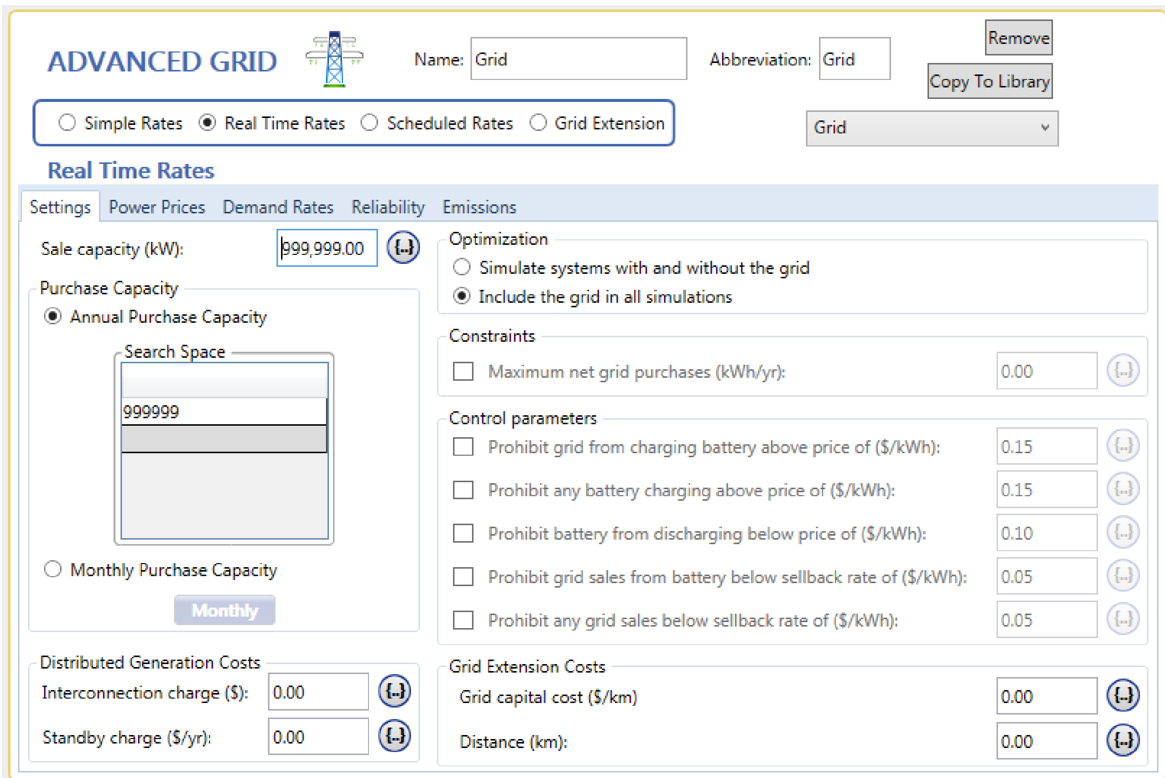
2.1.5 Deferrable Load

1.4.5 Advanced Grid Module

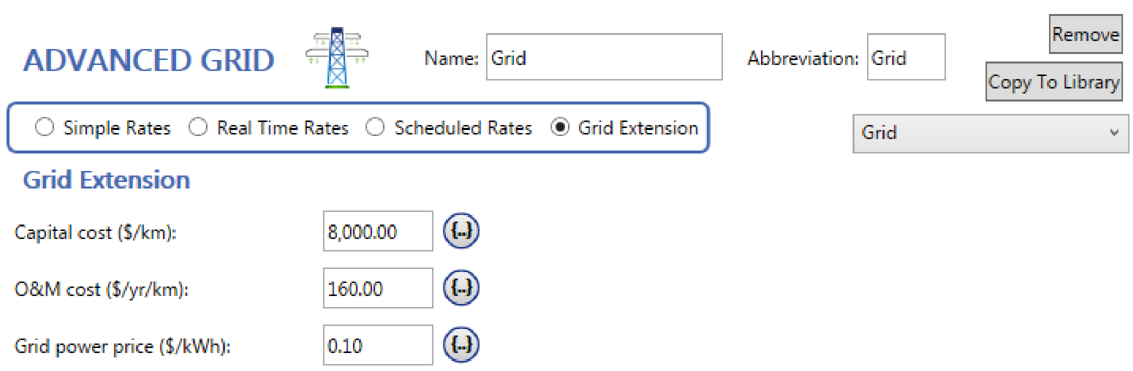
The Advanced Grid module is ideal for users who will model grid-connected systems with varying grid prices, detailed grid specification, or off-grid systems where grid extension is a possibility. This module allows you to model grid connected systems with real time or scheduled pricing, grid extension analysis, and grid outages. This module adds real time rates, scheduled rates, grid extension, and reliability menus to the grid.



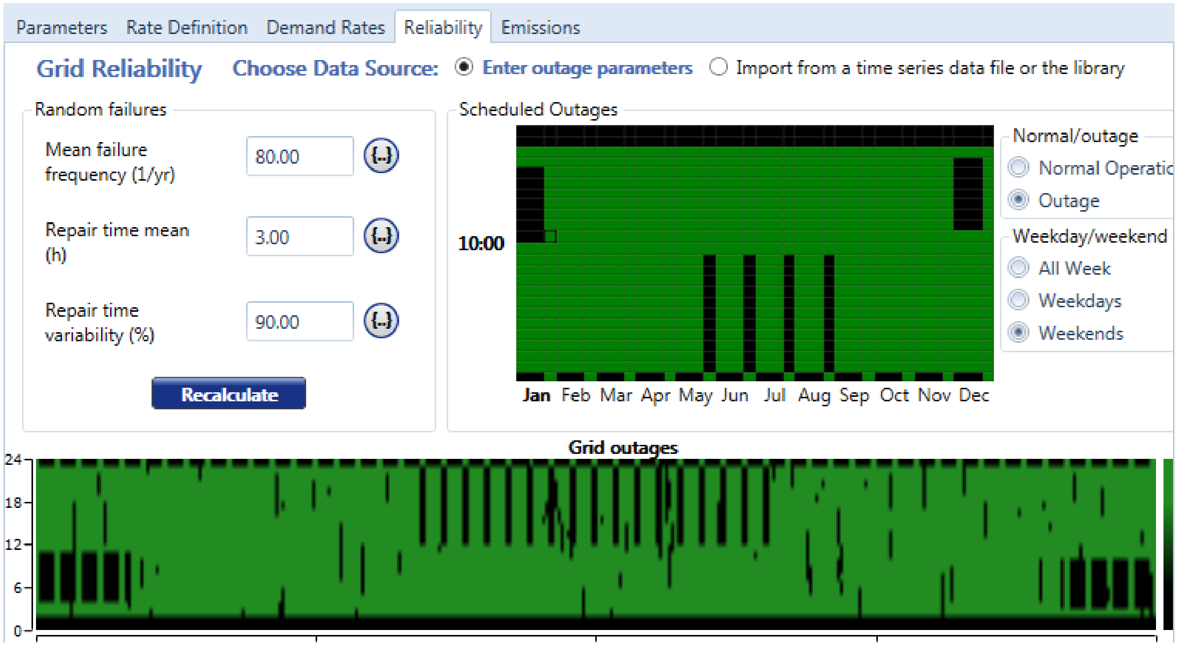
The Advanced Grid module also adds the following options: interconnection charge, standby charge, sale capacity, purchase capacity, and maximum net purchases. It also adds the option for net metering, and several advanced control parameters to adjust when the dispatch decides to buy or sell power and charge or discharge batteries based on the grid rate.



The Advanced Grid module can also perform an extension analysis, which compares the costs of grid extension with the costs of a standalone system. You can specify the capital cost and maintenance cost of grid extension in the grid extension menu.



Advanced Grid also includes the ability to model scheduled and random grid outages.



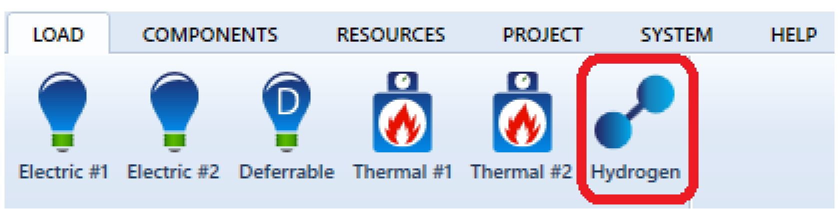
See also:

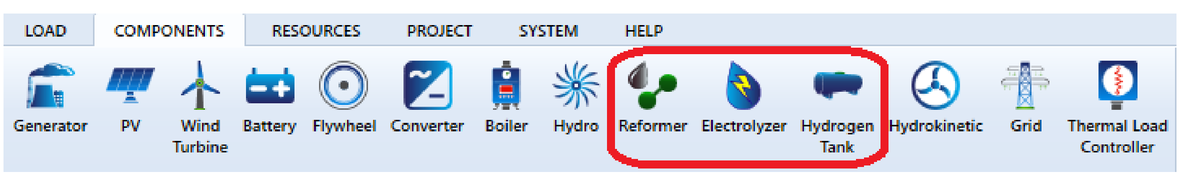
2.2.10 Grid

7.82 Grid Interconnection Charge

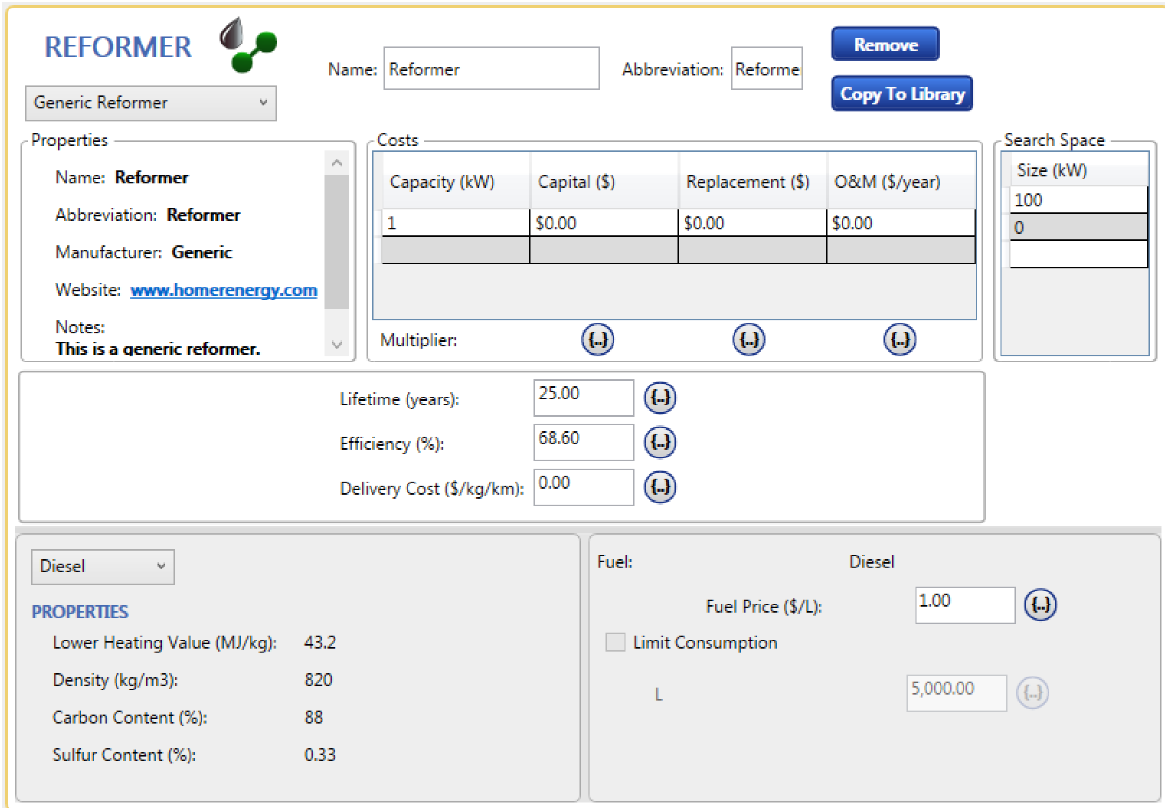
7.83 Grid Standby Charge

1.4.6 Hydrogen Module

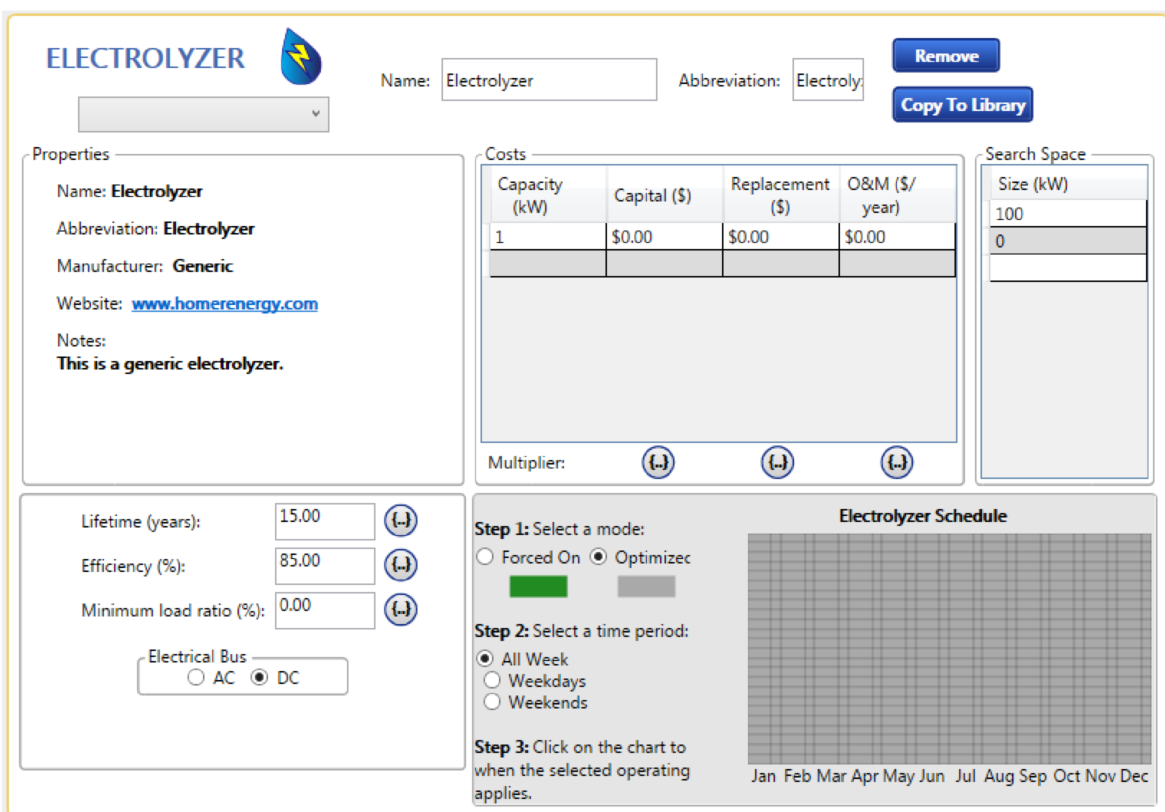


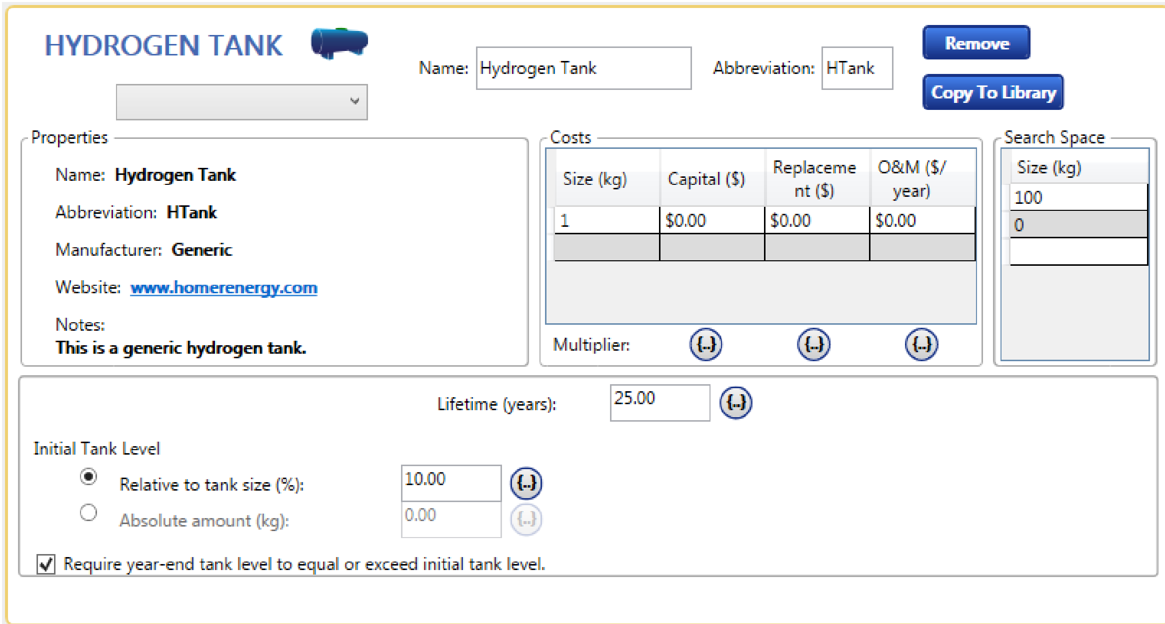


The Hydrogen module allows you to model systems that generate, store, and consume hydrogen. It is ideal for users who model fuel cells, remote off-grid operations, large industrial processes, or any system with hydrogen production, storage, or consumption.



This module adds the reformer, electrolyzer, and hydrogen tank components. It also adds the hydrogen load and stored hydrogen fueled generator.



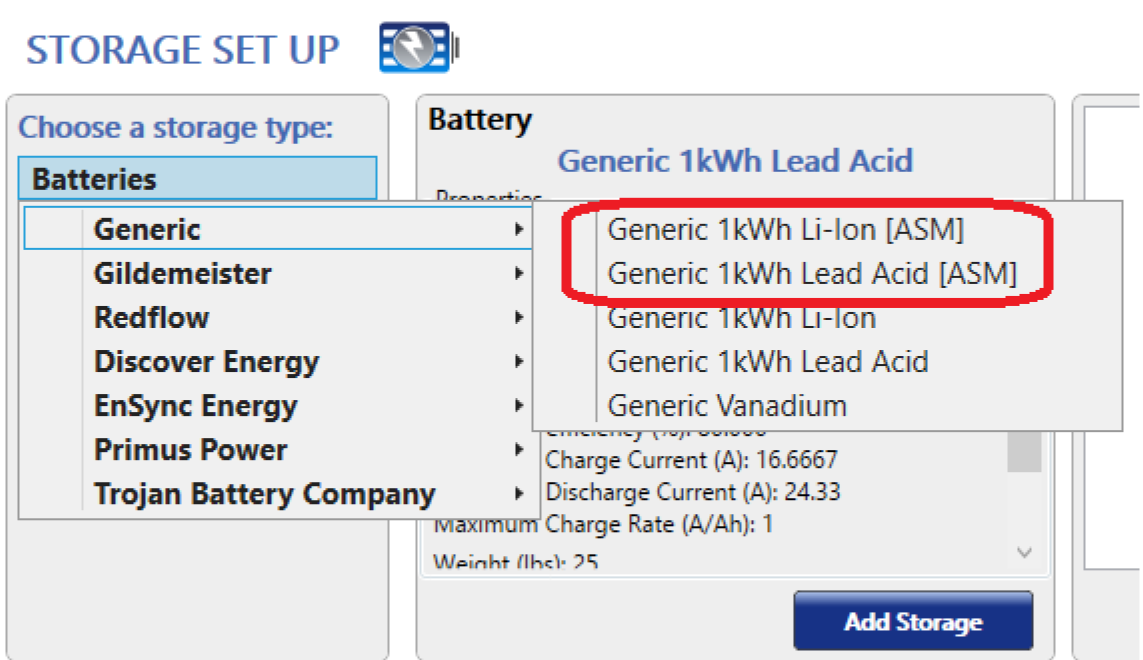


See also:

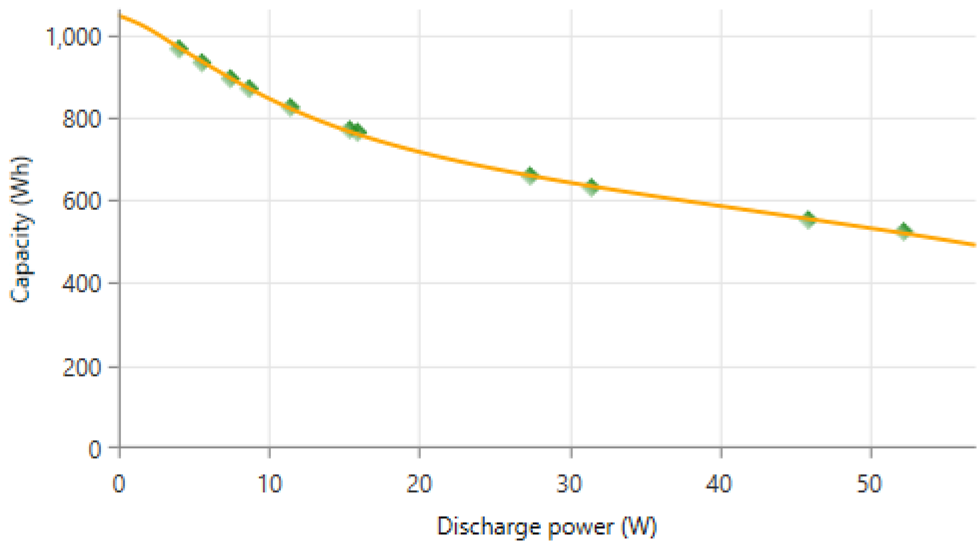
2.1.6 Hydrogen Load
2.2.11 Hydrogen Tank
2.2.12 Electrolyzer
2.2.13 Reformer
7.58 Fuel Cell

1.4.7 Advanced Storage Module

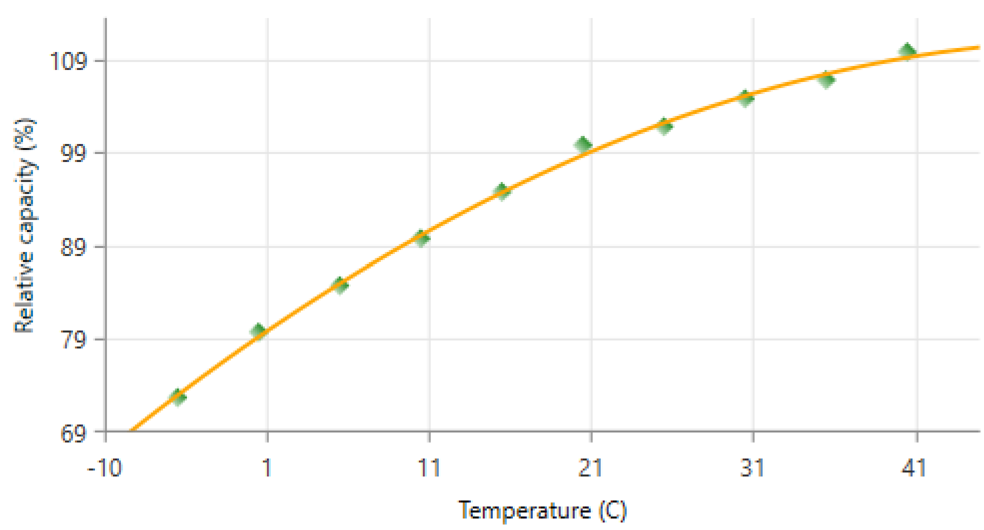
The Advanced Storage Module unlocks the Modified Kinetic Battery Model in HOMER. The Modified Kinetic Battery Model (MKBM) includes rate dependent losses, changes in capacity with temperature, variable depth-of-discharge for cycle life, and increased degradation rate at higher temperatures. With the Advanced Storage Module, you can create new batteries that use the MKBM, add such batteries to your HOMER models, and calculate results for HOMER models that include a battery with this feature.



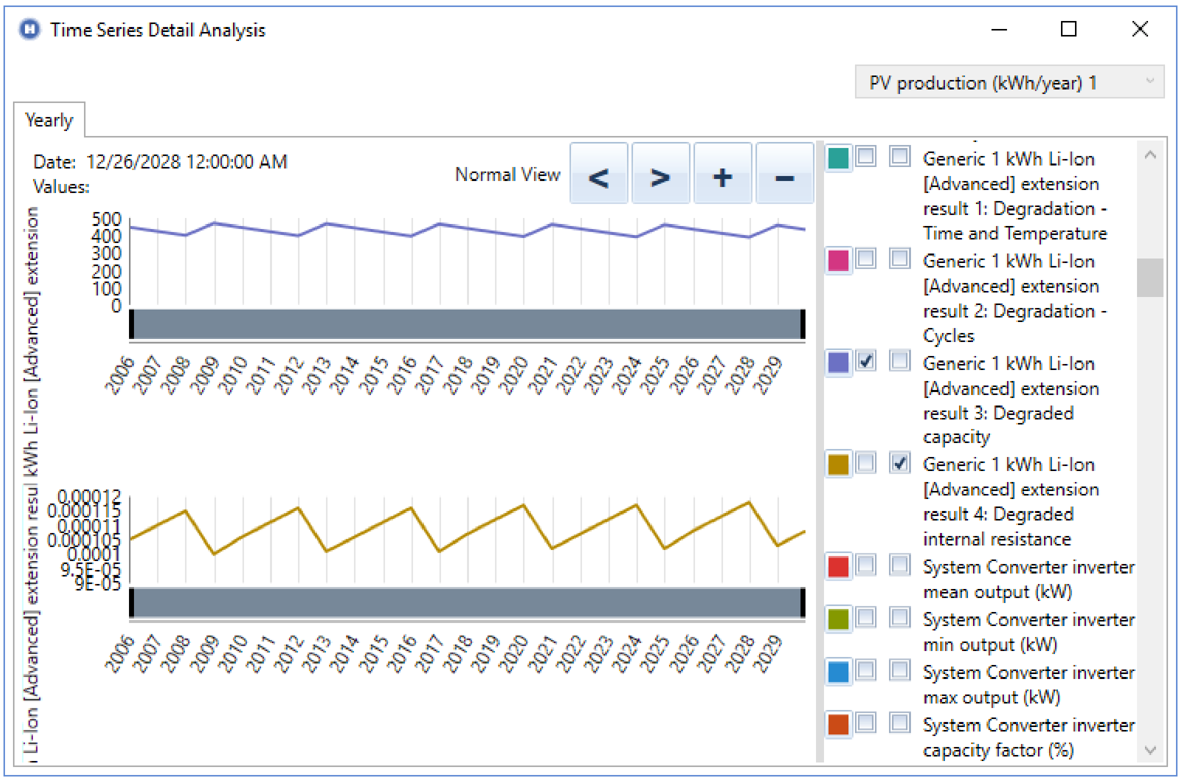
The MKBM is designed for practicality. Although the inner workings of the model are somewhat complicated, the parameters needed to design a battery with the MKBM are relatively simple. Some battery datasheets include all the necessary information. The MKBM adds a series resistance to the battery model, which improves model accuracy. For some batteries, in some conditions, this can better represent the true behavior.



The MKBM also includes variation in capacity with temperature. For example, many batteries show a decrease in available capacity at cold temperatures.



The Advanced Storage Module becomes more powerful when combined with the Multi-year module. When HOMER is run in Multi-year mode, the Modified Kinetic Battery Model includes performance degradation over the battery lifetime. This degradation calculation tracks temperature, time, and partial depth of discharge cycles over the course of the simulations.



See also:

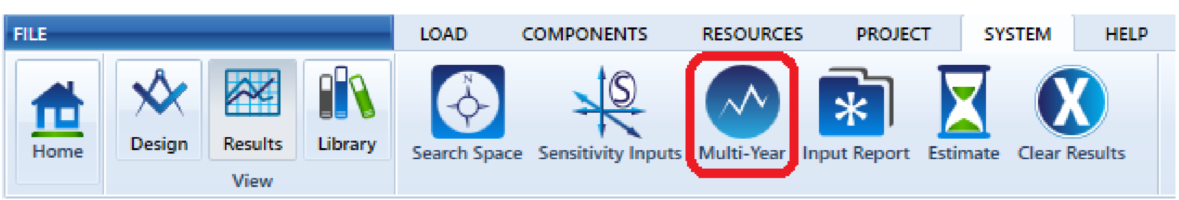
2.2.4 Storage

4.1.1.3 Creating a Modified Kinetic Storage Component

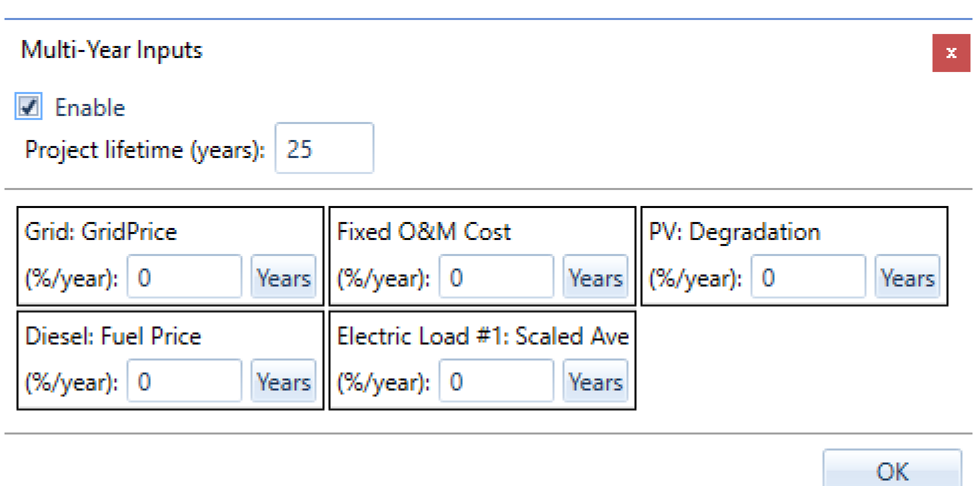
5.14 Modified Kinetic Battery Model

1.4.8 Multi-Year Module

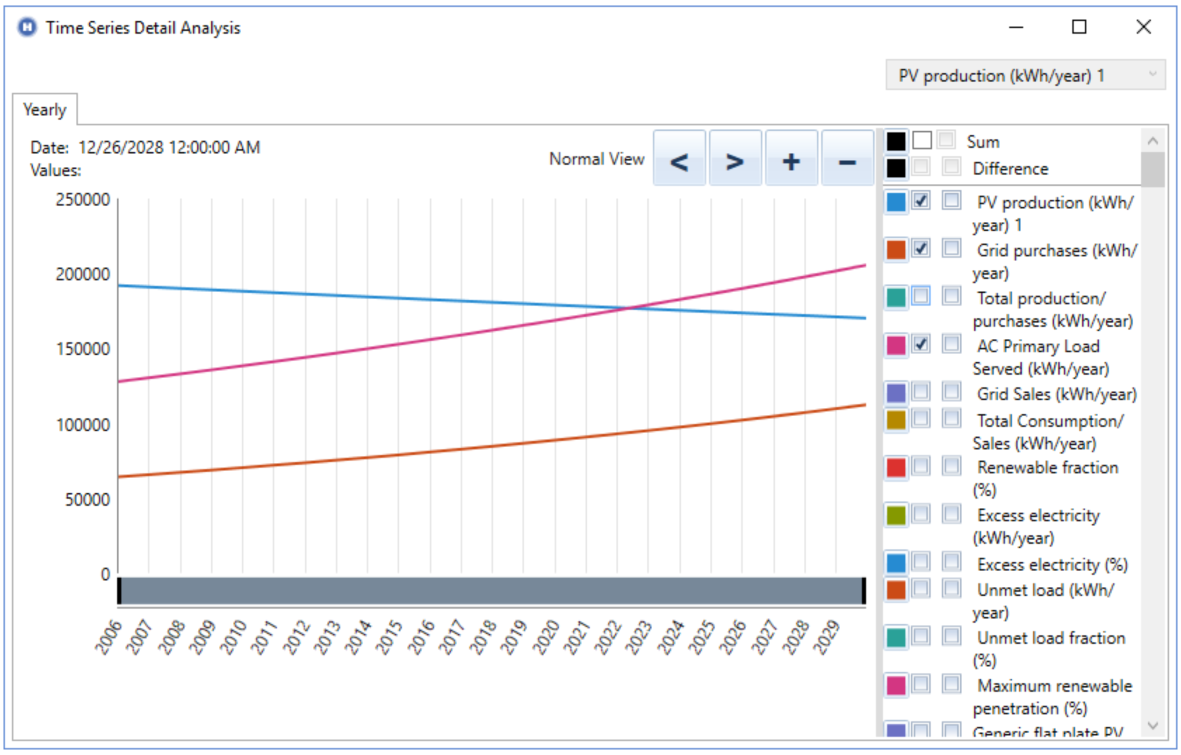
The Multi-Year module allows you to model changes that can occur over the lifetime of a project. PV degradation, grid price escalation, load growth, and fuel price escalation are a few of the model parameters that you can include in a HOMER model with the Multi-Year module.



The Multi-Year Inputs allow you to specify degradation or growth in terms of a percentage each year. You can also enter a year-by-year series of multipliers to match a forecast that isn't simply a percentage per year.



The Multi-Year module adds several features to HOMER's results. You can look at each year of the project life in the Simulation Results. The Multi-Year module also adds the Multi-Year plot, which allows you to plot any result quantity over the life of the project.



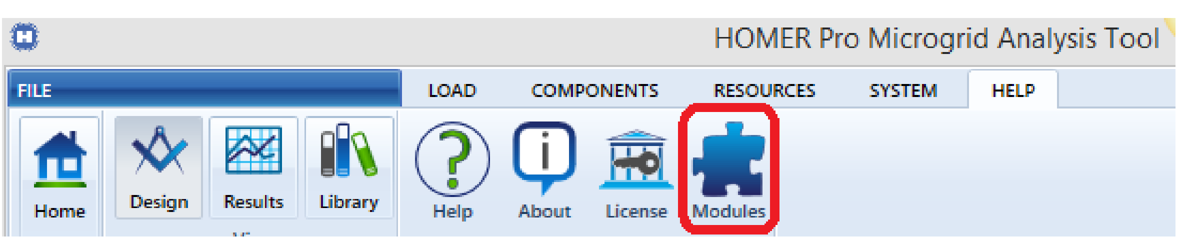
Using the Multi-Year module with the Advanced Storage module will unlock the full potential of both of these features. The Advanced Storage module includes the ability to model battery performance degradation over the battery lifetime. This aspect of the Advanced Storage module is only available if you have the Multi-Year module.

See also:

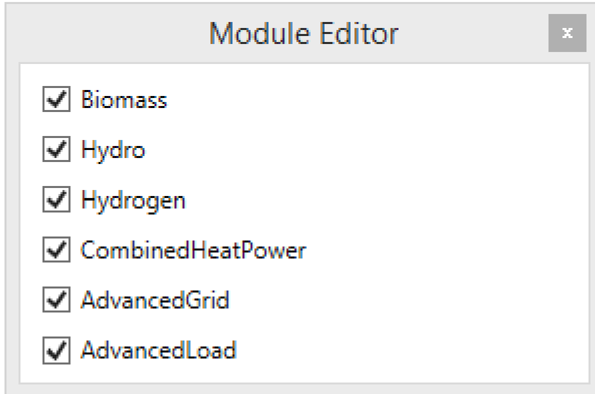
2.5.5 Multi-Year Inputs
3.1.24 Multi-Year Outputs

1.5 Free Trial License

A free 30-day evaluation license is available for all new HOMER Pro users. This evaluation includes all of the features of the full licensed product, plus one special added feature: the "Modules" button in the "Help" tab of the menu bar.



Select the "Help" tab of the menu bar, and then click on the "Modules" button. This brings up the module editor window, which is only available in the trial version. It allows you to add and remove modules as you please, in order to help you choose which modules you would like to include with a paid license.



This window is not available in the fully licensed version of HOMER Pro. You can purchase more modules for your full license at any time in the license menu (accessed through the "license" button in the help tab) with the "Add modules" button.

See the article titled **Add-on Modules** for more information about the different modules that are available.

1.6 Navigating HOMER

HOMER has three project views: **Design**, **Results**, and **Library**. When you first open HOMER, or when you load a new or existing project, the **Home** page is displayed.

The **Design** view is the next step. You can use the **Load**, **Components**, and **Resources** tabs to build your system while in the Design view. You can also use the **System** tab to change project parameters, check inputs, and change sensitivity and optimization variables.

Finally, when you click calculate, you will be taken to the **Results** view (also accessible from the Results button). Here you can review and plot the sensitivity cases, investigate optimal systems, and review the details of individual simulations.

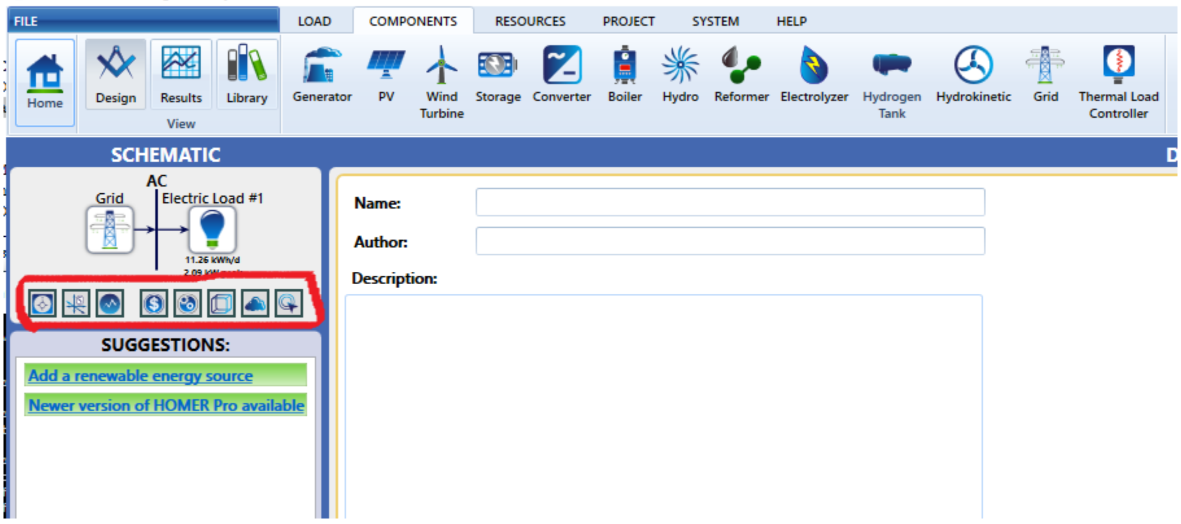
The **Library** button accesses your library, where you can save definitions for components, resources, loads, grid connections, and simulation configurations.

Home

When you open a file or start a new project, HOMER displays the Home page. On the Home page, you can display and edit metadata describing your project including project author, title and description. You can also assign a location for you project with the map. If you plan to add PV to your system, picking a location while on the Home page can streamline the process of adding PV and a solar resource.

2. Design View

Click the design button to display the design view, where the schematic is displayed and where you can add and edit loads, components, and resources. When you click the design button, HOMER will display the load, component, or resource you were last working on (or the home screen by default).



A row of small buttons provide shortcuts to several important menus. These are, from left to right, the **search space**, **sensitivity inputs**, **economics**, **system control**, **constraints**, and **emissions**.

The load, components and resources tabs continue to display when you are not in the design view (other views are the results view and the library view), and if you select any items from within these tabs, you will automatically be taken back to the design view.

2.1 Loads Tab

The Loads tab contains primary (electrical), thermal, and deferrable loads. This help topic explains several aspects of the process of specifying a load:

- **Adding a Load to the Model** - Instructions on how to add a load
- **Load Profile Menu** - Change load specifications after the load is added to the model
- **Primary Load**, **Thermal Load**, **Deferrable Load**, **Hydrogen Load** - More details on each load type

2.1.1 Adding a Load to the Model

You can add electric or thermal load data using exactly the same process, as described here. Measured load data is seldom available, so users often synthesize load data by specifying typical daily load profiles and then adding in some randomness. This process produces one year of hourly load data.

Electric Load Set Up

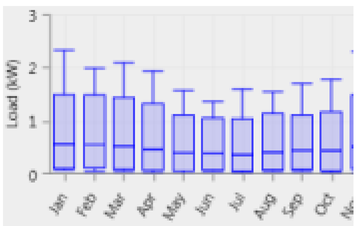
HOMER provides four methods to specify an electric load profile.

Create a synthetic load from a profile.

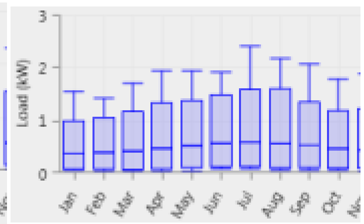
> This is a quick way to generate a load that can be relatively realistic. If you would like the load to have a cyclic annual variation, you can choose "January" or "July" as the peak month.

Choosing "None" will yield an annual profile that is uniform except for random variation.

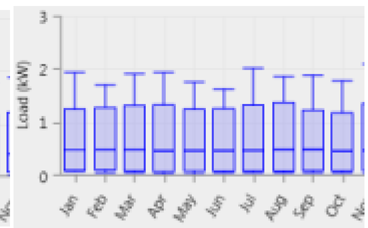
Peak Month: January



Peak Month: July

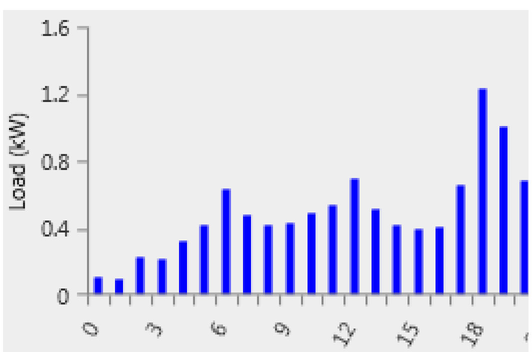


Peak Month: None

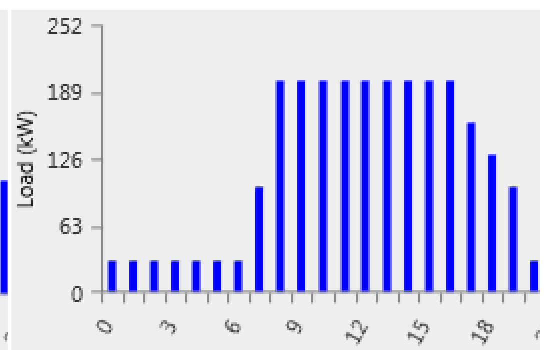


The drop-down menu contains a few pre-set load profiles: Residential, Commercial, Industrial, Community, and Blank. Blank is an empty template.

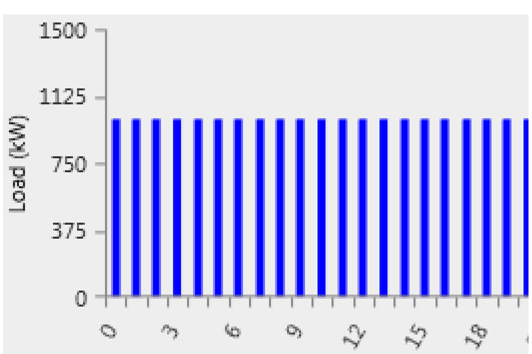
Residential



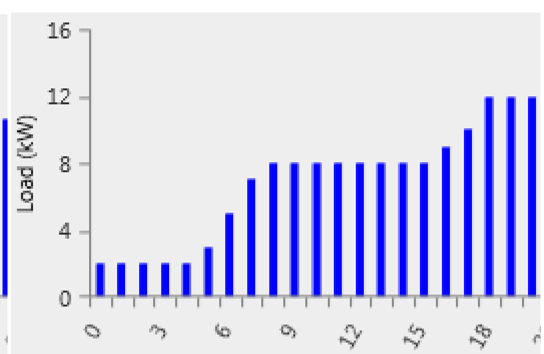
Commercial



Industrial

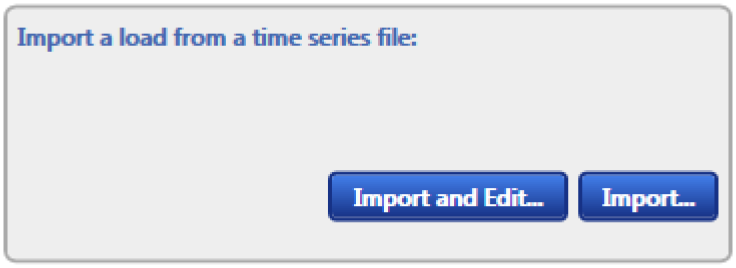


Community



These load templates all have different default overall magnitudes: 11.35, 2620, 24000, and 170 kWh/day, respectively. You can easily scale the average load of any of them to fit your application by changing the value for "Scaled Annual Average (kWh/day)".

Import a load from a time series file.



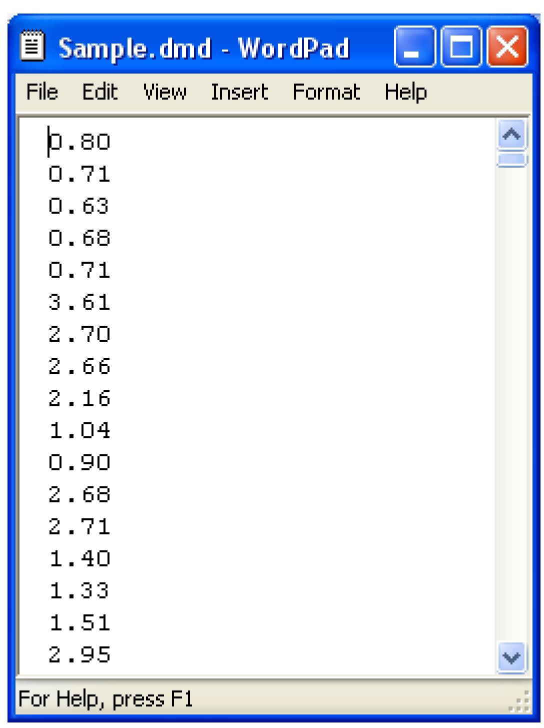
To import a file, you must prepare a text file that contains the electric load in each time step for a complete year.

Tip: You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average load (in kW) for that time step. The first time step starts at midnight on Sunday, January 1st. A sample input file appears below.

Tip: In HOMER, January 1st is always a Sunday.

The "Import..." button allows you to quickly import a simple time series file. "Import and Edit..." can import data files with gaps in the data or an incorrect number of rows. "Import and Edit..." includes basic gap-filling tools to fill in for missing data points.



Since the HOMER standard year starts on a Sunday, you might need to adjust your load time series to match. If any part of your HOMER model is sensitive to weekdays versus weekends (i.e. a grid rate schedule with different prices on weekends and weekdays), you may need to modify your load data so that the first day is a Sunday. Of course, natural resources in general will have no weekend/weekday bias (for example, wind speed is no higher or lower, on average, on weekends compared with weekdays). There are a few other ways your model could be sensitive to weekdays versus weekends:

- Imported grid outage time series with weekend or weekday bias
- Imported grid real-time rates with weekend/weekday differences
- Thermal, hydrogen, or other electric loads with weekend/weekday differences
- Imported biomass resource time series with weekend/weekday bias
- **Generators** and **electrolyzers** with an operation schedule (forced on, forced off, or optimized) with weekend/weekday differences

If none of the above conditions apply to your model, it may be safe to leave your load data as-is, even if it doesn't start on a Sunday. Otherwise, you can usually adjust your data to start on a Sunday by cutting a few days from the beginning of the load profile and pasting them at the end (or vice-versa). Keep in mind that if you view the hourly time series plot for your simulation, your load will be shifted by the number of days you moved.

When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.hmr) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates the average 24-hour load profile *for the whole year*, and displays it in the table and graph. HOMER also displays the name of the imported data file in the title of the load profile graph.

If you click Enter daily load profile(s) after importing data from a file, HOMER discards the data from the imported file and synthesizes new data based on the twelve monthly average load profiles it calculated from the imported data. You can edit synthesized data by selecting the month and changing values in the load profile table. To edit values from an imported file, you must edit the file directly and then import the modified file, as described above.

Build a synthetic load using measured data.

You can import load data for specific devices as a CSV file with 24 hours of data, either in hourly or minute-resolution. Refer to the chart below for appropriate formatting. The first row and first two columns are ignored, reserved for user row titles if desired. The second row (column 3 and onward, highlighted below in yellow) should contain descriptive names for each device. Row 3 through row 1442 (or row 3 through 26 for hourly data, below in orange) contains the load profile for each device in watts.

Note that HOMER will accept a mix of 1440-row and 24-row data columns in a single document. HOMER will infer the time step based on the number of rows of data for each column individually.

	A	B	C	D	E	F	G	H
1	Time (min)		0	1	2	3	4	
2	Coffee Pot	Coffee	1	857	1	1.1	1	1.
3	Microwave	Micro	1	0.8	1.1	1	0.9	1.
4	24" TV	TV 24	54.2	55.8	53.2	54.9	55.1	53.
5	15" Laptop 2	Laptop 15	15.2	16.1	15.8	35.8	31.5	15.
6	Refrigerator	Refr	0.2	0.3	0.1	0.2	65.6	66.
7	Fan	Fan	14.3	15.8	14.9	15.1	15.7	14.
8	Single LED Light 9 W		10.1	9.5	9.1	9.2	10.1	8.

Select the "Open Equipment Database" button in the upper right corner of the Load Designer menu, choose "Open...", and select your csv file. The load designer will import each column in the file as a separate device. You can drag and drop rows from the Equipment Database popup into the Load Designer. Once you are done, close the Equipment Database popup. You can now edit the quantities of each item, if desired. You can also set the "Jitter", which offsets the load profiles randomly so that load peaks in the duplicate devices (if set to quantity greater than one) will not always line up exactly.

Choose a load from the library.

Choose this option to retrieve load profiles from the **HOMER Library**.

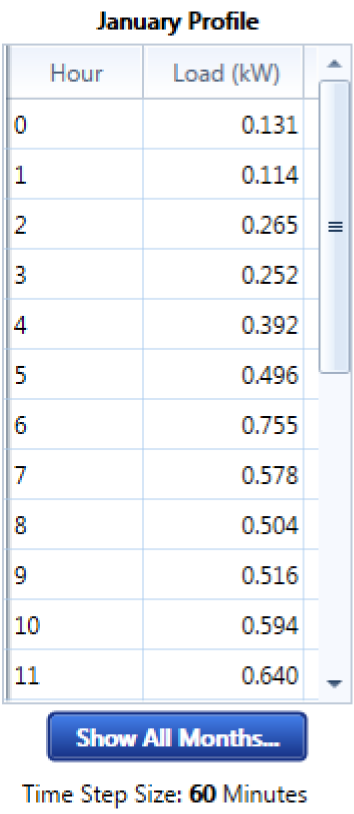
2.1.2 Load Profile Menu

Once you have created a load using one of the methods offered by the **Load Set Up**, you will be taken to the Load Profile Menu. You can return to this page by clicking on the corresponding load icon in the system schematic or through the Load tab at the top of the HOMER window. The options for electric and thermal loads are similar.

The load profile menu displays the load profile graphically and presents summary statistics for the data. You can modify some details of the load in this menu.

Hourly Data

You can modify the daily profile, hour-by-hour in the table on the left side of the menu.



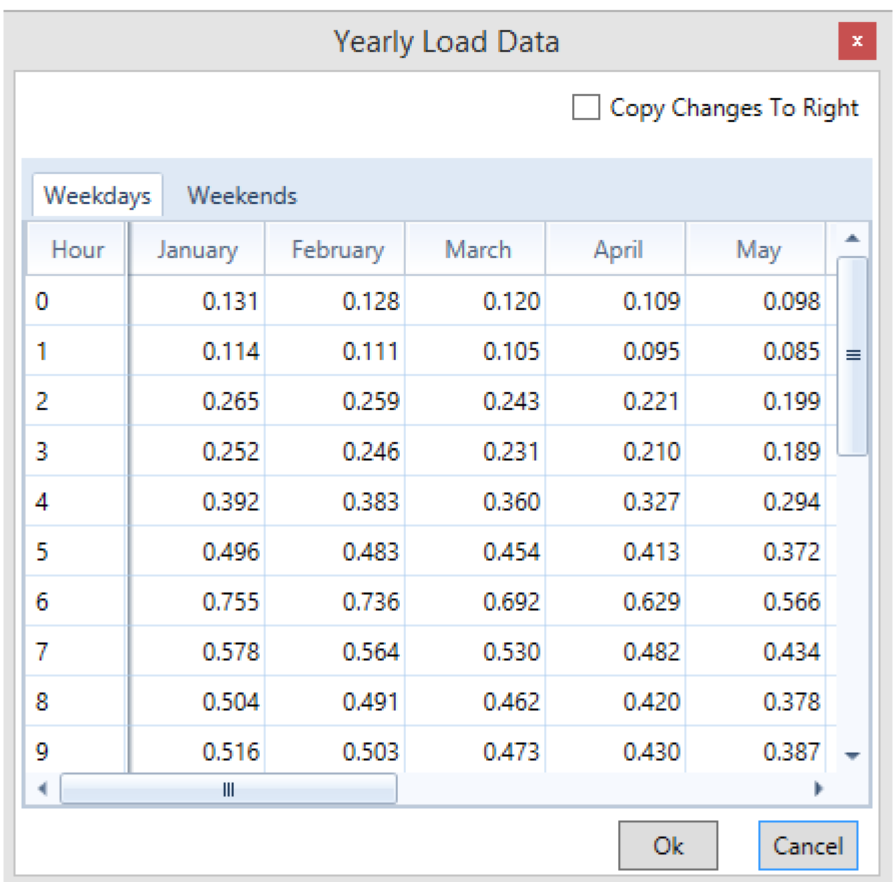
January Profile

Hour	Load (kW)
0	0.131
1	0.114
2	0.265
3	0.252
4	0.392
5	0.496
6	0.755
7	0.578
8	0.504
9	0.516
10	0.594
11	0.640

Show All Months...

Time Step Size: **60** Minutes

By clicking on "Show All Months..." you can set a different daily profile for weekends and weekdays and for each month of the year.



Yearly Load Data

Copy Changes To Right

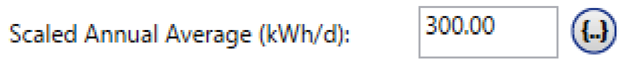
Weekdays | Weekends

Hour	January	February	March	April	May
0	0.131	0.128	0.120	0.109	0.098
1	0.114	0.111	0.105	0.095	0.085
2	0.265	0.259	0.243	0.221	0.199
3	0.252	0.246	0.231	0.210	0.189
4	0.392	0.383	0.360	0.327	0.294
5	0.496	0.483	0.454	0.413	0.372
6	0.755	0.736	0.692	0.629	0.566
7	0.578	0.564	0.530	0.482	0.434
8	0.504	0.491	0.462	0.420	0.378
9	0.516	0.503	0.473	0.430	0.387

Ok | Cancel

If you select "Copy Changes to Right", any value you enter will be copied across all remaining months. For example, if you enter "10" for January, hour 0, then all months, hour 0, will be set to 10. If you then enter "9" for hour 0 in February, January will stay set to 10 and February through December will be set to 9. You can edit values for weekends or for weekdays by selecting the tab at the top of the table. Changes made to the profile for weekends do not affect the profile for weekdays, and vice versa.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. Note that the average load is reported in kWh/day but the peak load is reported in kW.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion (eg. to convert from W to kW) or to perform a **sensitivity analysis** on the size of the thermal load. Click the sensitivities button (to the right of the text box) to enter multiple values for a sensitivity analysis.

The Export button allows you to export the scaled data to a text file.

Other options

Variable	Description
Random variability	Sets the daily or hourly variability used in **synthesizing artificial data**.
Load Type	Select whether the load is alternating current (AC) or direct current (DC)
Efficiency (Advanced)	Check this box to calculate cost-effectiveness of efficiency measures. The inputs below are enabled when the box is checked. *
Efficiency multiplier	The factor by which this primary load would be multiplied if the efficiency package was implemented. (Enter 0.80 for a 20% reduction in load.) *
Capital cost ($)	The cost of implementing efficiency measures, in $. *
Lifetime (yr)	The lifetime of efficiency measures, in years. *

*This input requires the Advanced Load module

See also

2.1.1 Adding a Load to the Model

2.1.2.1 Efficiency (Advanced)

This feature requires the Advanced Load Module.
Click for more information.

Use these inputs to analyze the cost-effectiveness of efficiency measures that reduce the electrical demand. For example, you might want to consider using fluorescent lights which are more efficient but also more expensive than incandescent lights. Using the Efficiency Inputs window, you could specify the cost of switching to fluorescent lights and the effect this would have on the size of the primary load. HOMER would then simulate each system both with and without the efficiency measures to see if their savings offset their cost.

The three variables used to define efficiency measures are as follows:

Variable	Description
Efficiency multiplier	The factor by which this primary load would be multiplied if the efficiency package was implemented. (Enter 0.80 for a 20% reduction in load.)
Capital cost	The amount of money required to implement the efficiency package.
Lifetime	The number of years over which the capital cost is annualized.

Example: Switching to LED lights would reduce the demand of a particular system by 80%, but would cost an additional $8000.
The LEDs are expected to last 20 years before they need to be replaced.
In this case, the efficiency multiplier would be 0.20, the capital cost would be $8000, and the lifetime would be 20 years.

The Efficiency inputs window is accessed by clicking on the **Electric Load** window.

See also

2.1.3 Electric Load

2.1.3 Electric Load

Primary load is electrical load that the system must meet immediately in order to avoid **unmet load**. In each time step, HOMER dispatches the power-producing components of the system to serve the *total primary load*.

The details of a load in a given system are sometimes not available, so HOMER can build (simulate) a load a few different ways (see **Adding a Load to the Model**). Once HOMER has created the load, you can edit it in several ways, including modifying individual time steps.

> **Note:** To the right of the Annual Average input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

2.1.1 Adding a Load to the Model

6. Finding Data to Run HOMER

2.1.4 Thermal Load

This feature requires the Combined Heat and Power Module. Click for more information.

Thermal load is demand for heat energy. The heat may be needed for space heating, hot water heating, or some industrial process. The thermal load can be served by the boiler, by a generator from which waste heat can be recovered, or by surplus electricity. If you want a generator to serve the thermal load with waste heat, you must specify a non-zero value for that generator's **heat recovery ratio**. If you want surplus electricity to serve the thermal load, you must add a thermal load controller.

See also

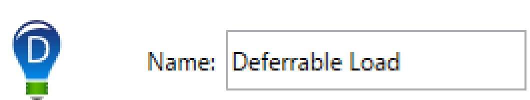
2.1.1 Adding a Load to the Model

2.1.5 Deferrable Load

This feature requires the Advanced Load Module. Click for more information.

Deferrable load is electrical load that must be met within some time period, but the exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Water pumping is a common example - there is some flexibility as to when the pump actually operates, provided the water tank does not run dry. Other examples include ice making and storage charging.

The descriptive name is used as a label to identify the deferrable load in the schematic.



Monthly Average Values

The baseline data is the set of 12 values representing the average deferrable load, in kWh/day, for each month of the year. The average deferrable load is the rate at which energy leaves the deferrable load storage tank; so, it is the amount of power required to keep the level in the storage tank constant.

Enter the average deferrable load for each month of the year in the table on the left. HOMER assumes that the deferrable load is constant throughout each month. HOMER calculates the resulting annual average deferrable load and displays it below the table. The monthly average values are displayed in the deferrable load graph as you enter them.

Scaled data for simulation

HOMER scales the baseline deferrable load data for use in its calculations. To scale the baseline data, HOMER multiplies each of the 12 baseline values by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the seasonal shape of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no deferrable load.

You can use the scaled annual average to perform a **sensitivity analysis** on the size of the deferrable load.

Other inputs

Variable	Description
Storage capacity	The size of the storage tank, expressed in kWh of energy needed to fill the tank
Peak Load	The maximum amount of power, in kW, that can serve the deferrable load. In a water pumping application, it is equal to the rated electrical consumption of the pump.
Minimum Load Ratio	The minimum amount of power that can serve the deferrable load, expressed as a percentage of the peak load. In a water pumping application, if the pump is rated at 0.75 kW and requires at least 0.5 kW to operate, the minimum load ratio is 67%.
Electrical Bus	Specifies whether the deferrable load must be served by alternating current (AC) or direct current (DC) power

The deferrable load is second in priority behind the primary load, but ahead of charging the batteries. Under the **load following** strategy, HOMER serves the deferrable load only when the system is producing excess electricity or when the storage tank becomes empty. Under the **cycle charging** strategy, HOMER will also serve the deferrable load whenever a generator is operating and able to produce more electricity than is needed to serve the primary load.

Regardless of dispatch strategy, when the level of the storage tank drops to zero, the peak deferrable load is treated as a primary load. The dispatchable power sources (generator, grid or storage bank) will then serve as much as possible of the peak deferrable load.

Example: Each day, 4.5 m^3 of water is needed for irrigation, and there is an 18 m^3 water tank. At full power, the pump draws 400 W of electrical power and pumps 3 m^3 per hour. To model this situation using HOMER:

- The peak deferrable load is 0.4 kW, which is the rated power of the pump.
- It would take the pump 6 hours at full power to fill the tank, so the storage capacity is 6 hours times 0.4 kW, which is 2.4 kWh.
- It would take the pump 1.5 hours at full power to meet the daily requirement of water, so the average deferrable load is 1.5 hours per day times 0.4 kW, which is 0.6 kWh/day.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.1.6 Hydrogen Load

A hydrogen load represents an external demand for hydrogen. Either the reformer or the electrolyzer will serve this demand. You have the same options for specifying the hydrogen load as you do for the primary electrical load and the thermal load: you can either synthesize hourly data by entering daily load profiles, or you can import time series data. Please refer to the articles on the primary or thermal load for information on doing so.

See also:

2.1.3 Electric Load
2.1.4 Thermal Load
2.2.12 Electrolyzer
2.2.13 Reformer

2.2 Components Tab

A component is a piece of equipment that is part of a power system. You can include **generator**, **PV**, **wind, storage**, **converter**, **hydro**, **reformer**, **electrolyzer**, **hydrogen tank**, **hydrokinetic**, **grid**, and **thermal load controller**. Select all the components you want to consider as part of the power system.

If you add a component that requires resource information, you should add the corresponding resource. The **resources help page** lists the resources and the corresponding components.

For the wind turbine, generator, PV, and storage components, you can add more than one component to consider. Adding more than one component makes it possible to compare components that have different properties. You can compare wind turbines with different power curves, generators with different fuels and efficiency curves, storage systems with different chemistries, and PVs with different orientations.

Tip: *Add more than one component only if you want to compare components that have different properties*. Use the **search space** to compare *different quantities or sizes of the same component.*

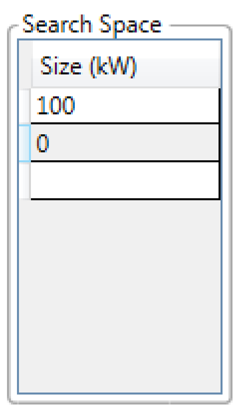
2.2.1 Generator

The Generator window allows you to enter the cost, and size characteristics of a generator. It also provides access to the following tabs:

- **Fuel Resource**: specify the fuel used by the generator, set the cost, and optionally set a maximum consumption.
- **Fuel Curve**: set fuel consumption parameters
- **Emissions**: enter the emission factors for the generator
- **Maintenance**: set a maintenance costs and down-time for the generator.
- **Schedule**: set the generator to be forced on, forced off, or optimized (default) according to the HOMER dispatcher.

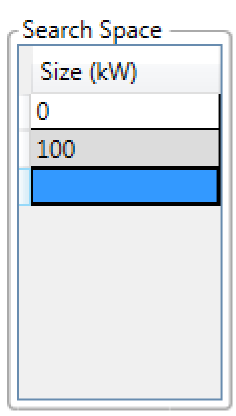
Generator Size

Use the box labeled **Search Space** to input what size generator you would like to consider.



In this table, enter the generator sizes you want HOMER to consider as it searches for the optimal system. HOMER will use the information you entered in the cost table to calculate the costs of each generator size, interpolating and extrapolating as necessary.

By default, once you have added the generator component, HOMER will only consider systems that include a generator. If you want HOMER to consider systems both with and without a generator, be sure to include zero in the search space.



System designers commonly specify just a single nonzero generator size, one large enough to comfortably serve the peak load. When given a choice of generator sizes, HOMER will invariably choose the smallest one that meets the **maximum annual capacity shortage** constraint, since smaller generators typically cost less to operate than larger generators.

Costs

The Costs box includes the initial **capital cost** and **replacement cost** of the generator, as well as annual **operation and maintenance** (O&M) costs. When specifying the capital and replacement costs, remember to account for all costs associated with the generator, including installation.

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1	$500.00	$500.00	$0.03

Multiplier: {..} {..} {..}

Note that the **capital cost** is the initial purchase price, the **replacement cost** is the cost of replacing the generator at the end of its lifetime, and the **O&M** cost is the annual cost of operating and maintaining the generator. The costs in each row should correspond to the size entered in the first column.

You can enter additional rows in the costs table to account for changing costs with scale.

Cost Curve Example

In the cost table, enter the generator cost curve, (i.e. the way the cost varies with size). If you have a particular generator in mind, you can enter its size and cost. Take an example where a 40 kW generator costs $20,000 initially, $16,000 to replace at the end of its life, and $0.60 per hour for operation and maintenance.

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1	$500.00	$400.00	$0.02

Multiplier: {..} {..} {..}

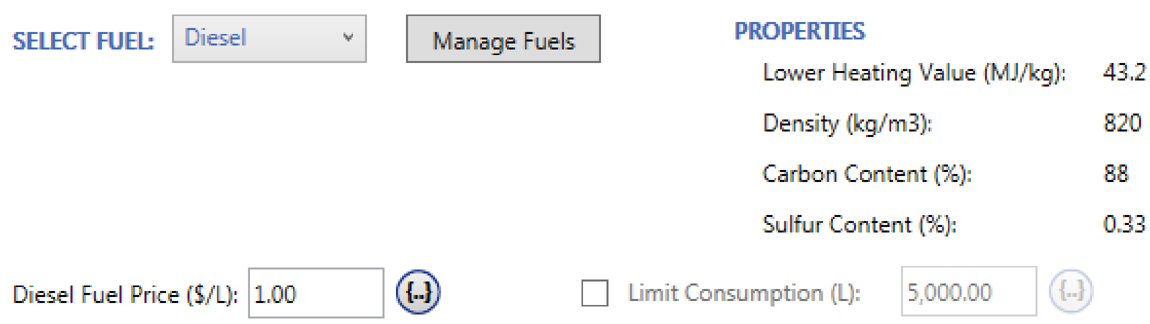
HOMER only uses this table to calculate costs, so it is exactly equivalent to specify these costs as follows:

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
2	$1,000.00	$800.00	$0.03

In other words, for both sets of inputs, the capital cost is $500/kW, the replacement cost is $400/kW, and the operating and maintenance cost is $0.02/kW per hour.

Fuel Resource



This drop-down box contains all the fuels stored in your **component library**. Choose the appropriate fuel from this list.

Choose "stored hydrogen" to connect the generator to the hydrogen bus to model, for example, a hydrogen fuel cell. The fuel curve of the generator will now be in terms of kg of hydrogen. Hydrogen can only be supplied from components connected to the hydrogen bus, like a reformer or electrolyzer. Hydrogen can't be purchased like conventional fuels. If no hydrogen is available in the current time step (i.e. the hydrogen tank is empty), the generator will not be able to run.

Choose "biogas" to use the biomass resource. When you select biogas (or any bio fuel: see **Fuels**) a button to the Biomass Resource will appear. You can also access the Biomass resource at any time through the Resources tab of the menu bar. If you select a bio fuel, the generator fuel curve will be in kg of biogas. Each kg of biomass feedstock is gasified to produce a fraction of a kg of biogas according to the gasification ratio.

Fuel Curve

Variable	Description
Intercept coefficient	the no-load fuel consumption of the generator divided by its rated capacity
Slope	marginal fuel consumption of the generator

See the **Fuel Curve** tab documentation for more information on these inputs, and for instructions on how to use the fuel curve calculator.

Emissions

The Emissions tab in the **Generator** window gives you access to the following emissions factors input variables:

Variable	Description
Carbon Monoxide	The quantity of carbon monoxide emitted per unit of fuel consumed by the generator, in g/L*
Unburned Hydrocarbons	The quantity of unburned hydrocarbons emitted per unit of fuel consumed by the generator, in g/L*

Particulate Matter	The quantity of particulate matter emitted per unit of fuel consumed by the generator, in g/L*
Proportion of Fuel Sulfur Converted to PM	The fraction of the sulfur in the fuel that is emitted as particulate matter (the rest is emitted as sulfur dioxide), in %
Nitrogen Oxides	The quantity of nitrogen oxides emitted per unit of fuel consumed by the generator, in g/L*

*These units will be in g/m^3 for fuels that are measured in m^3 and g/kg for fuels measured in kg.

> **Note:** To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Maintenance

HOMER can include the cost and downtime for specific maintenance tasks in the simulation. Check the option "Consider Maintenance Schedule" if you wish to use this option. The following inputs, found under the "Maintenance" tab, can be used to define a maintenance requirement:

Variable	Description
Procedure	Descriptive name for the maintenance item
Interval (hrs.)	How often the maintenance will have to be performed, in terms of number hours that the generator is operating OR total (calendar) hours, depending on the selection in the Type field.
Type	Specifies whether the maintenance interval is in terms of Operating hours (only hours the generator is on) or Calendar hours (total hours including when the generator is off)
Down time (hrs.)	Number of hours for which the generator will be forced off when the maintenance event occurs
Cost ($)	Cost of the maintenance procedure. This cost will be incurred at the end of each maintenance interval
Marginal cost	Additional cost added to the maintenance event, per kW of generator capacity

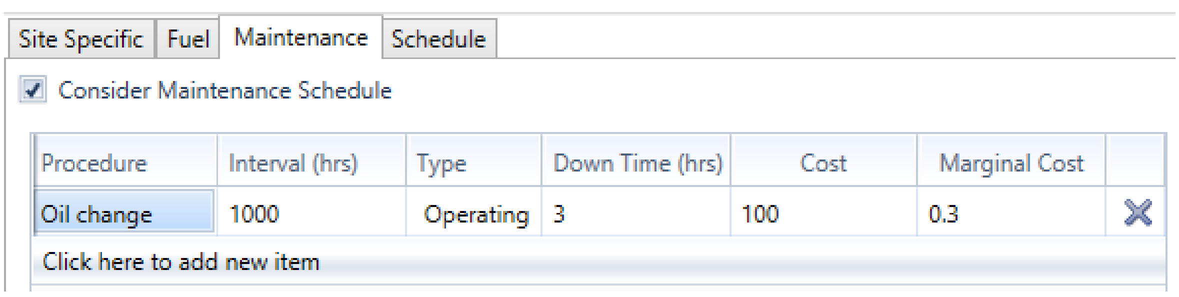
Each row in the table corresponds to a maintenance event with a name, interval between occurrences, generator down time, and cost. You can specify the interval in terms of Operating hours (hours that the generator is turned on), or Calendar hours (all hours including when the generator is off) with the drop-down menu in the Type column.

For example, a maintenance event that occurs every 8,760 Calendar hours will happen once per year at the same time and date each year.

The countdown to the next occurrence of the maintenance event restarts immediately after it elapses. The countdown even runs during the downtime for the event, if there is any. On the other hand, if Operating is selected in the Type column, only hours where the generator is on are counted. The countdown to the next event begins after the downtime for the current event has elapsed, and the countdown pauses whenever the generator is not running.

Note: An event that occurs every 8,760 Calendar hours (once per year) will only occur 24 times in a 25 year project. The event will occur at the end of every year from the first year to the 24th year, but not at the end of the 25th year.

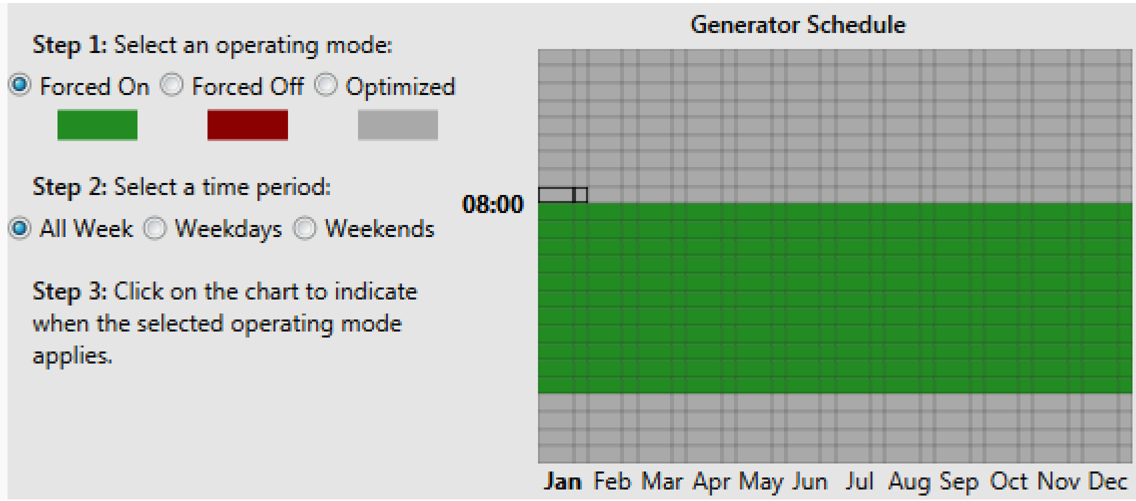
The cost is calculated based on the Cost, Marginal cost, and generator size. The Marginal cost is multiplied by the generator size, then added to the fixed Cost, to calculate the total cost for the maintenance event. For example, consider the hypothetical maintenance event "Oil change". It occurs every 1,000 operating hours, and the generator is forced off for three hours during the event. The cost is $100, and the marginal cost is $0.50 per kW of capacity. The oil change procedure costs $100, plus $0.30 per kW for the quantity of oil required for larger engines. For a 100 kW generator, the total cost of the event is $130 ($100 + $0.30 * 100).



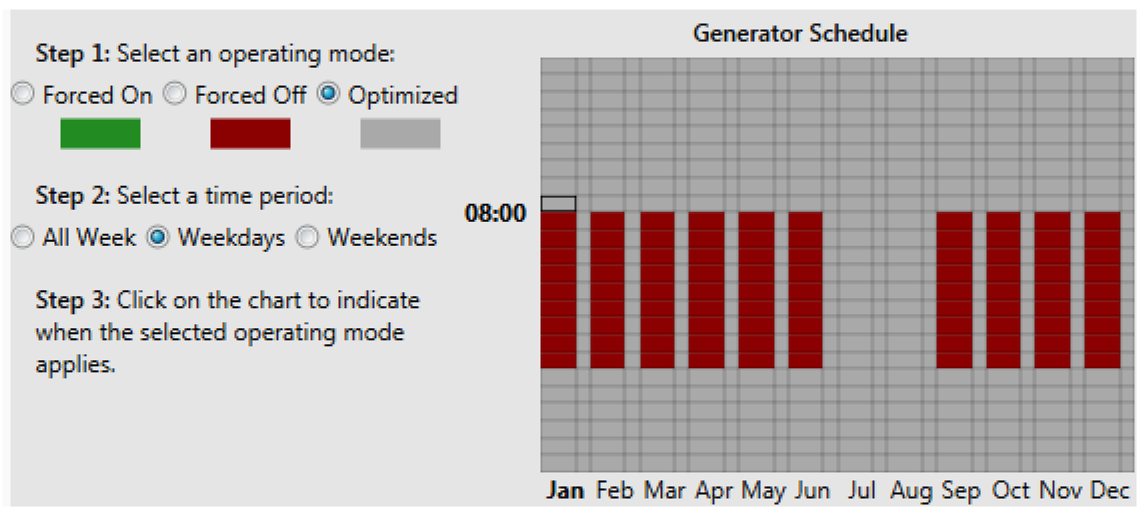
Schedule

By default, HOMER decides each time step whether or not to operate the generator based on the electrical demand and the economics of the generator versus other power sources. You can, however, use the generator schedule inputs to prevent HOMER from using the generator during certain times, or force it to use the generator during other times.

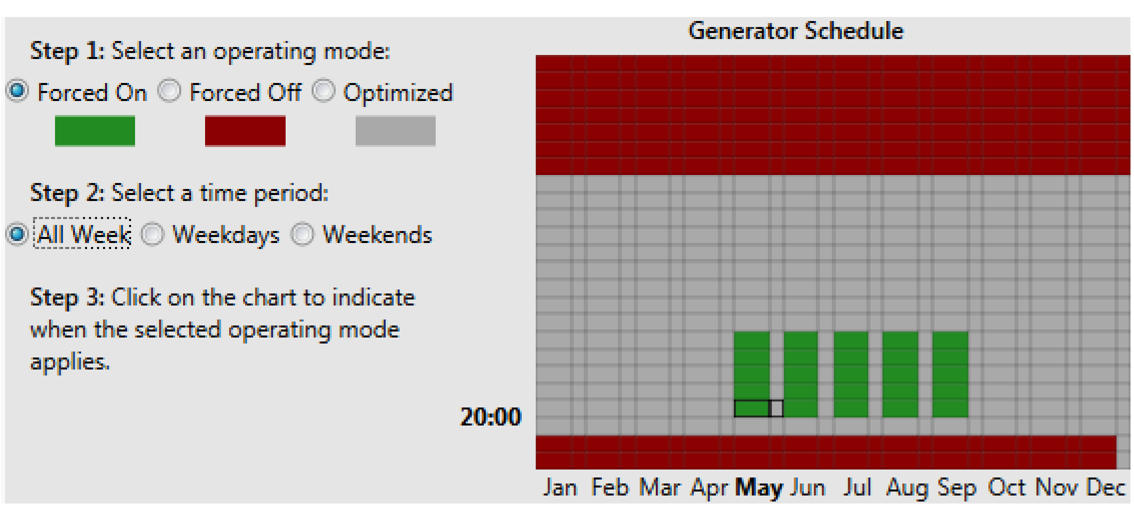
The schedule diagram on the right side of the window shows the times of the day and year during which the generator must operate and must not operate, and when HOMER can decide based on economics. In the example below, the generator must operate between 8am and 8pm every day. At all other times, HOMER can decide whether to run the generator based on economics.



It is also possible to treat weekdays and weekends differently. In the example below, the generator may not operate during school hours, which are 8am to 5pm on weekdays, except for July and August. (Such constraints are sometimes necessary in small village power systems because of generator noise.) At all other times, HOMER can decide whether to run the generator or not.



In the example below, the generator must operate during weekday evenings May through September, and must not operate before 7am or after 10pm throughout the year. At all other times, HOMER can decide whether to run the generator or not.



To modify the generator schedule, choose a drawing mode on the left side of the window and then draw on the schedule diagram on the right side of the window. For example, to force the generator to operate weekday afternoons in July:

1. Click the button labeled Forced On
2. Click the button labeled Weekdays
3. Move the mouse to the column representing July and row representing 12pm-1pm
4. Click and drag the mouse to the row representing 5pm-6pm

Note that when you move the mouse over the schedule diagram, the cursor changes depending on whether you have selected weekdays, weekends, or all week.

You can view the generator status, as specified by the schedule, in the time series results. The generator status is coded with a "0", "1", or "2" to correspond to the possible states.

Status	Meaning
0	Optimized / normal operation (could be on or off, dispatch decides)
1	Forced off
2	Forced on

> **Note:** To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also:

4.1.2 Generator

5.3 How HOMER Calculates Emissions

2.2.1.1 Fuel Curve

The Fuel Curve tab provides assistance in calculating the two fuel curve inputs on the **Generator** window.

Reference Generator Capacity

Enter the rated size of the generator for which you have fuel consumption data. This input affects the value calculated for the "Intercept Coefficient"

Fuel consumption data

Fuel Curve Table:

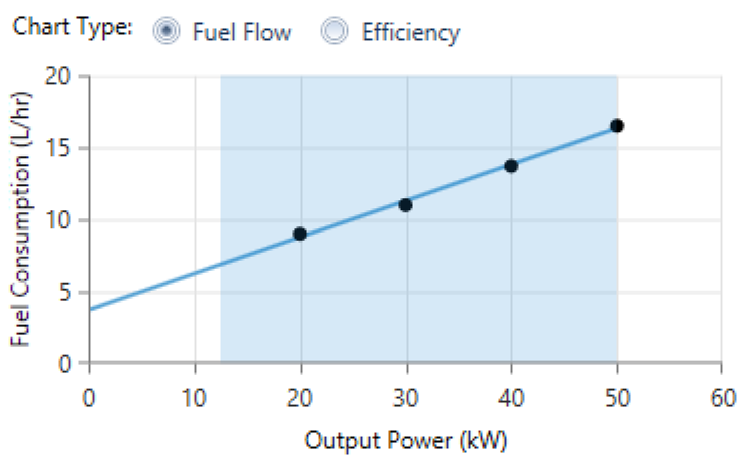
Output (kW)	Consumption (L/hr)
20	9
30	11
40	13.7
50	16.5

In this table, you enter data points on the generator's fuel curve. You must enter at least two points, but you can enter more than that if you have sufficient data.

> **Note:** The units of the fuel consumption column change according to the units of the fuel this

generator uses. If the generator consumes a fuel denominated in liters, the units of the fuel consumption column will be L/hr. But if the fuel is denominated in cubic meters, the units of the fuel consumption will be m^3/hr.

HOMER plots the fuel consumption data in the fuel curve. The example shown below corresponds to the data shown in the table above. HOMER fits a line to the data points using the linear least-squares method. The straight line represents the line of best fit, which in this example fits the data very well. A straight line may not represent certain types of generators, such as fuel cells and variable-speed diesels, quite as well. But for the more common constant-speed internal combustion generators and microturbines, the straight-line fuel curve is a good fit.



The *y*-intercept of the fuel curve is sometimes called the "no-load fuel consumption". This represents the amount of fuel consumed by the generator when idling (producing no electricity). The slope of the fuel curve is sometimes called the "marginal fuel consumption".

Using the straight line it fits to the fuel consumption data, HOMER calculates the generator's efficiency at various points between zero output and rated output. That calculation takes into account the energy content of the fuel. HOMER plots the results as the efficiency curve.

Calculated fuel curve parameters

Note that HOMER's two fuel curve inputs are not the intercept and slope, but rather the *intercept coefficient* and the slope. The intercept coefficient is equal to the intercept divided by the generator capacity. Defining the fuel curve in this manner allows HOMER to apply it to a family of generators, over a range of sizes. This is necessary when you enter multiple sizes in the "Sizes to consider" table of the **Generator Inputs** window, since the fuel curve inputs apply to each specified generator size.

The units of the two fuel curve parameters correspond to the units of the fuel used by the generator. For example, if the fuel is measured in liters, the fuel curve slope and intercept coefficient will be in units of L/hr/kW (liters per hour per kilowatt, or equivalently L/kWh).

When you click OK, HOMER copies the two calculated parameters to the `Generator Inputs` window.

See also

2.2.1 Generator

7.68 Generator Fuel Curve Intercept Coefficient

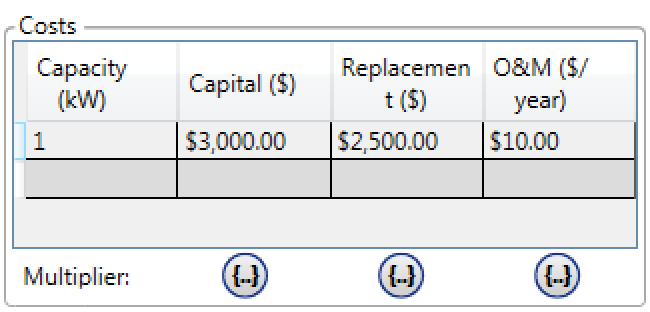
7.69 Generator Fuel Curve Slope

2.2.2 Photovoltaic Panels (PV)

The PV window allows you to enter the cost, performance characteristics and orientation of an array of photovoltaic (PV) panels as well as choose the sizes you want HOMER to consider as it searches for the optimal system. Both flat panel and concentrating PV technologies can be represented by the PV component. Whether or not a PV is concentrating can be specified in the library. This window also provides access to the following tabs:

- **Inverter**: If the "Electrical Bus" is set to "AC", inverter parameters are specified here.
- **MPPT**: If the "Electrical Bus" is set to "DC", the parameters of the maximum power point tracker (DC to DC converter) are set here.
- **Advanced Inputs**, where you can set certain advanced variables
- **Temperature**: specify whether to consider the effect of ambient temperature on panel efficiency, and if so set the relevant inputs

Costs



The Costs box includes the initial **capital cost** and **replacement cost** per kilowatt of the PV system, as well as annual **operation and maintenance** (O&M) costs per kilowatt. When specifying the capital and replacement costs, remember to account for all costs associated with the PV system, which may include:

- PV panels
- mounting hardware
- tracking system
- wiring
- installation

You can include the cost of the power electronics in the capital cost, or account for them separately in the MPPT or inverter tab. Note that the capital cost is the initial purchase price, the replacement cost is the cost of replacing the PV system at the end of its lifetime, and the O&M cost is the annual cost of operating and maintaining the PV system.

Cost Curve

In the cost table, enter the PV *cost curve*, meaning the way the cost varies with size. Typically this requires only a single row since analysts often assume that PV costs vary linearly with size. In the sample above, the capital cost of PV panels is specified at $3,000/kW and the replacement cost is specified at $2,500/kW. The operating and maintenance cost is specified as zero.

You would enter multiple rows of data in the cost table if the cost of the PV subsystem was not linear with size. For example, if the marginal capital and replacement costs dropped to $2,500/kW and $2,100/kW, respectively, for quantities above 2 kW, you could fill in the cost table as follows:

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
1	$3,000.00	$2,500.00	$0.00
2	$6,000.00	$5,000.00	$0.00
3	$8,500.00	$7,100.00	$0.00
Multiplier:	{..}	{..}	{..}

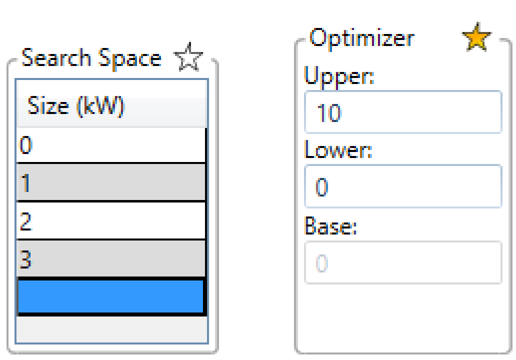
If HOMER then had to simulate a system with a PV array size of 0.1 kW, it would extrapolate from the 1 kW and 2 kW costs, giving a capital cost of $300. For a PV array size of 2.5 kW, HOMER would interpolate between the 2 kW costs and the 3 kW costs, giving a capital cost of $7,250. For a PV array size of 6 kW, HOMER would extrapolate from the 2 kW and 3 kW costs, giving a capital cost of $16,000.

Note that the **capital cost** is the initial purchase price, the **replacement cost** is the cost of replacing the PV panels at the end of their lifetime and the operating and maintenance cost is the annual cost of operating and maintaining the PV array.

Search Space

Enter the nominal capacity of the PV in kW, or enter several quantities for HOMER to consider in the system optimization. Include a zero if you would like HOMER to consider systems without this PV.

Click the star icon to enable the optimizer. The search space will be replaced by a lower bound and an upper bound. With the optimizer turned on, HOMER will automatically find the best capacity for you.



See the help article about the **Optimization** menu for a more detailed explanation of HOMER's optimizer.

PV Inputs

From the main section of the PV window, you can edit the following inputs:

Variable	Description
Electrical Bus	This determines whether the PV array produces AC or DC power. All PV cells produce DC electricity, but some PV arrays have built-in inverters to convert to AC.
Lifetime	The number of years before the PV panels must be replaced at the replacement cost specified in the costs table
Derating Factor	A scaling factor applied to the PV array power output to account for reduced output in real-world operating conditions compared to operating conditions at which the array was rated

> **Note:** To the right of each numerical input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Inverter

If the PV system is on the AC electrical bus, you can specify a dedicated inverter. You can define the cost table, size (search space), and lifetime in a similar manner to other components. You can also specify the efficiency with a single value, or check "Use efficiency table", and enter values for efficiency versus input load percentage.

If you don't want to model the inverter, check the box "Ignore dedicated converter".

MPPT

A Maximum Power Point Tracker (or MPPT) is a DC to DC converter that matches the PV to the DC bus voltage, while varying the voltage of the PV array itself to maximize the power output. The inputs for the MPPT are identical to those for the inverter, described above.

Advanced Inputs

The Advanced Input tab contains options that affect the calculation of the PV power output. The article **How HOMER Calculates the Radiation Incident on the PV** contains more information on ground reflectance, panel slope, and panel azimuth.

Variable	Description
Ground Reflectance	The fraction of solar radiation incident on the ground that is reflected, in %
Tracking System	The type of tracking system used to direct the PV panels towards the sun

Use default slope	If this input is checked, the slope input is disabled and the slope will be set to match the latitude
Panel Slope	The angle at which the panels are mounted relative to the horizontal, in degrees
Use default azimuth	If this input is checked, the azimuth input is disabled and the azimuth will be set to 0 or 180 degrees for projects in the northern or southern hemisphere, respectively
Panel Azimuth	The direction towards which the panels face, in degrees

Temperature

The Temperature tab contains setting model or ignore temperature effects. See **How HOMER Calculates the PV Array Power Output** for detailed information on temperature effects on power, nominal operating cell temperature, and efficiency at standard test conditions.

Variable	Description
Consider Effect of Temperature	HOMER will consider the effect of PV cell temperature on the power output of the PV array
Temperature Coefficient of Power	A number indicating how strongly the power output of the PV array depends on cell temperature, in %/degrees Celsius
Nominal Operating Cell Temperature	The cell temperature at 0.8 kW/m2 and 20?C ambient temperature in degrees Celsius
Efficiency at Standard Test Conditions	The maximum power point efficiency under standard test conditions, in %

See also:

4.1.3 Photovoltaic (PV)
5.1 How HOMER Calculates the PV Array Power Output
5.8 How HOMER Calculates the PV Cell Temperature
5.9 How HOMER Calculates the Radiation Incident on the PV Array
7.156 Standard Test Conditions

2.2.3 Wind Turbine

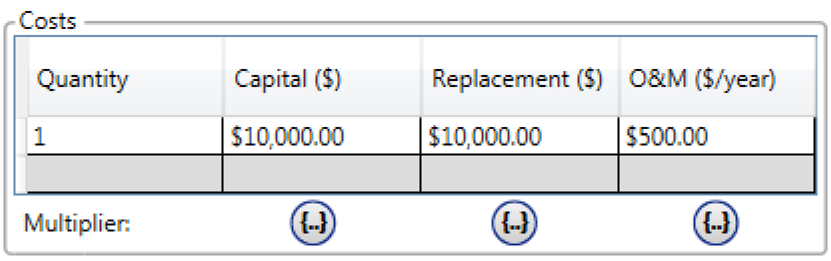
The Wind Turbine window allows you to choose the type of wind turbine you want to model, specify its costs, and tell HOMER how many to consider as it searches for the optimal system. This window also provides access to the following tabs:

- **Power Curve**: view and edit the power curve for the selected wind turbine
- **Turbine Losses**: specify different loss modes
- **Maintenance**: consider maintenance tasks, costs, and down time

Turbine type

This drop-down menu located at the top of the wind turbine set up page contains all the wind turbine types stored in your **component library** . Choose an appropriate wind turbine model from this list. When you make a selection with this drop-down box, a summary of the selected wind turbine's properties are displayed in the space below. Click on "Add Wind Turbine" to add the selected turbine to your model.

Costs


Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$10,000.00	$10,000.00	$500.00

Multiplier: {..} {..} {..}

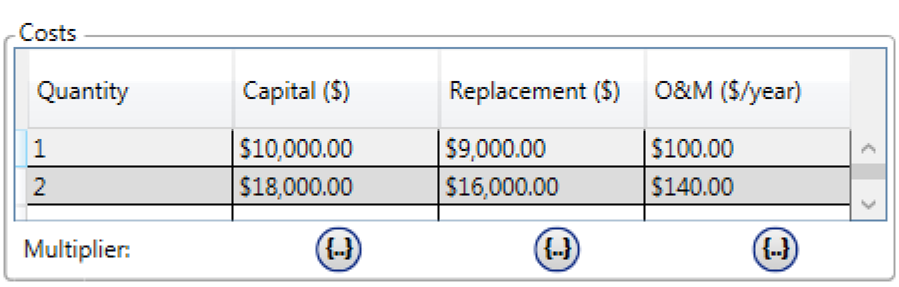
In the Costs table, the **capital cost** is the initial purchase price for a turbine, the **replacement cost** is the cost of replacing the wind turbine at the end of its lifetime, and the operating and maintenance cost is the annual cost of operating and maintaining the turbine (about 2% percent of the capital cost is typical).

When specifying the capital and replacement costs, remember to account for all costs associated with the wind energy system, which may include:

- turbine rotor and tower
- control system
- wiring
- installation

Cost Curve

In the cost table, enter the wind turbine's *cost curve* in as much detail as you would like. In the simplest case, where each wind turbine costs the same regardless of how many you purchase, you only need to enter one row of data in the cost table. You would enter a quantity of one, along with the per-turbine capital, replacement, and operating and maintenance costs. HOMER extrapolates these costs as needed, so if you modeled a system with three wind turbines, the associated capital, replacement, and O&M costs would be three times the values entered in the cost table.


Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$10,000.00	$9,000.00	$100.00
2	$18,000.00	$16,000.00	$140.00

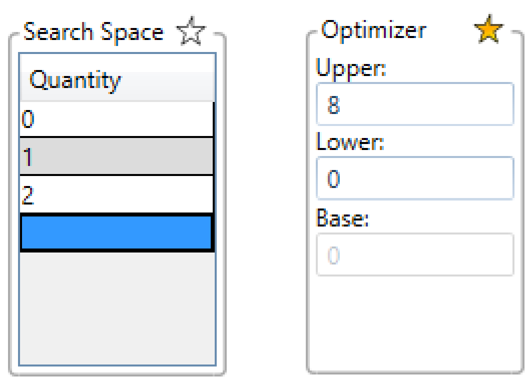
Multiplier: {..} {..} {..}

You would enter multiple rows of data in the cost table if the cost of wind power was not directly proportional to the number of wind turbines purchased. In the example shown above, the second wind turbine is cheaper than the first (this could be because of a volume discount from the manufacturer or because certain fixed costs can be spread over multiple turbines). If the third turbine were cheaper yet, another row of costs could be added. With just these two rows specified though, HOMER would extrapolate the costs by assuming that the third, fourth, and subsequent turbines cost the same as the second.

Search Space

Enter the quantity of turbines you would like, or enter several quantities for HOMER to consider in the system optimization. Include a zero if you would like HOMER to consider systems without this wind turbine.

Click the star icon to enable the optimizer. The search space will be replaced by a lower bound and an upper bound. With the optimizer turned on, HOMER will automatically find the best quantity for you.



Tip: If you are considering a small number of wind turbines (i.e. 0, 1, or 2) it can be better to just enter the quantities in the search space, and not use the optimizer. If you are considering four or more different quantities of wind turbines, the optimizer can be a good choice.

See the help article about the **Optimization** menu for a more detailed explanation of HOMER's optimizer.

Electrical Bus

Select whether the turbine will produce AC or DC power. Power electronics are not modeled explicitly, but you can account for a dedicated converter efficiency by scaling the power curve.

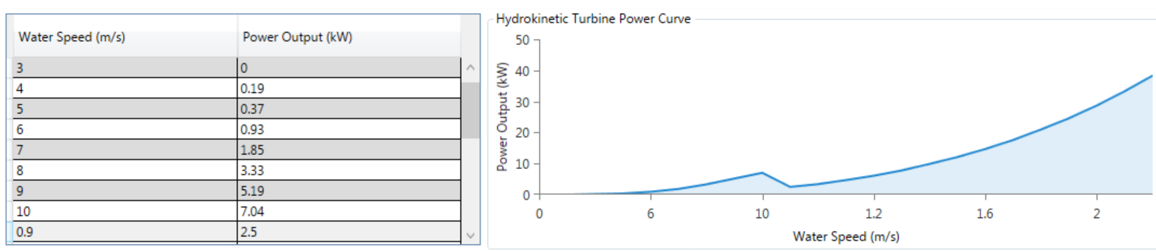
Site Specific Inputs

Variable	Description
Lifetime	The number of years the turbine is expected to last before it requires replacement
Hub height	The height above ground of the hub (the center of the rotor), in meters
Consider ambient temperature effects?	HOMER will compensate for the change in air density with temperature. If checked, you must define a temperature resource.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Power Curve

The Power Curve tab in the **Wind Turbine** window allows you to view the power curve of the selected wind turbine model in both tabular and graphical form. A wind turbine's power curve shows how much power it will produce depending on the incoming hub-height wind speed at standard atmospheric conditions. Use this graph to verify that the wind turbine you have selected is an appropriate size for your system.



Losses

The Losses tab allows you to derate the turbine performance with several different factors. The "Overall loss factor" is calculated multiplicatively as in the following equation:

$$L_{overall} = \prod_{i=1}^{n} 1 + \frac{L_i}{100}$$

In this equation, each loss percentage is an L_i , from L_1 (availability losses) to L_7 (other losses). The turbine power output is then scaled down by the resulting factor.

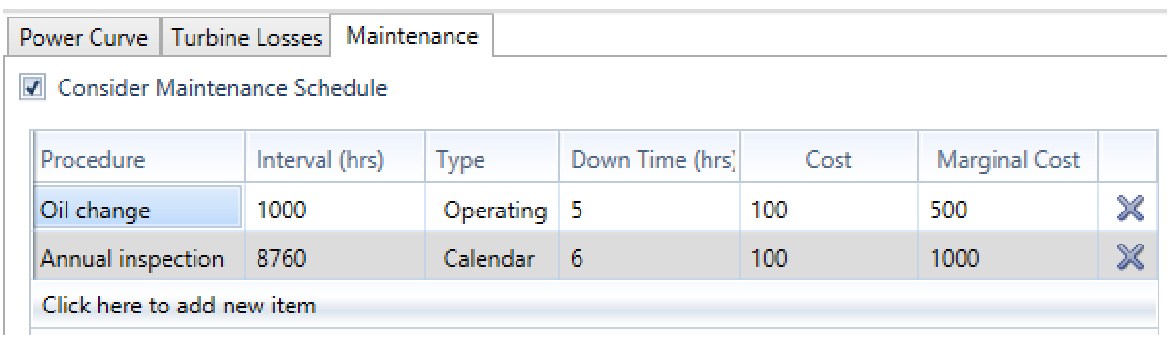
Maintenance

HOMER can include the cost and downtime for specific maintenance tasks in the simulation. Check the option "Consider Maintenance Schedule" if you wish to use this option. The following inputs, found under the "Maintenance" tab, can be used to define a maintenance requirement:

Variable	Description
Procedure	Descriptive name for the maintenance item
Interval (hrs.)	How often the maintenance will have to be performed, in terms of number hours that the wind turbine is operating OR total (calendar) hours, depending on the selection in the Type field.
Type	Specifies whether the maintenance interval is in terms of Operating hours or Calendar hours (i.e. total hours including when the wind turbine is off)
Down time	Number of hours for which the wind turbine will be forced off once the

(hrs.)	number when the end of the maintenance interval is reached
Cost ($)	Cost of the maintenance procedure. This cost will be incurred at the end of each maintenance interval
Marginal cost	Additional cost added to the maintenance event, per wind turbine

The cost for a maintenance event is computed as the Cost (fixed cost) plus the marginal cost times the number of turbines. In the example maintenance items pictured below, $100 is the fixed cost, which could be the minimum cost for the maintenance personnel to travel to the site. In the case of the oil change, there is an additional cost of $500 per wind turbine (marginal cost). If there were 5 wind turbines, the total cost of this event would be $2600.



The oil change event occurs every 1,000 operating hours. Hours where the wind turbine is off are not counted. The wind turbine could be not operational if the wind speed is too low or too high, or during down time for a maintenance event. The annual inspection occurs every 8,760 Calendar hours. This event will occur every year at the same date and time.

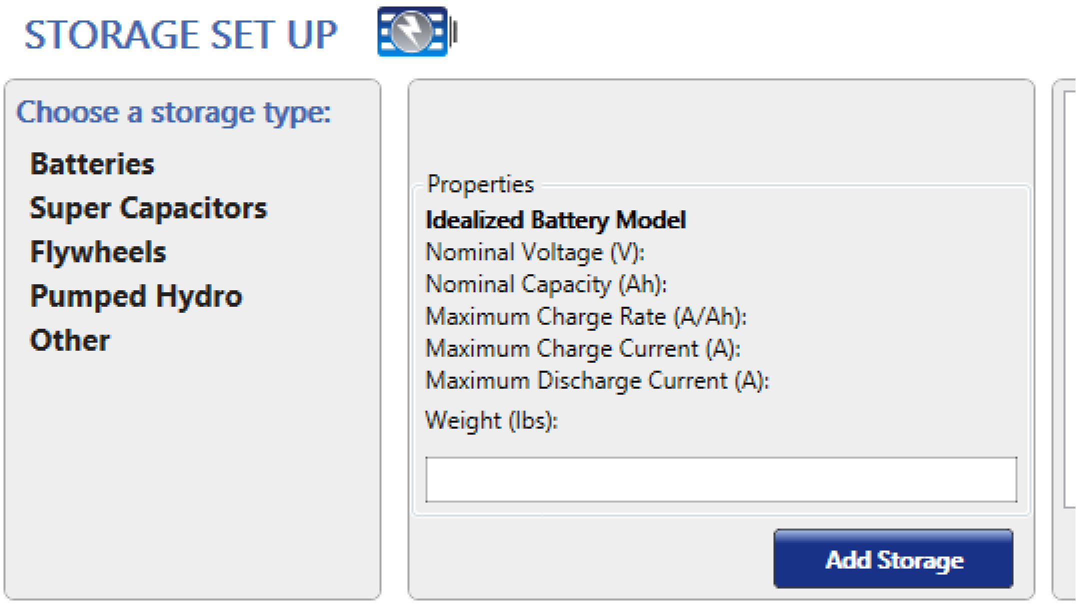
Note: An event that occurs every 8,760 Calendar hours (once per year) will only occur 24 times in a 25 year project. The event will occur at the end of every year from the first year to the 24th year, but not at the end of the 25th year.

See also

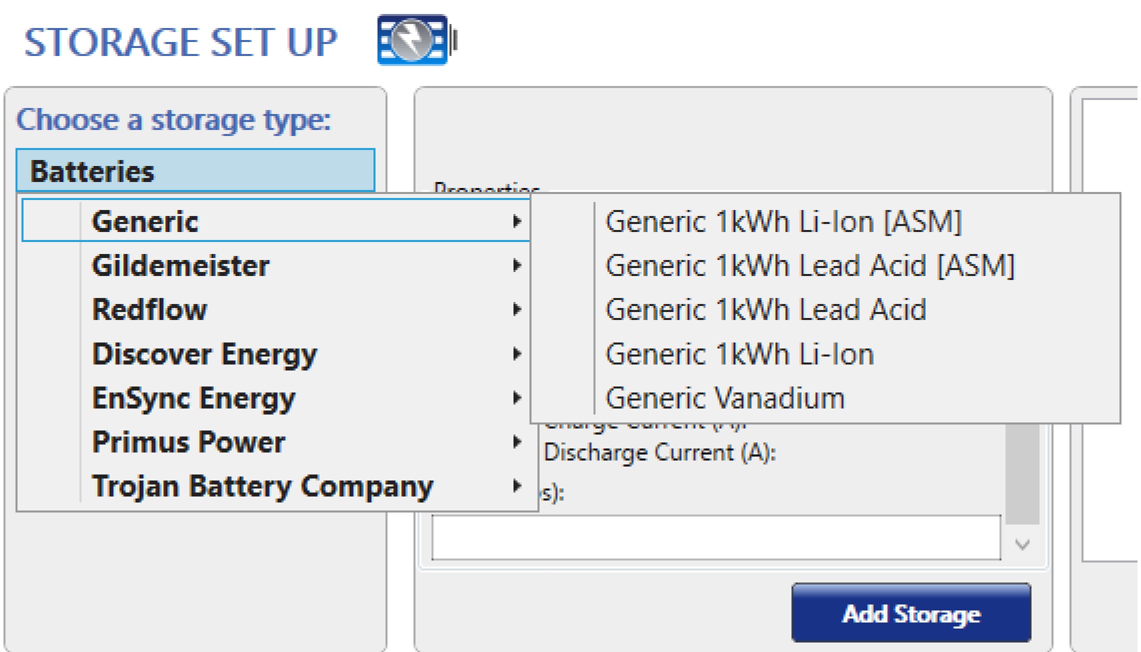
2.3.4 Wind Resource
4.1.4 Wind Turbine
7.37 Component Library
2.4.5 Optimization

2.2.4 Storage

The Storage window allows you to choose a storage component from the library, look at the technical details, and specify storage costs. You can define new storage models in the **Component Library**.



You can select your desired storage model using the dropdown menus on the left side of the Storage Set Up page. First choose a storage type: Batteries, Supercapacitors, Flywheels, Pumped Hydro, or Other. Each of these menus is then divided up by Manufacturer. Once you choose a manufacturer, you can choose a Storage Component from the list of items. This menu tree contains all the storage items stored in your library, including the build in items included with HOMER (these appear in regular font) and the ones you have created or imported into your personal library (these appear in bold font).



Tip: Components marked with the text **[ASM]** after the name require the **Advanced Storage Module**.

Click on "Add Storage" to add the selected storage to your model. The storage specification page will then display. You can navigate between the Storage Set Up page and one or more storage specification pages with the tabs at the top of the pane.

Note: HOMER can only simulate one storage component at a time. You can add more than one storage component to the model, but each one must include a zero in the search space. HOMER will simulate each of the storage types, one component at a time. HOMER can also include one flywheel storage component in addition to the one of any other kind of storage component in a single simulation.

Costs

The Costs box includes the initial **capital cost** and **replacement cost** per storage item, as well as annual **operation and maintenance** (O&M) costs per storage. When specifying the capital and replacement costs, remember to account for all costs associated with the storage, including installation and power electronics.

Note that the capital cost is the initial purchase price, the replacement cost is the cost of replacing the storage at the end of its lifetime, and the O&M cost is the annual cost of operating and maintaining the storage.

Note: Below each numerical input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Cost Curve

In this table, enter the *cost curve* in as much detail as you would like. We'll use batteries for this explanation, although the storage component can represent a range of different kinds of energy storage technologies.

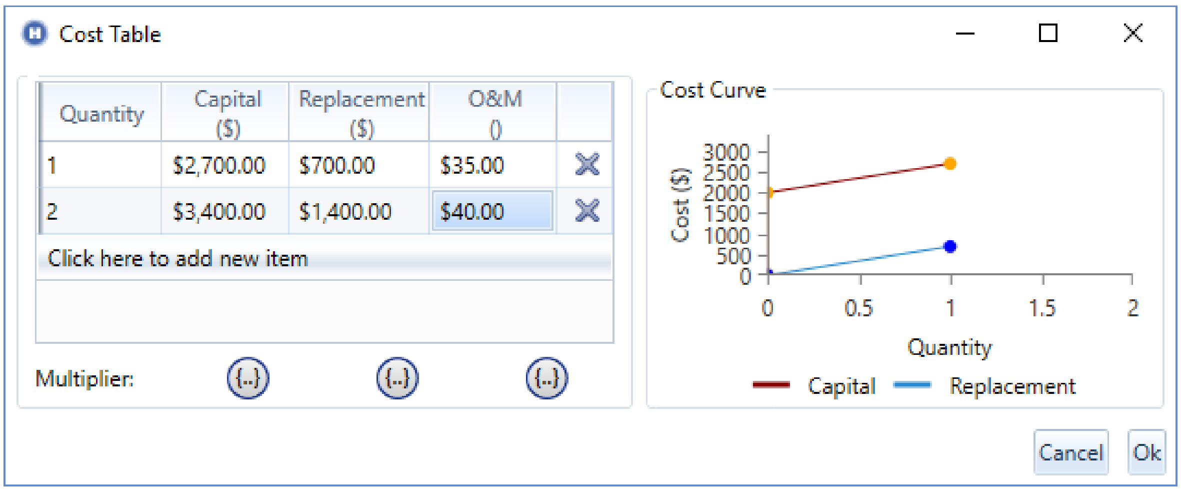
Tip: If you need multiple rows in the cost table, click the "More..." button to access the full table.

In the simplest case, where each battery costs the same regardless of how many you purchase, you only need to enter data in the basic cost table pictured above. You would enter a quantity of one, along with the per-component capital, replacement, and operating and maintenance costs. In the example shown above, each battery costs $1,800 initially, $1,600 to replace, and $10 annually for operating and maintenance. HOMER extrapolates these costs as needed, so if you modeled a system with three batteries, the associated capital, replacement, and O&M costs would be three times the values entered in the cost table.

Quantity	Capital ($)	Replacement ($)	O&M ()
1	$1,800.00	$1,600.00	$10.00

More...

If you would like the battery bank's costs to vary with quantity (i.e. the per item cost might be lower for larger quantities), click the "More..." button and enter multiple rows in the cost table. In the example shown below, the fixed cost of the battery bank is $2,000 initially plus $30/yr for operating and maintenance. (This could be the cost of a room or a building in which to house the batteries.) Each battery then costs $700 plus $5/yr for operating and maintenance.

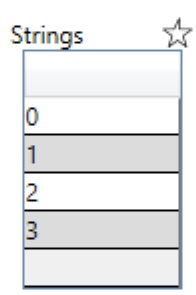


Note that the **capital cost** is the initial purchase price, the **replacement cost** is the cost of replacing the batteries at the end of their lifetime, and the O&M cost is the annual cost of operating and maintaining the battery bank.

> **Note:** HOMER will not assess this $2,000 capital cost to a system that contains zero batteries. It applies only to systems containing battery banks. To add a fixed capital or O&M cost, see **Economics**.

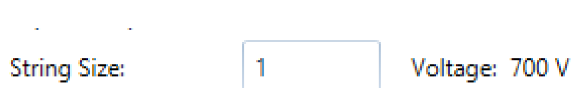
HOMER will use the number of batteries/strings you entered in the cost table to calculate the corresponding costs, interpolating and extrapolating as necessary.

Search Space with Strings



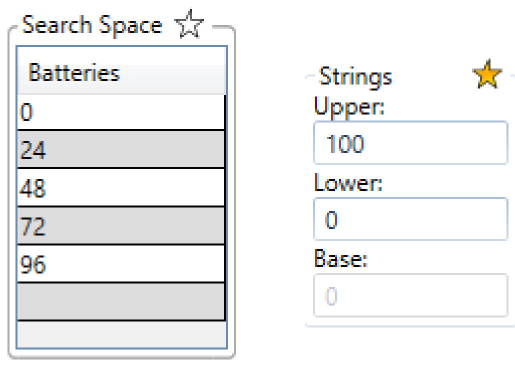
Two or more batteries connected in series form a string, and strings are connected in parallel to form a storage bank. Idealized, Kinetic, and Modified Kinetic energy storage models include the string size input. If the string size is greater than one, the sizes to consider table shows numbers of strings. The cost table quantity always refers to the number of batteries, not the number of strings. In results tables and graphs, HOMER always displays the number of batteries, regardless of how you specify the number of batteries in the sizes to consider table.

HOMER shows the DC bus voltage in parentheses next to the number of batteries per string. (The bus voltage is the storage's nominal voltage multiplied by the number of storage items per string.) You can use that to decide how many storage items to use per string.



Tip: If you only want to determine the optimal storage capacity, you can set the string size to one and ignore the bus voltage. This approach might be appropriate for a preliminary sizing analysis.

Click the star icon to enable the optimizer. The search space will be replaced by a lower bound and an upper bound. With the optimizer turned on, HOMER will automatically find the best quantity for you.



Tip: If you are considering a small number of batteries (i.e. 0, 1, or 2) it can be better to just enter the quantities in the search space, and not use the optimizer. If you are considering four or more different quantities of batteries, the optimizer can be a good choice.

See the help article about the **Optimization** menu for a more detailed explanation of HOMER's optimizer.

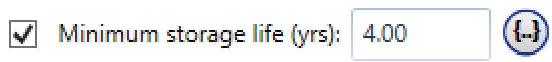
Storage Inputs

Variable	Description
String size	A string is a set of storage items connected in series. The number of storage items per string multiplied by the nominal voltage is the bus voltage.
Initial State of Charge	The state of charge of the storage bank at the beginning of the HOMER simulation, in %
Minimum State of Charge	A lower limit on the state of charge of the storage bank, in %
Enforce Minimum Storage Life	Enable the Minimum Storage Life constraint
Minimum Storage Life	A lower limit on the lifetime of the storage bank (systems that do not meet this constraint are discarded as infeasible)

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Minimum Storage Life

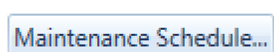
The minimum storage life is a lower limit on the **lifetime of the storage bank**. This constraint is not normally necessary, but you can use it if necessary to prevent HOMER from recommending a relatively small storage bank that lasts an unacceptably short time.



For example, HOMER may determine that the optimal system contains a small storage bank that lasts only 1.5 years before needing replacement. If that 1.5 year replacement cycle is unacceptably short, you could implement a minimum 4 year storage lifetime, which would cause HOMER to discard that optimal system and choose another, probably with a larger storage bank. It would be a more expensive system (otherwise it would have been optimal without the storage life constraint) but it would conform to the constraint.

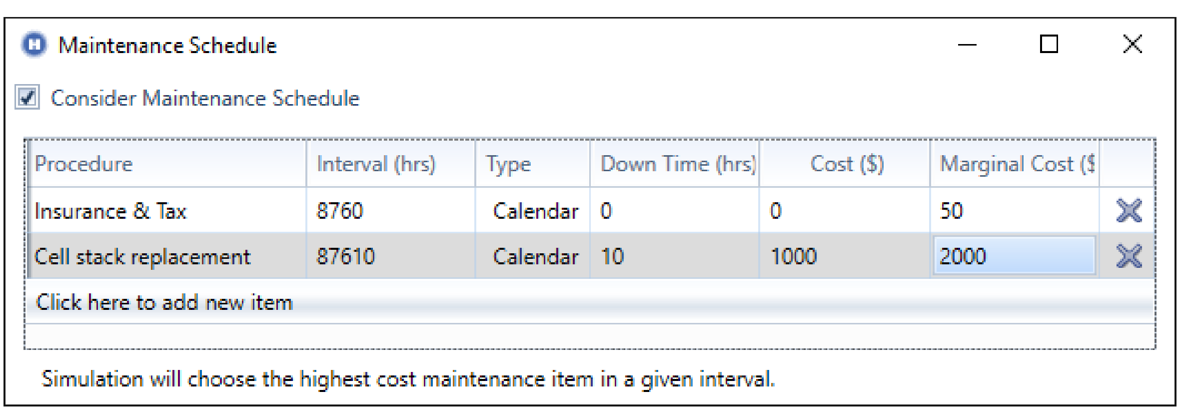
Maintenance Schedule

The "Maintenance Schedule" button pops up a new window where you can enter maintenance events. You can specify the maintenance schedule instead of, or in addition to, the O&M cost you specify in the cost table. You can find the maintenance schedule button in the lower-right corner of the storage design inputs view.



The maintenance schedule allows you to input costs and/or downtime that occur at regular intervals. Check the box for "Consider Maintenance Schedule" to enable the maintenance schedule table, and include maintenance events in the simulation and economics calculations. In the example pictured below, we've included taxes and insurance as a yearly cost (8,760 calendar hours, which is once per year). The cell stack replacement after ten years is also included, with a downtime of ten hours.

> **Note:** An event that occurs every 8,760 Calendar hours (once per year) will only occur 24 times in a 25 year project. The event will occur at the end of every year from the first year to the 24th year, but not at the end of the 25th year.



The cost of each maintenance event is defined in terms of a Cost (fixed cost) and a Marginal Cost. The fixed cost is assessed the same regardless of the search space value being simulated. The marginal cost is multiplied by the value in the search space and added to the fixed cost to determine the total cost of the maintenance procedure. The Insurance and Tax event cost $50 per unit. So if we have a quantity or capacity of one for that storage component, the total cost per year for this item is $50 . If we also have a 3 in that search space, the simulation for quantity 3 would assess $150 per year for the Insurance and Tax event.

> **Note:** HOMER can only model the downtime for a maintenance event if it occurs in the first year, or if you are running HOMER in multi-year mode.

The cell stack replacement fixed cost is $1000. This could be the cost for the technician to come to the site and perhaps the cost to disconnect the battery bank as a whole and prepare if for service, and is assessed regardless of the size or quantity of the storage component. The marginal cost for this item is $2000. This could be the cost of the materials, plus the cost of the technician's time to replace the cell stacks in each battery. To continue with the example above, in the simulation with a size or quantity of one, the total cost of cell stack replacement would be $3000 every ten years. For the simulation with the search space entry of 3, the cost would be $7000 ($1000 + 3 x $2000).

> **Note:** HOMER does not model the storage charge controller as a separate component. You must include its cost and efficiency in the values you specify for the storage or in other components in the system.

See also

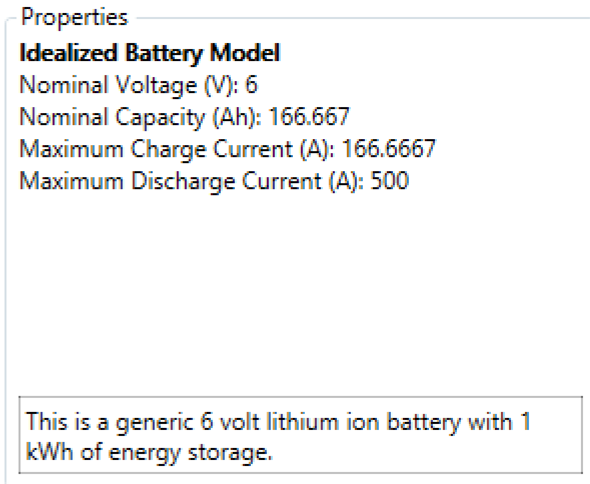
4.1.1 Storage

2.2.4.1 Idealized Battery

This type of battery is based on the Idealized Storage Model. To learn more about this model, please refer the article on the **Idealized Storage Model**.

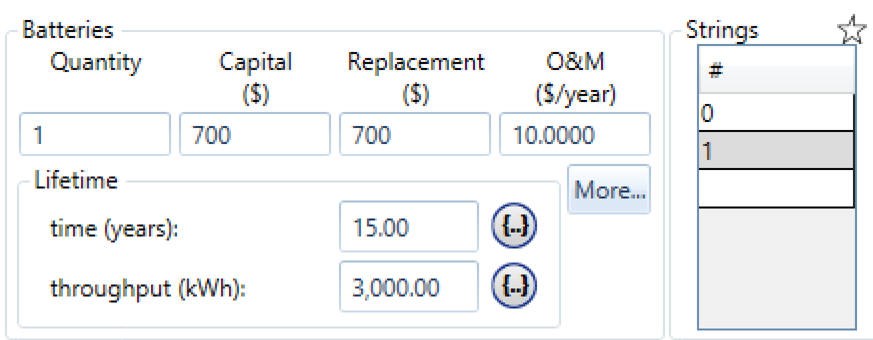
Properties of the Idealized Battery

This section gives information about the nominal voltage, nominal capacity, maximum charge and discharge current of the idealized battery. This battery is based on the Idealized Storage Model which assumes a flat capacity curve. This topic also explains how to specify an idealized battery in a HOMER model.



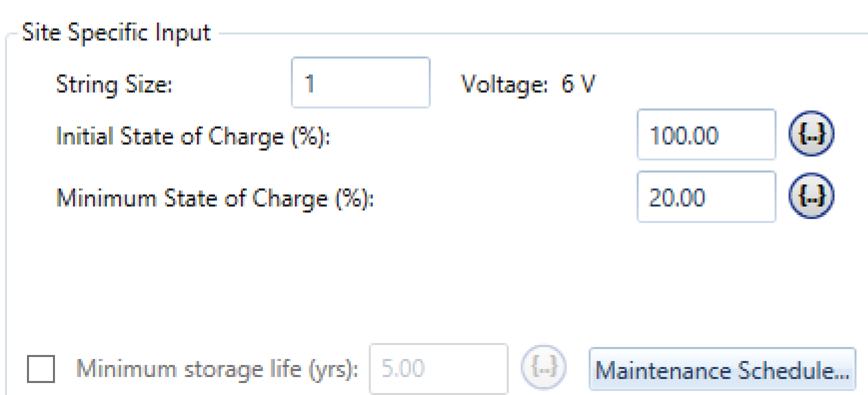
Lifetime Inputs

You can specify the lifetime of the supercapacitor bank with the lifetime inputs that appear just below the cost table. You can specify the lifetime in years, or throughput in kWh. If both time (years) and throughput (kWh) are specified, the component replacement occurs according to the one that elapses first.



Site Specific Inputs of the Supercapacitor

The site specific input section allows you to enter parameters that might change from project to project. The initial state of charge input sets the state of charge of the battery at the beginning of the simulation, in percent. The minimum state of charge input sets the lower limit on the state of charge, in percent.

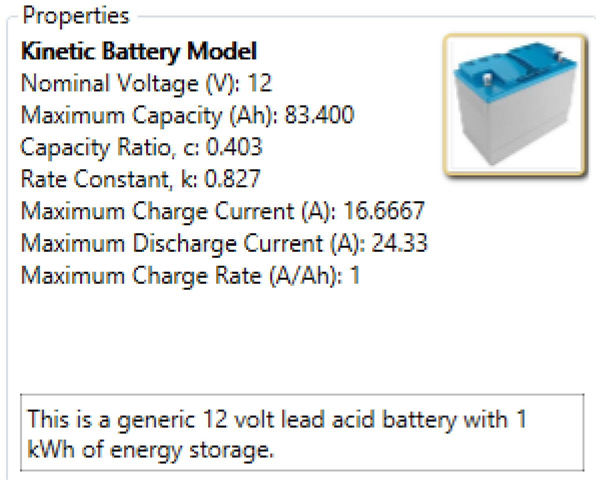


2.2.4.2 Kinetic Battery

The Kinetic Battery window allows you to define the costs of the battery, as well as parameters like the lifetime, throughput, and state of charge of the storage system.

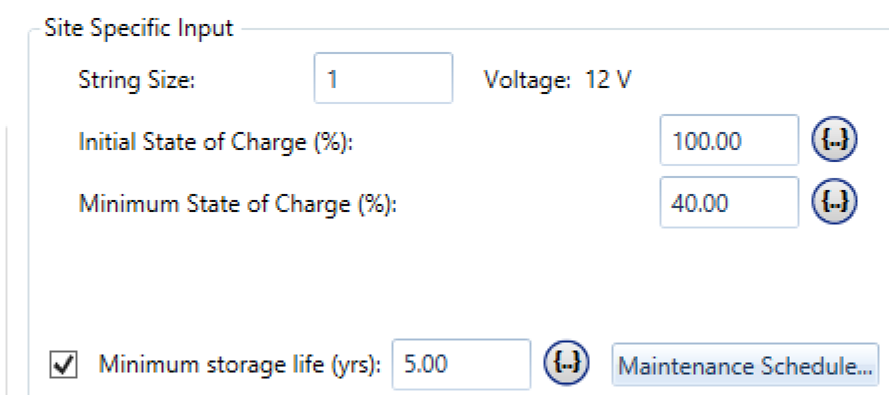
Properties of the Kinetic Battery

This section gives details of the kinetic battery model. You can change these properties in the **Library**. To find out more about the Kinetic Battery Model, please refer the article on the **Kinetic Battery Model**.



Site Specific Inputs of the Kinetic Battery

The site specific input section allows you to enter parameters that might change from project to project. The initial state of charge input sets the state of charge of the battery at the beginning of the simulation, in percent. The minimum state of charge input sets the lower limit on the state of charge, in percent.



Note: To the right of each numerical input is a sensitivity button ({..})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

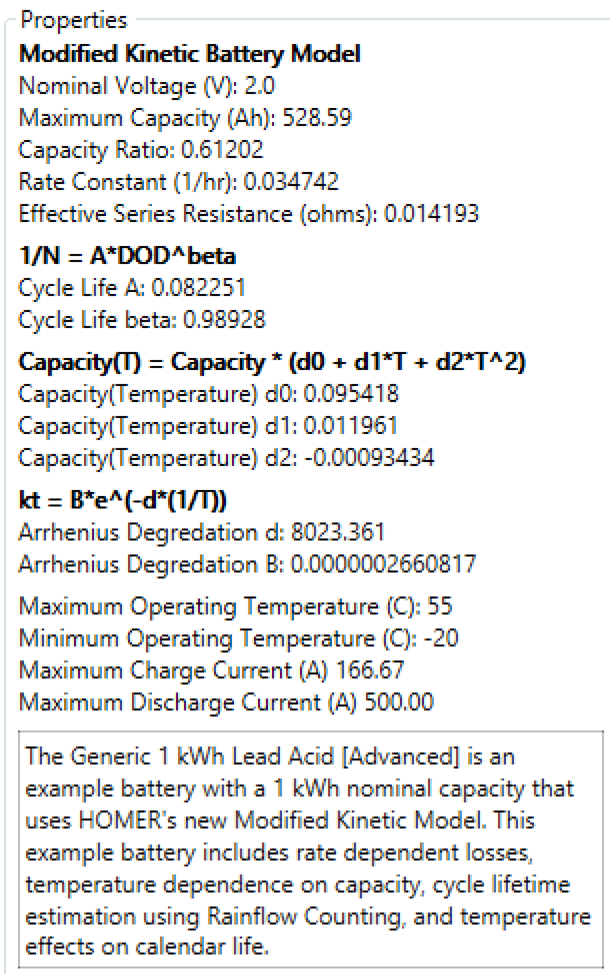
2.2.4.3 Modified Kinetic Battery

This feature requires the Advanced Storage Module. Click for more information.

The Modified Kinetic Battery Model accounts for rate dependent losses, temperature dependence on capacity, and temperature effects on calendar life. The model estimates cycle lifetime using the Rainflow Counting method. The storage components that require the Advanced Storage Module are denoted with the text **[ASM]** appended to their name.

Properties of the Modified Kinetic Battery

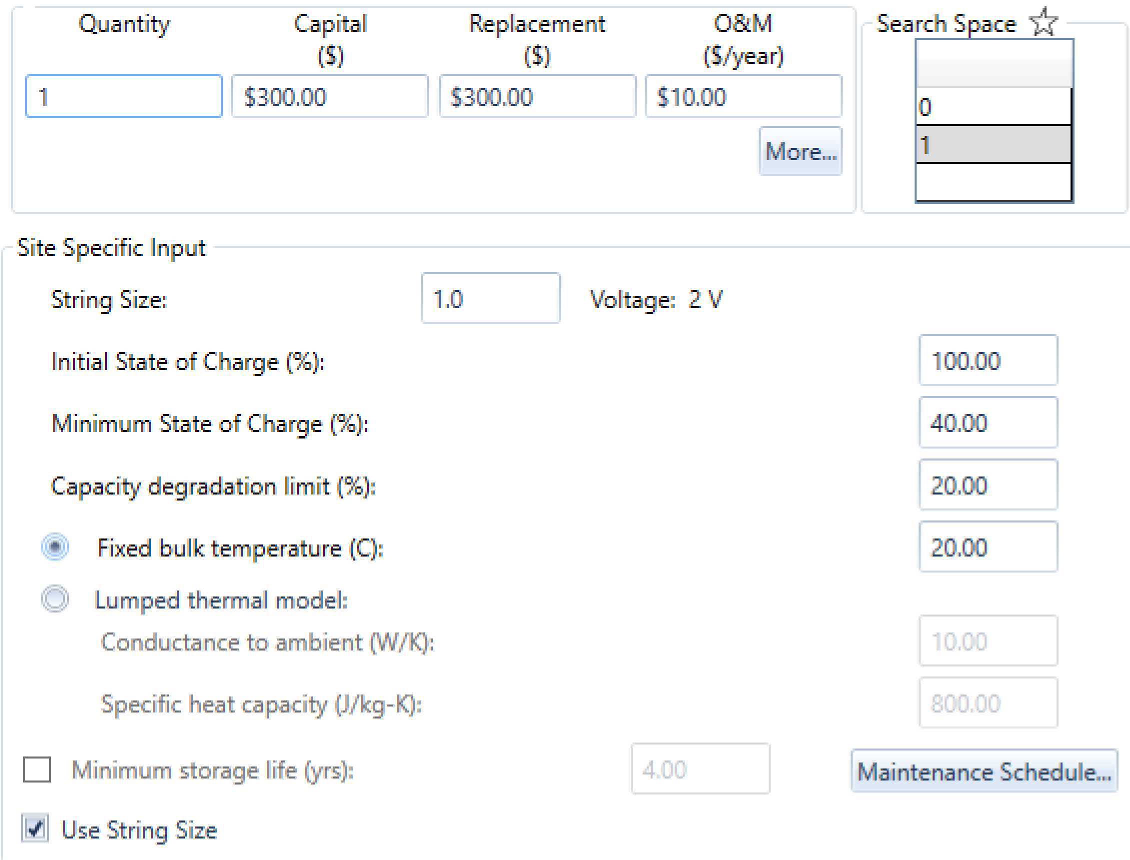
The properties box lists the parameters of the Modified Kinetic Battery Model for the selected battery. You can change these properties in the **Library**.



See the help topics **Creating a Modified Kinetic Storage Component** and **Modified Kinetic Battery Model** for a detailed explanation of these properties.

Site Specific Inputs of the Modified Kinetic Battery

The site specific input section allows you to enter several parameters that could vary from project to project. You can also set multiple values for any of these parameters to do a sensitivity analysis.



Variable	Description
Initial State of Charge (%)	The state of charge at the start of the simulation, in percent.
Minimum State of Charge (%)	The minimum allowed state of charge of the battery during simulation.
Consider temperature effects?	Specifies whether HOMER simulates the battery with a fixed internal temperature or uses a lumped thermal model to simulate the battery bank's internal temperature.
Capacity degradation limit	The percent degradation in capacity that triggers replacement of the component. The component is replaced when either of the two degradation variables exceed this limit. See **Modified Kinetic Battery Model** for details.

Note: To the right of each numerical input is a sensitivity button ({..})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.2.4.4 Supercapacitor

The Supercapacitor is based on the Idealized Storage Model. To learn more about this model, please refer the article on the **Idealized Storage Model**.

Properties of the Supercapacitor

This section gives information about the nominal voltage, nominal capacity, maximum charge and discharge current of the idealized battery. The Energy (joules) stored in a supercapacitor can be calculated with the following formula:

$$E_{joules} = 1/2\ C\ V^2 \qquad (1)$$

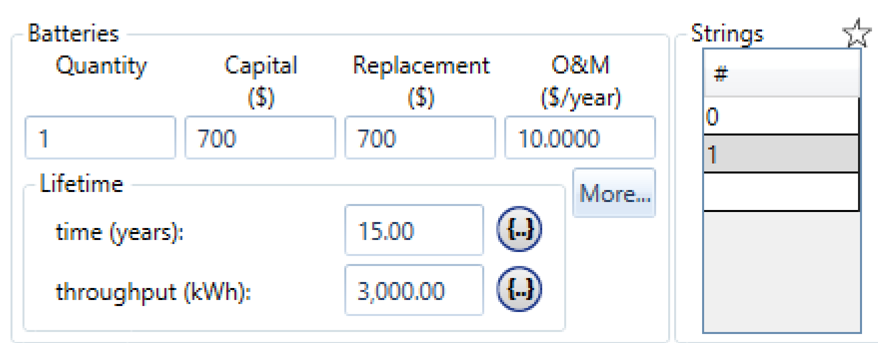
In the equation above, E is the energy stored in joules, C is the capacitance in farads, and V is the voltage. Then, we can specify the nominal capacity as the energy capacity (in watt-hours) divided by the nominal voltage, to get an effective capacity in amp-hours. This is not the same as calculating the charge capacity of a capacitor (farads x volts), since this would not produce the correct total energy capacity. Equation (1) above takes into account the proportional decrease in voltage over the discharge of a capacitor. The calculation for the nominal capacity input (in Ah) for HOMER is as follows:

$$N_{Ah} = E_{joules} / V / 3600 = 1/2\ C\ V / 3600 \qquad (2)$$

In this equation, N_{Ah} is the nominal capacity in amp-hours. We divide by 3600 to convert from joules to watt hours (or, equivalently, from coulombs or amp-seconds to amp-hours).

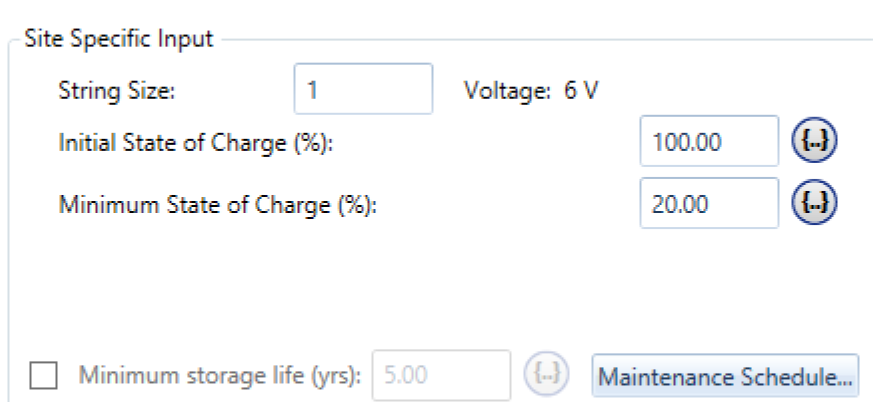
Lifetime Inputs

You can specify the lifetime of the supercapacitor bank with the lifetime inputs that appear just below the cost table. You can specify the lifetime by calendar years, or by throughput in kWh. If both time (years) and throughput (kWh) are specified, the component replacement occurs according to the one that elapses first.



Site Specific Inputs of the Supercapacitor

The site specific input section allows you to enter parameters that might change from project to project. The initial state of charge input sets the state of charge of the battery at the beginning of the simulation, in percent. The minimum state of charge input sets the lower limit on the state of charge, in percent.



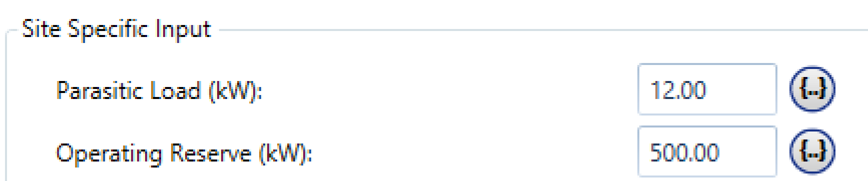
2.2.4.5 Flywheel

A flywheel provides operating reserve on the AC bus, helping to absorb sudden increases or make up for sudden decreases in renewable power output. A flywheel can also maintain power quality and system stability through active and reactive power control, although HOMER does not explicitly model those effects. These effects can be important in medium and high renewable penetration systems serving isolated networks or on soft grids (such as near the end of distribution lines). Flywheels typically connect to the AC bus via an AC/AC inverter system that converts the variable-frequency AC power from the flywheel rotor to constant-frequency, grid-quality AC power on the AC bus.

In HOMER, the flywheel adds its "charge/discharge capacity" to the operating reserve as a constant value, and then draws its "parasitic load" constantly from the AC bus. HOMER does not model the state of charge of the flywheel - it is assumed to only add power in time scales shorter than the simulation time step. To model a flywheel as an energy storage device, you can use one of the other storage models, such as the **Idealized Storage Model**. See the **Beacon Flywheel** for an example.

Site Specific Inputs of the Flywheel

In the Site Specific Inputs section, you can enter parameters that affect how the flywheel operates in the simulation.



The Parasitic Load is the amount of electricity necessary to operate the flywheel. HOMER models this as a constant electrical load, and considers a system **feasible** only if it can meet this load at all times during the simulation. The Operating Reserve input is the maximum amount of power the flywheel can absorb or provide. (HOMER assumes that the flywheel's capacity to absorb power is equal to its capacity to provide power.) This is the amount of **operating capacity** that the flywheel provides to the system.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why would I Do a Sensitivity Analysis?**

2.2.4.6 Pumped Hydro

A Pumped Hydro System works on building potential energy (storing water in a reservoir at a certain height) when there is excess energy, and converting the potential energy to electricity (releasing the potential energy to turn the turbine generator) when there is a demand. The reservoir is located at a certain height above the turbine generator (the head height) to generate potential energy. The flow rate is the amount of water (meters cubed per second) that flows in or out. You can use the following equation to calculate the energy storage capacity of a pumped hydro system:

$$E\ [J] = 9.81 \rho_{water} V_{res} h_{head} \eta$$

E is the energy stored in joules. Divide by 3.6×10^6 to convert to kWh.
ρ_{water} is the density of water, usually about 1000 kg/m^3.
V_{res} is the volume of the reservoir in cubic meters.
h_{head} is the head height in meters.
η is the efficiency of the energy conversion, and should consider losses like turbine efficiency, generator efficiency, and hydrodynamic losses.

You can convert from flow rate in meters cubed per second to power in kW using the following relationship:

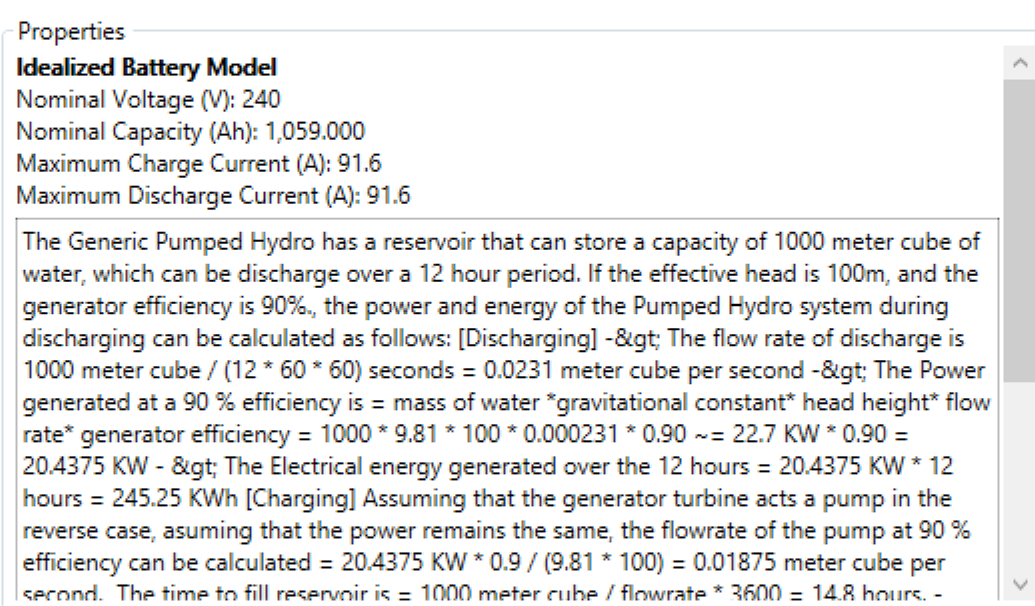
$$P\ [kW] = 9.81\ \rho_{water} h_{head}\ \eta\ F / 1000$$

F is the flow rate in meters cubed per second.

The storage in this example is based on the Idealized Storage Model. For many pumped hydro systems, the Idealized Storage Model will be the most applicable of the storage models that are available in HOMER. To learn more about this model, including how to create your own, please refer the article on the **Idealized Storage Model**.

Properties of the Pumped Hydro Storage

This section gives information about the nominal voltage, nominal capacity, maximum charge and discharge current of the idealized storage. To interpret these terminologies for the pumped hydro storage system, refer to the definitions below:

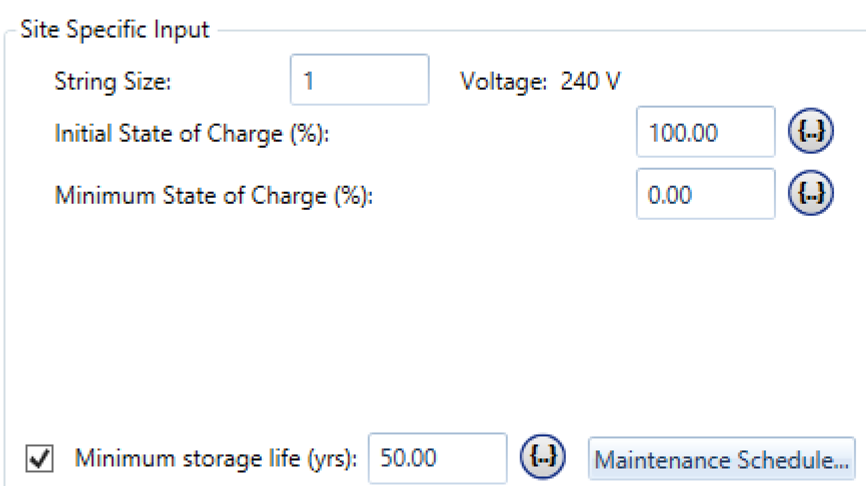


Variable	Pumped Hydro Storage System Interpretation
Nominal	The nominal voltage of the generator used in the pumped hydro system

Voltage	
Nominal Capacity	The total potential energy capacity of the reservoir: E [kWh] = 1000 [kg/m^3] * Volume [m^3] * 9.81 [m/s^2] * Head Height [m] / 3.6 x 10^6 [J / kWh]
Maximum Charge Current	Maximum current for charging the reservoir. This can also be computed as maximum pumping power divided by nominal voltage.
Maximum Discharge Current	Maximum current produced by discharging the reservoir, or maximum generating power output divided by the nominal voltage.
Roundtrip efficiency	The fraction on energy charging input that is recovered when discharging. This can include electrical losses, hydrodynamic losses, frictional losses, and other sources of loss, if applicable. You can also calculate it as pumping efficiency times generating efficiency, where both numbers are a fraction less than one, i.e. 0.8 * 0.85.

Site Specific Inputs of the Pumped Hydro storage

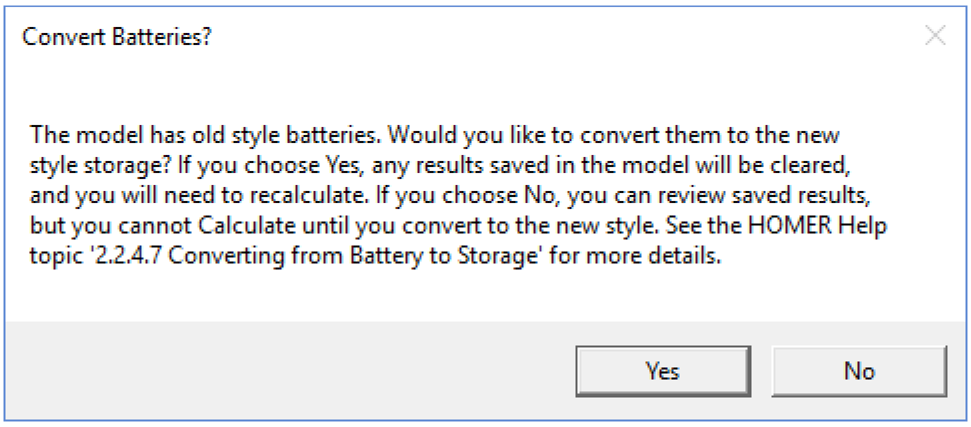
If the Pumped Hydro Storage component is modeled using the idealized energy storage model, the site specific inputs will be as described in the **Idealized Energy Storage** topic. The initial state of charge sets the fraction of the storage reservoir that is filled with water at the start of the simulation. The minimum state of charge sets the point when the storage is considered "empty" and no more energy can be taken out. For pumped hydro, this may be set to zero.



2.2.4.7 Converting from Battery to Storage

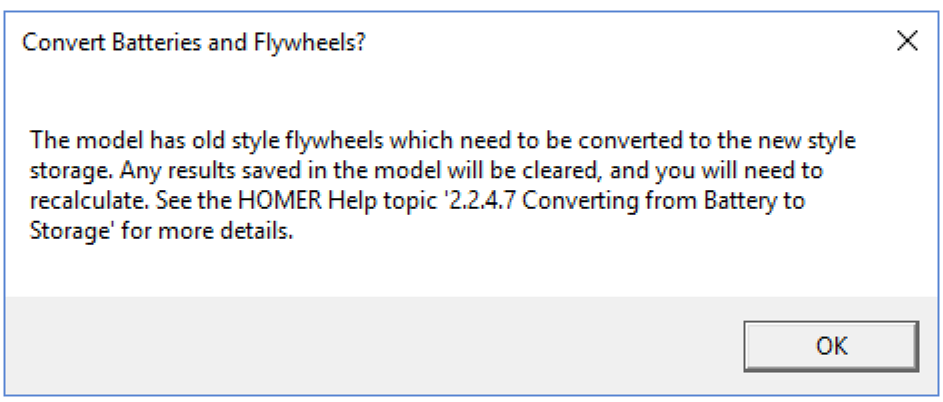
HOMER Pro versions 3.5.4 and earlier use the component called "Battery". In HOMER Pro 3.6 and later, this battery component has been replaced with a new component called "Storage". The new Storage component is designed to represent a wider range of storage technologies.

If you load a .homer file with a battery component, a pop-up message will appear asking you convert the battery components in your file to the new storage model. If you agree to convert, HOMER will automatically convert the batteries to the new storage type. This will not change the results. However, HOMER will erase the previous results saved in the .homer file, and you will need to recalculate the results.



You can choose not to convert to the new storage model, and you will be able to view the previous results. HOMER will prompt you again each time you open the file. You will not be able to calculate new results until you convert the model to use the new storage components.

Older style flywheels will be converted to the new storage component, since they can no longer be supported in the results. If you have any older style flywheels in your model, you will see a similar pop-up message, but you will not be given the choice; all of your flywheel and battery components will be converted to the new Storage component.

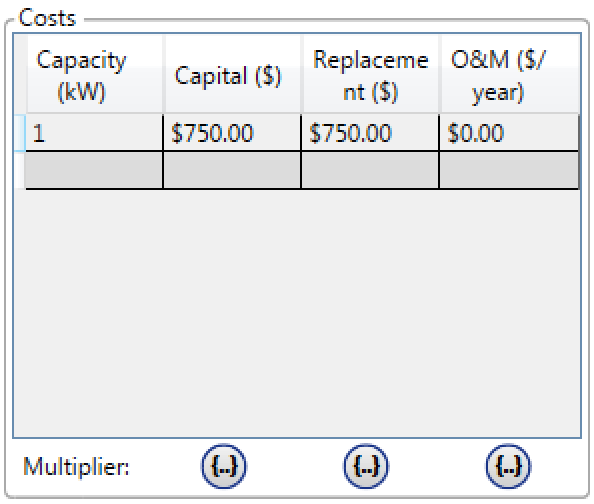


We apologize for any inconvenience this may cause. If there is any substantive change in your results, please send us an email at support@homerenergy.com

2.2.5 Converter

Any system that contains both AC and DC elements requires a converter. The Converter window allows you to define the costs of the converter as well as specify inverter and rectifier parameters.

Costs



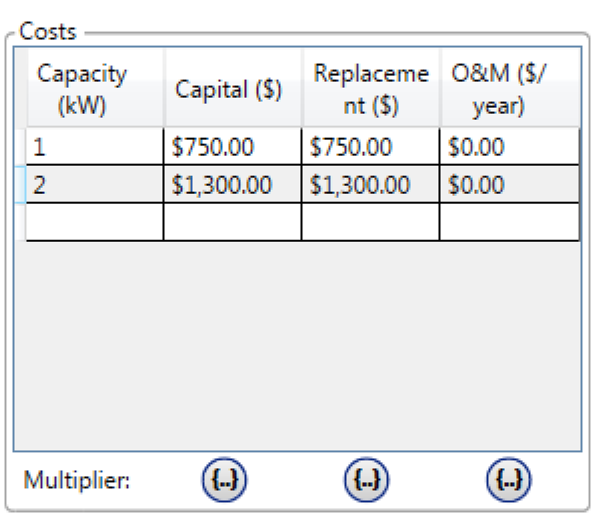
The Costs box includes the initial capital cost and **replacement cost** of the converter, as well as annual **operation and maintenance** (O&M) costs. When specifying the capital and replacement costs, remember to account for all costs associated with the converter, including installation.

Note that the **capital cost** is the initial purchase price, the replacement cost is the cost of replacing the converter at the end of its lifetime, and the O&M cost is the annual cost of operating and maintaining the converter.

Cost Curve

In the cost table, you can enter the converter *cost curve*, meaning the way the cost varies with size. Typically this requires only a single row since analysts often assume that costs vary linearly with size. In the sample above, the capital cost and the replacement cost of the converter is specified at $750/kW. The operating and maintenance cost is specified as zero.

You would enter multiple rows of data in the cost table if the cost of the converter subsystem was not linear with size. For example, if the capital and replacement costs dropped from $750/kW to $550/kW for quantities above 2 kW, you could fill in the cost table as follows:

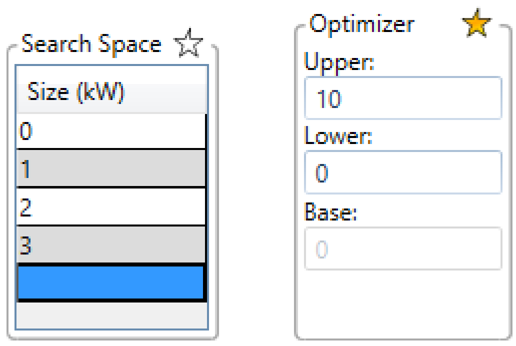


If you specify sizes other than those listed in the cost table, HOMER will interpolate or extrapolate based on the nearest two data points.

Search Space

Enter the nominal capacity of the inverter in kW, or enter several quantities for HOMER to consider in the system optimization. Include a zero if you would like HOMER to consider systems without the converter. The rectifier is sized proportionally to the inverter, as specified by the "Relative capacity" input.

Click the star icon to enable the optimizer. The search space will be replaced by a lower bound and an upper bound. With the optimizer turned on, HOMER will automatically find the best capacity for you.



See the help article about the **Optimization** menu for a more detailed explanation of HOMER's optimizer.

Inverter input

An inverter converts DC electricity to AC electricity. The `Inverter Input` box contains the following inputs:

Variable	Description
Lifetime	The expected lifetime of the inverter, in years
Efficiency	The efficiency with which the inverter converts DC electricity to AC electricity, in %
Parallel with AC generator?	Check this box if the inverter can operate at the same time as one or more AC generators. Inverters that are not able to operate this way are sometimes called switched inverters.

Note: It is possible to have a capacity shortage on one bus and excess electricity on the other in the same time step. An undersized converter, or one with the "Parallel with AC generator?" option **not** selected, can cause this to happen. Since this can be confusing, the converter will display a warning message whenever the "Parallel with AC generator?" option is not selected.

Rectifier input

A rectifier converts AC electricity to DC electricity. The `Rectifier Input` box contains the following inputs:

Variable	Description
Relative capacity	The rated capacity of the rectifier relative to that of the inverter, in %

Efficiency	The efficiency with which the rectifier converts AC electricity to DC electricity, in %

Note: To the right of each numerical input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why would I Do a Sensitivity Analysis?**

Note: HOMER assumes the inverter and rectifier efficiencies are constant. In fact, most solid-state converters are less efficient at very low load because of standing losses.

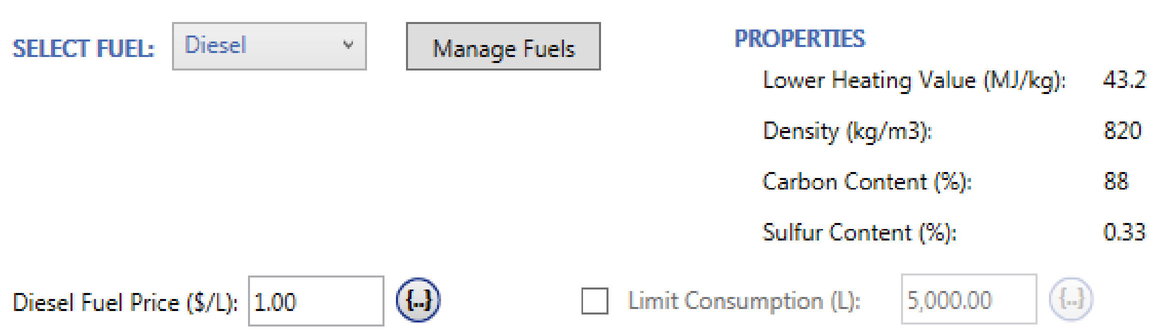
2.2.6 Boiler

This feature requires the Combined Heat and Power Module. Click for more information.

HOMER considers the serving of thermal load to be less important than the serving of electric load. When dispatching generators to serve the electric load, HOMER considers the value of any usable waste heat that can be recovered from each generator, but it will not dispatch a generator simply to serve the thermal load. It assumes the boiler can serve any thermal load that the generators do not. In other words, HOMER treats the boiler as a backup source of heat that can serve any amount of thermal load whenever necessary. HOMER requires you to add a boiler to the system whenever you have a thermal load.

Fuel Resource

This drop-down box contains all the fuels stored in your **component library**. Choose the appropriate fuel from this list. When a fuel is selected from the drop-down menu, detailed properties of the selected fuel are displayed.



You can create a new fuel type and remove or redefine an existing fuel in the library.

Fuel Price

Enter the price for the chosen fuel, and add sensitivity values for this cost. Will depend on the fuel, either in $/L or $/m^3.

Efficiency

Enter the fraction of the fuel's energy that gets converted to heat in the boiler.

Emissions factors

In this box, you can modify the following variables:

Variable	Description
Carbon Monoxide Emissions Factor	The quantity of carbon monoxide (in grams) emitted per unit of fuel consumed by the boiler
Unburned Hydrocarbons Emissions Factor	The quantity of unburned hydrocarbons (in grams) emitted per unit of fuel consumed by the boiler
Particulate Matter Emissions Factor	The quantity of particulate matter (in grams) emitted per unit of fuel consumed by the boiler
Proportion of fuel sulfur emitted as PM	The fraction of the sulfur in the fuel that is emitted as particulate matter (the rest is emitted as sulfur dioxide)
Nitrogen Oxides Emissions Factor	The quantity of nitrogen oxides (in grams) emitted per unit of fuel consumed by the boiler

See also:
5.3 How HOMER Calculates Emissions

2.2.7 Hydro

**This feature requires the Hydro Module.
Click for more information.**

HOMER can only consider a single size of hydro system. For this reason, the Hydro window does not contain tables of costs or sizes to consider. Instead, you simply specify the cost and properties of the size of hydro system that you want to consider.

Economics

These inputs specify the costs of the hydro system. Remember to include all costs associated with the hydro system, including the civil works.

Variable	Description
Capital Cost	The **initial capital cost** of the hydro system
Replacement Cost	The **replacement cost** of the hydro system
O&M Cost	The annual cost of operating and maintaining the hydro system

Lifetime	The number of years that the hydro system is expected to last

Turbine

These inputs specify the properties of the hydro turbine.

Variable	Description
Available Head	The vertical drop between the intake and the turbine
Design Flow Rate	The flow rate for which this hydro turbine was designed. It is often the flow rate at which the turbine operates at maximum efficiency.
Minimum Flow Ratio	The minimum flow rate of the hydro turbine, as a percentage of its design flow rate. Below this rate, the turbine will produce no power.
Maximum Flow Ratio	The maximum flow rate of the hydro turbine, as a percentage of its design flow rate. The turbine will generate power at the specified efficiency up to this flow. Additional flow above this level will not increase turbine power output.
Efficiency	The efficiency with which the hydro system converts the energy in the water to electricity

Intake pipe

This input allows you to specify the frictional losses that occur in the intake pipe which reduce the energy of the water before it goes through the hydro turbine. See the glossary entry on **Pipe Head Loss** for help calculating the head loss.

Variable	Description
Pipe Head Loss	Pipe friction losses expressed as a percentage of the available head

Systems to consider

The choice you make in this section will affect which systems HOMER considers as it searches for the least-cost system.

Variable	Description
Simulate systems with and without the hydro turbine	Choose this option to simulate systems both with and without the hydro turbine. HOMER will rank the systems according to cost so you can see whether or not the hydro system is cost-effective.
Include the hydro turbine in all simulated systems	Choose this option if you want all systems to include the hydro turbine.

Note: To the right of each numerical input is a sensitivity button ()which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also:

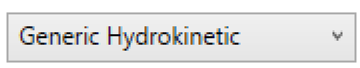
5.4 How HOMER Calculates the Hydro Power Output
6.6 Recommended Reading
7.118 Pipe Head Loss

2.2.8 Hydrokinetic

The hydrokinetic component can represent several different types of low-head hydro power generation including run-of-the-river, tidal, and wave energy electric generation. The component is described as a turbine, but the hydrokinetic component can also represent other technologies such as a wave energy converter. With a hydrokinetic component, you must also specify the **hydrokinetic resource**

The `Hydrokinetic` window allows you to choose the type of hydrokinetic installation you want to model, specify its costs, and tell HOMER how many to consider as it searches for the optimal system. You can also view and modify the power curve of the hydrokinetic turbine in the lower portion of the menu.

Turbine type



This drop-down menu located at the top of the hydrokinetic set up page contains all the hydrokinetic component types stored in your **component library**. Choose an appropriate model from this list. When you make a selection with this drop-down box, the selected turbine's properties are displayed in the space below.

Costs

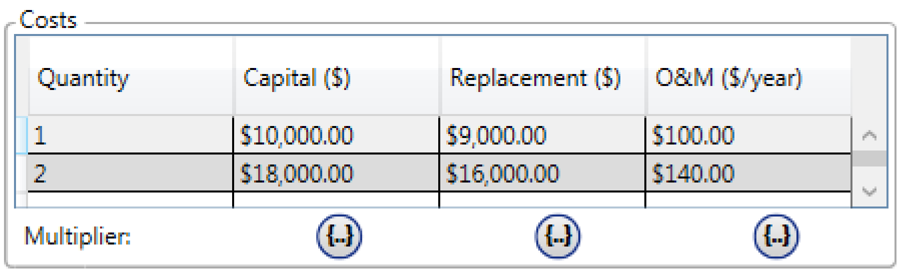
Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$10,000.00	$10,000.00	$500.00
Multiplier:	{...}	{...}	{...}

In the `Costs` table, the **capital cost** is the initial purchase price for a turbine, the **replacement cost** is the cost of replacing the turbine at the end of its lifetime, and the operating and maintenance cost is the annual cost of operating and maintaining the turbine.

Cost Curve

In the cost table, enter the turbine's *cost curve* in as much detail as you would like. In the simplest case, where each turbine costs the same regardless of how many you purchase, you only need to enter one row of data in the cost table. You would enter a quantity of one, along with the per-turbine capital, replacement, and operating and maintenance costs. HOMER extrapolates these costs as needed, so if you were to model a system with three turbines, the associated capital, replacement, and O&M costs would be three times the values entered in the cost table.



Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$10,000.00	$9,000.00	$100.00
2	$18,000.00	$16,000.00	$140.00

Multiplier:

You would enter multiple rows of data in the cost table if the cost of power was not directly proportional to the number of turbines purchased. In the example shown above, the second turbine is less expensive than the first (this could be because of a volume discount from the manufacturer or because certain fixed costs can be spread over multiple turbines). If the third turbine was even less expensive, another row of costs could be added. With just these two rows specified though, HOMER would extrapolate the costs by assuming that the third, fourth, and subsequent turbines cost the same as the second.

Search Space

Enter the quantity of turbines you would like, or enter several quantities for HOMER to consider in the system optimization. Include a zero if you would like HOMER to consider systems without this hydrokinetic turbine.

Electrical Bus

Select whether the turbine will produce AC or DC power. Power electronics are not modeled explicitly, but you can account for a dedicated converter efficiency by scaling the power curve.

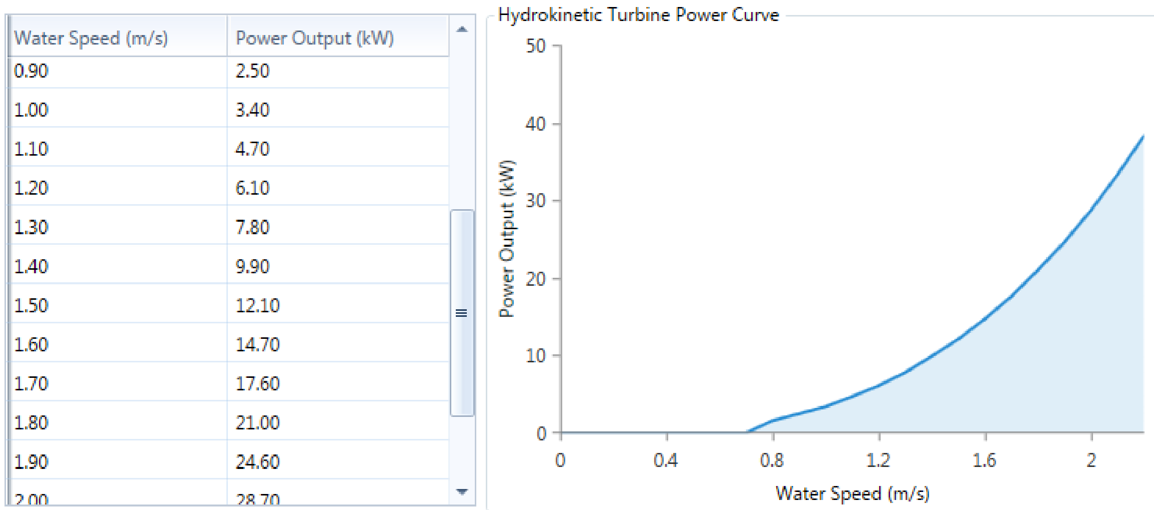
Site Specific Input

Variable	Description
Lifetime	The number of years the turbine is expected to last before it requires replacement

Note: To the right of each numerical input is a sensitivity button ()which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Power Curve

The Turbine Power Curve pane allows you to view the power curve of the selected turbine model in both tabular and graphical form. A turbine's power curve shows how much power it will produce depending on the water speed. Use this graph to verify that the turbine you have selected is an appropriate size for your system.



Manufacturer Properties

The Manufacturer Properties box displays some basic information for the turbine model you have selected.

Variable	Description
Abbreviation	A short label which is used to identify the turbine
Rated Capacity	The maximum rated power output for the turbine, in kW
Manufacturer	The company that manufacturers the turbine model
Website	The manufacturer's website

See also

2.3.7 Hydrokinetic Resource
4.1.9 Hydrokinetic
7.37 Component Library

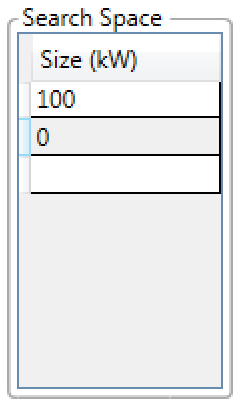
2.2.9 Thermal Load Controller

This feature requires the
Combined Heat and Power Module.
Click for more information.

The thermal load controller allows excess electrical production to serve loads on the thermal bus. A thermal load controller is not required for systems with a thermal load, but without it, excess electrical production is not used.

Size

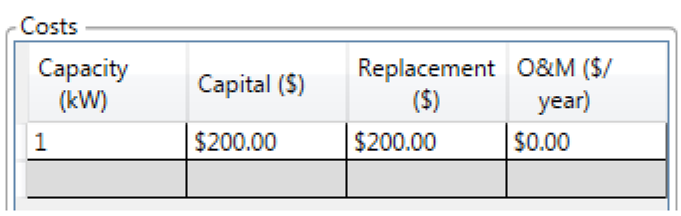
Use the box labeled Size to input what capacities you would like to consider.



In this table, enter the capacities you want HOMER to consider as it searches for the optimal system. HOMER will use the information you entered in the cost table to calculate the costs of each size, interpolating and extrapolating as necessary. You can see the results in the cost curve graph.

Costs

The Costs box includes the initial **capital cost** and **replacement cost**, as well as annual **operation and maintenance** (O&M) costs. The table also includes the size (kW) corresponding to the costs in each row. When specifying the capital and replacement costs, remember to account for all costs associated with the thermal load controller, including installation.



Note that the **capital cost** is the initial purchase price, the **replacement cost** is the cost of replacing the thermal load controller at the end of its lifetime, and the **O&M** cost is the annual cost of operating and maintaining the thermal load controller.

You can enter additional rows in the costs table to account for changing costs with scale.

Other Inputs

Variable	Description
Lifetime	The service life in years of the thermal load controller
Bus Connection	Specify "AC", "DC", or "Both" for the buses from which excess electrical production can be drawn
Do not include the thermal load controller in the optimization	This option models the thermal load controller with infinite capacity and no cost.

Note: To the right of each numerical input is a sensitivity button ({..})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also:

2.1.4 Thermal Load

2.2.6 Boiler

2.2.10 Grid

You can add the grid like any component and it will be treated as another part of your hybrid system. If you want an off-grid system, do not add a grid component.

The Grid window allows you to specify the grid several different ways:

- **Simple rates** mode allows you to specify a constant power price, sell back price, and sale capacity. All other modes require the Advanced Grid module.
- **Real time rates** define prices on an hourly basis by importing a properly formatted text file with time series data (requires Advanced Grid module).
- **Scheduled rates** permit different prices at each time of day and month of the year (requires Advanced Grid module).
- **Grid extension** mode will compare the cost of a grid extension with the cost of each stand-alone system configuration in the model (requires Advanced Grid module).

You can access other grid properties in addition to the rates by clicking on the corresponding tab.

- **Demand rates** provides options to model demand charges. This tab is only available in the **Real time rates** and **Scheduled rates** modes.
- **Reliability** provides options to model an unreliable grid with random outages. This tab is only available in the **Real time rates** and **Scheduled rates** modes.
- **Emissions** lets you specify emissions factors for several pollutants in terms of g/kWh.

See also:

5.3 How HOMER Calculates Emissions

2.2.10.1 Simple Rates

Simple rates mode allows you to set a constant power price and sellback price. You can also choose whether to use net metering, and set emissions factors associated with grid electricity. Simple rates mode is the only option that does not require the Advanced Grid module.

Rates

Grid rates refer to the prices associated with buying electricity from the grid and selling electricity to the grid. In HOMER, grid rates encompass the following variables:

Variable	Description

Grid Power Price ($/kWh)	The cost of buying power from the grid, in $/kWh.
Grid Sellback Price ($/kWh)	The price that the utility pays you for power you sell to the grid in $/kWh.
Net Metering	Select this option to base grid energy charges on net usage. See **Net metering** for explanation.
Net purchases calculated monthly	With this option net usage is calculated monthly
Net Purchases Calculated Annually	With this option net usage is calculated annually

See also:

2.2.10.8 Emissions
2.2.10.9 Net Metering

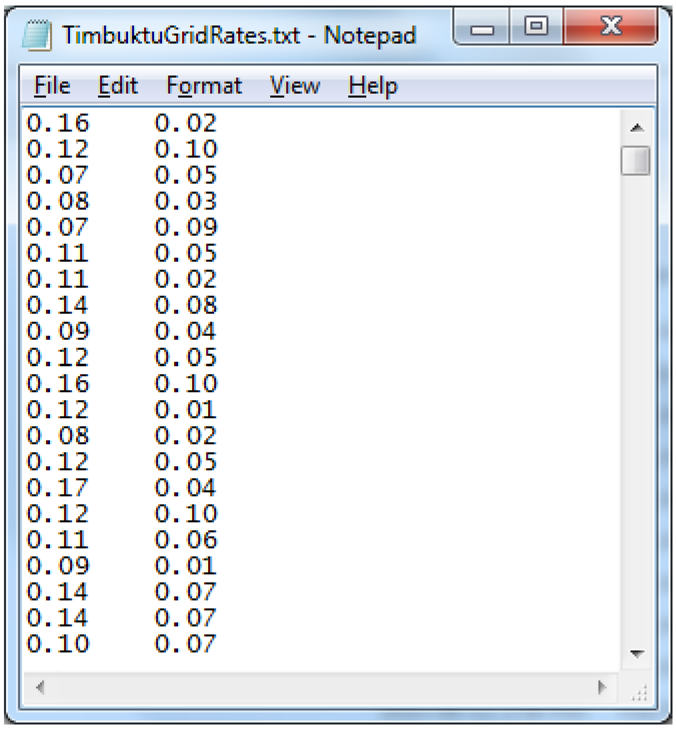
2.2.10.2 Real Time Prices

This feature requires the Advanced Grid Module. Click for more information.

Real time prices models the situation where grid power prices can change from time step to time step. In the advanced grid menu, select the "Real time prices" radio button to choose this mode. You can import the time-series price data in the "Power Prices" tab by clicking the "Import Rates" button. The price data will display in the two D-maps to the right of the "Import Rates" button. In this mode, you can control many prices and limits in the "Settings" tab (described in detail below). You can also define **demand charges**, **grid outages**, and **grid emissions** in the other tabs.

Tip: In HOMER, January 1st is always a Sunday.

To model real time prices you must create an input file with two data columns, one for the power price [$/kWh] in each time step and one for the sellback rate [$/kWh] in each time step. The data file must contain one line of data for each time step of one year: 8,760 lines for hourly data, 35,040 lines for 15-minute data, 52,560 for 10-minute data, and so on. You can import data with any time step down to one minute. The first entry in the file should correspond to midnight on Sunday, January 1st. The file cannot contain any header information, so every line of the file should simply contain two numbers separated by commas or tabs. The screenshot below shows an example of a valid input file.



Since the HOMER standard year starts on a Sunday, you might need to adjust your price time series to match. If any part of your HOMER model is sensitive to weekdays versus weekends (i.e. a load that is higher on weekdays), you may need to modify your grid rate data so that the first day is a Sunday. You can usually adjust your data to start on a Sunday by cutting a few days from the beginning of the load profile and pasting them at the end (or vice-versa). Keep in mind that if you view the hourly time series plot for your simulation, your load will be shifted by the number of days you moved.

You cannot specify the demand charge on a time step by time step basis, so even if you choose real time prices you will need to specify demand charges using the **demand rate** schedule.

Control Parameters

The following options affect when the system is able to buy from or sell to the grid.

Control	Description
Prohibit grid from charging battery above power price	If enabled, this prevents the grid from charging the battery if the grid power price is above the specified value
Prohibit any battery charging above power price	If enabled, this prevents any battery charging if the grid power price is above the specified value
Prohibit grid from discharging battery below power price	If enabled, this prevents discharging of the battery to the grid if the grid power price is below the specified value
Prohibit grid sales from battery below sellback rate	If enabled, this prevents grid sales from the battery if the grid sellback rate is below the specified value
Prohibit any grid sales below sellback rate	If enabled, this prevents any grid sales if the grid sellback rate is below the specified value

Additional Options

Variable	Description
Interconnection Charge	The one-time fee charged by the utility for allowing a power system to be connected to the grid. This fee does not apply to grid-only systems.
Standby Charge	The annual fee charged by the utility for providing backup grid power for a grid-connected power system. This fee does not apply to grid-only systems.
Grid capital cost (grid extension)	A one-time cost incurred for any system that includes the grid, per kilometer of grid extension required. If "Simulate systems with and without the grid" is selected, systems without the grid will not include this fee.
Grid extension distance	The distance, in kilometers, that the grid must be extended to connect to the system. This is multiplied by the "Grid capital cost" to determine the total additional cost applied to grid connected systems.
Maximum Net Grid Purchases	The maximum net amount of energy that can be drawn from the grid, in kWh/yr
Net Metering	Select this option to base grid energy charges on net usage. See **Net metering** for explanation.
Net purchases calculated monthly	With this option net usage is calculated monthly
Net Purchases Calculated Annually	With this option net usage is calculated annually
Simulate systems with and without the grid	Include grid-connected systems and standalone systems in the optimization. Standalone systems will only appear in the results if the load can be met without the grid connection (according to the **maximum annual capacity shortage** setting).
Include the grid in all simulations	The system will be grid connected in all simulations.
Sale capacity	Maximum instantaneous grid sales, in kW. See **Purchase and Sale Capacities**.
Purchase capacity	Maximum instantaneous grid purchases, in kW. See **Purchase and Sale Capacities**.

See also:

2.2.10.8 Emissions

2.2.10.3 Scheduled Rates

This feature requires the Advanced Grid Module. Click for more information.

The scheduled rates option allows you to define grid prices with a regular schedule according to time of day, month of the year, and weekdays or weekends (often called "Time of Use" rates or TOU). In the advanced grid menu, select the "Scheduled rates" radio button to choose this mode. To define a scheduled price structure, select the "Power Prices" tab, add one or more rates to the rate table, specify the properties for each rate, and define the schedule on the grid rate schedule chart. In this mode, you can control many prices and limits in the "Settings" tab (described in detail below). You can also define **demand charges**, **grid outages**, and **grid emissions** in the other tabs.

Rate Table

Users can define several rates and use the schedule diagram to indicate when each rate applies. Each rate can have different values of power price and sellback rate.

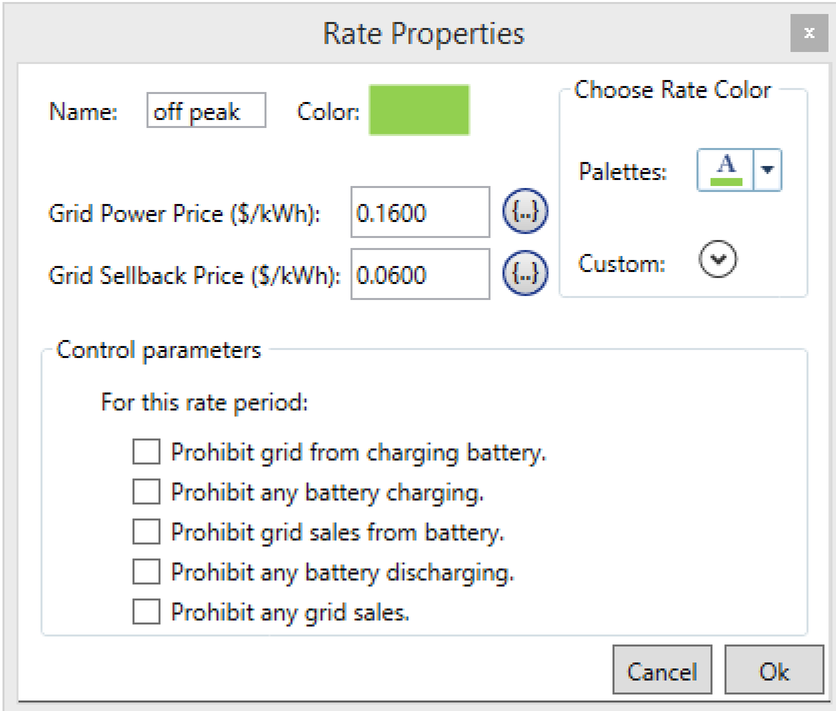
You can change the properties of a rate in the rate table. Click on the button to create a new rate. Click and drag over the rate schedule chart while that row is highlighted to schedule the new rate.

If the power price and sellback rate never change, you only need to define a single rate (equivalent to **Simple rates** mode). This is often the case for residential consumers. On the other hand, if the power price or sellback rate changes according to the time of day or the day of the year, you will need to define more than one rate. In the following example, the user has defined three rates, each with different values of power price and sellback rate.

			Price	Sellback		
⚠	peak		0.2001	0.0600	Edit	✕
⚠	shoulder		0.2000	0.0600	Edit	✕
	off peak		0.1600	0.0600	Edit	✕

Rate Properties

Each rate is defined in the rate properties window. Click on the Edit button to access the rate properties menu.



This window allows you to view and edit the properties of a grid rate, including:

Variable	Description
Name	The name HOMER uses to identify the rate
Power Price	The cost of buying power from the grid, in $/kWh
Sellback Rate	The price that the utility pays you for power you sell to the grid, in $/kWh. Under net metering, the sellback rate applies only to net excess generation.

Note: To the right of each numerical input is a sensitivity button ({..})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

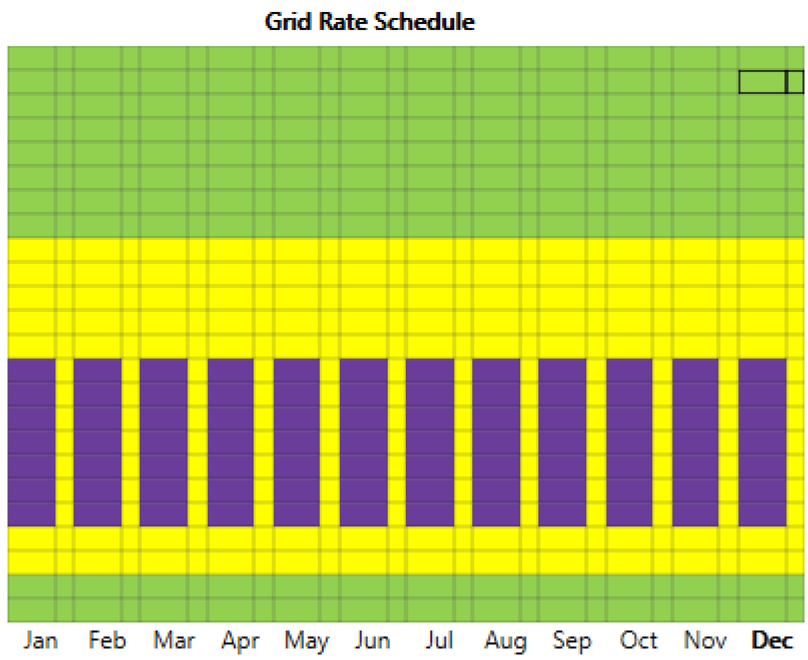
In addition to these basic options, you can set six control options that affect the behavior of the system. These settings affect the system control only during times when the selected rate is scheduled.

Control	Description
Prohibit grid from charging battery	If enabled, this prevents any battery charging from the grid during this rate.
Prohibit any battery charging	If enabled, this prevents any battery charging during this rate.
Prohibit grid sales from battery	If enabled, this prevents discharging of the battery at any time when power is being sold to the grid during this rate.
Prohibit any battery discharging	If enabled, this prevents the battery from discharging during this rate.

Prohibit any grid sales	If enabled, this prevents any grid sales during this rate.

Schedule

The table at the bottom of the window shows the times at which each rate applies. If you define multiple rates, you can click and drag on the rate schedule chart to indicate when each rate applies. In the following example the 'Peak' rate applies weekdays from 1pm to 8pm. The 'Shoulder' rate applies all week from 8am to 10pm. The 'Off-peak' rate applies at all other times.



To modify the schedule shown above, you could select the 'Peak' rate, click the All Week button to the left of the rate table, then click on the rate schedule cell for 2pm-3pm in April, then holding the mouse button down, drag to the cell for 7pm-8pm in October and release the mouse button. This would change the rate schedule so that weekends from 2pm - 8pm in April-October would also fall under the peak rate (instead of 'shoulder').

Additional Options

Variable	Description
Interconnection Charge	The one-time fee charged by the utility for allowing a power system to be connected to the grid. This fee does not apply to grid-only systems.
Standby Charge	The annual fee charged by the utility for providing backup grid power for a grid-connected power system. This fee does not apply to grid-only systems.
Grid capital cost	A one-time cost incurred for any system that includes the grid. If "Simulate systems with and without the grid" is selected, systems without the grid will not include this fee.
Maximum Net Grid Purchases	The maximum net amount of energy that can be drawn from the grid, in kWh/yr

Net Metering	Select this option to base grid energy charges on net usage. See **Net metering** for explanation.
Net purchases calculated monthly	With this option net usage is calculated monthly
Net Purchases Calculated Annually	With this option net usage is calculated annually
Simulate systems with and without the grid	Include grid-connected systems and standalone systems in the optimization. Standalone systems will only appear in the results if the load can be met without the grid connection (according to the **maximum annual capacity shortage** setting).
Include the grid in all simulations	The system will be grid connected in all simulations.
Sale capacity	Maximum instantaneous grid sales, in kW. See **Purchase and Sale Capacities**.
Purchase capacity	Maximum instantaneous grid purchases, in kW. See **Purchase and Sale Capacities**.

2.2.10.4 Grid Extension

This feature requires the Advanced Grid Module. Click for more information.

Use this option if you want to consider grid extension as an *alternative* to a stand-alone system. HOMER will compare the cost of the grid extension with the cost of each stand-alone system configuration that you model. For each stand-alone system configuration, HOMER will calculate the break-even grid extension distance, which is the distance from the grid at which the total net present cost of the grid extension is equal to the total net present cost of the stand-alone system.

Variable	Description
Capital Cost	The initial capital cost of the grid extension, in $/km
O&M Cost	The annual cost of maintaining the grid extension, in $/yr/km
Grid Power Price	The price of electricity from the grid, in $kWh

Note: You can also use the option "Simulate systems with and without the grid" under "Systems to consider" in the "real time prices" or "scheduled rates" grid modes. This allows you to compare systems with and without the grid connection with a more detailed grid model that can include a more complex grid rate structure and many other parameters. See **Real Time Prices** or **Scheduled Rates** for more details.

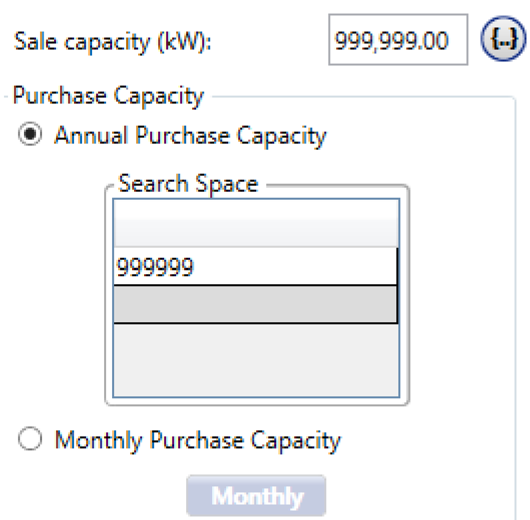
See also

2.2.10.1 Simple Rates
7.26 Break-even Grid Extension Distance

2.2.10.5 Purchase and Sale Capacities

This feature requires the Advanced Grid Module.
Click for more information.

Real time rates mode and scheduled rates mode include a sale capacity input (sensitivity variable) and a purchase capacity input (optimization variable). You can use these variables to model the grid connection capacity or optimize peak shaving for demand rate reduction.



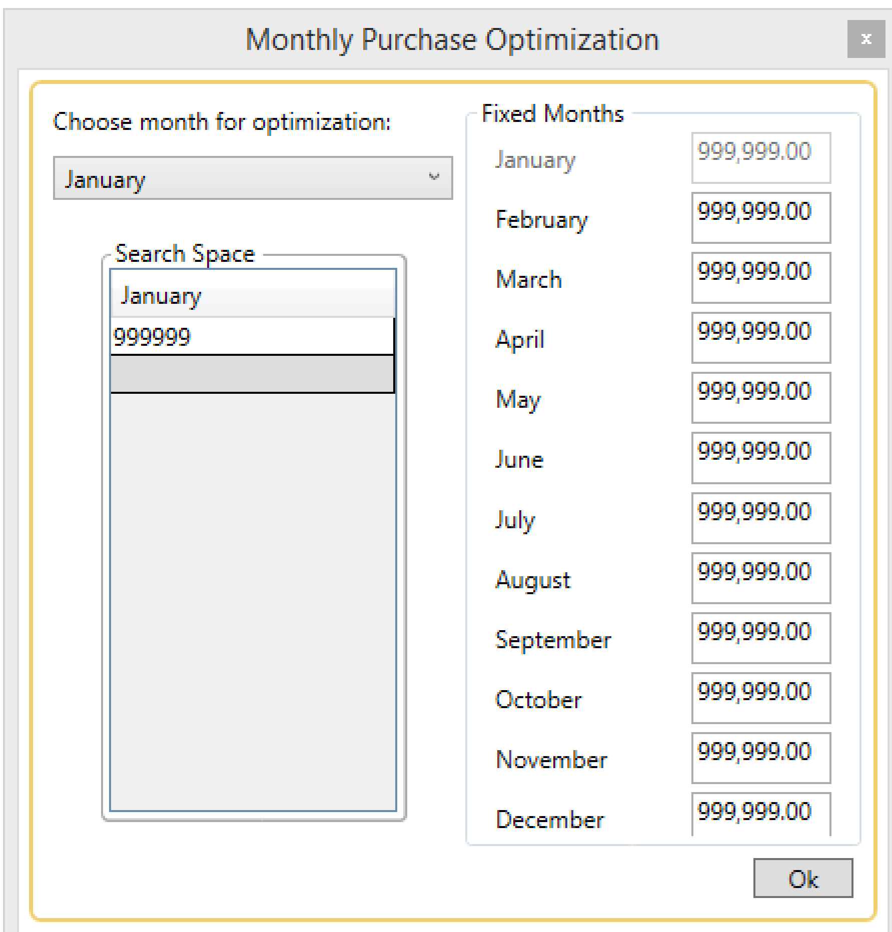
The **sale capacity** is the maximum power that can be sold back to the grid, in kW. For example, with a sale capacity of 100 kW, the grid sales can never exceed 100 kW for a time step. With one-hour time steps, this implies that no more than 100 kWh can be sold to the grid in any single time step. Sale capacity is a sensitivity variable, allowing you to explore the effect of different connection capacities.

The **purchase capacity** is the maximum power that can be purchased from the grid. This can correspond to the grid connection capacity. For example, similar to sale capacity, with one hour time steps, a purchase capacity of 100 kW would mean that a maximum of 100 kWh could be purchased from the grid in any one time step.

The purchase capacity is an optimization variable, which can be useful to reduce demand charges for peak shaving systems. You can set several purchase capacities to see how much the demand charge can be reduced by forcing the system to use it's other sources for peak demands (i.e. generator, batteries, etc). For example, you could set several values for storage bank size, and several values for purchase capacity. Larger storage bank sizes would allow a lower purchase capacity to be feasible, and thus lower demand charges, but would increase capital costs. HOMER can find the storage bank size that is most cost-effective for demand charge reductions.

Note: Purchase capacity is a **decision variable** because of the effect of demand charges. If the demand rate is zero, you need only specify a single value for the maximum grid demand. If the demand rate is not zero, specify a value equal to or greater than the peak load, plus at least one value smaller than the peak load. HOMER will find the optimal value.

You can also select the "Monthly purchase capacities" radio button and then click the "Monthly" button to set **monthly purchase capacities**, corresponding with demand charges that are structured on a monthly basis. Setting the purchase capacity on a monthly basis may provide a more accurate representation of potential demand charge savings.



The monthly purchase capacity menu is structured to only allow optimization of one month at a time, because optimizing all twelve months is computationally prohibitive, since HOMER will simulate all permutations of the optimization variables (i.e. even with four values per month, 4^12 is almost 17 million simulations). You can manually set the search space for any of the months (and more than one month at a time) using the **search space editor**.

2.2.10.6 Demand Rates

This feature requires the Advanced Grid Module. Click for more information.

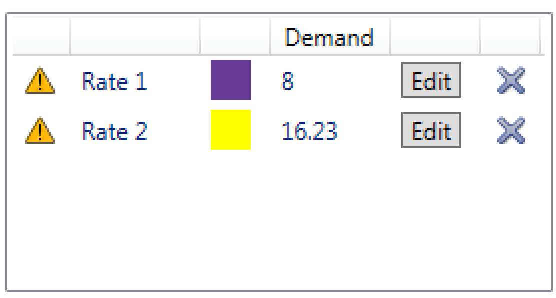
In "**Real time rates**" and "**Scheduled rates**" modes, there is a tab labeled Demand Rates. The settings in this tab allow you to specify a demand rate structure for the grid.

Rate Table

Users can define several rates and use the schedule diagram to indicate when each rate applies. Each rate can have a different value of the demand rate, and different storage control settings.

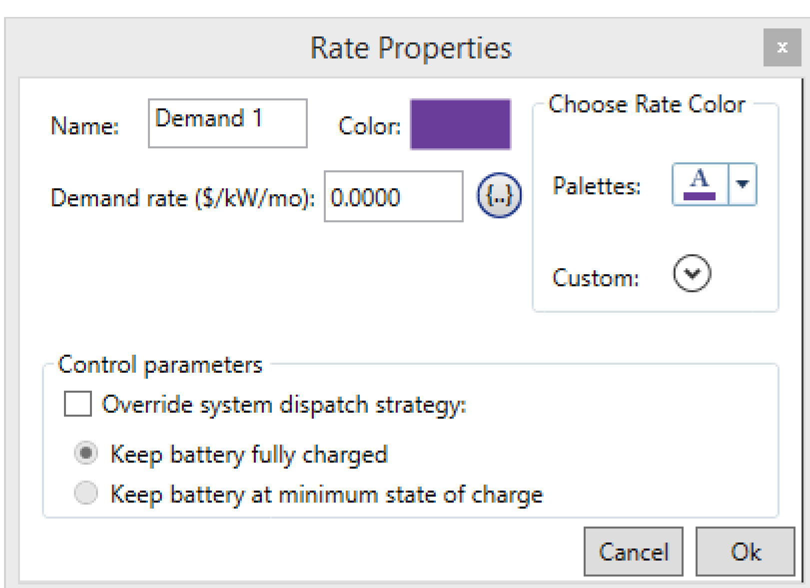
You can change the properties of a rate in the rate table. Click on the button to create a new rate. Click and drag over the rate schedule chart while that row is highlighted to schedule the new rate.

If the demand rate does not depend on the time of day or day of the year, you only need to define a single rate. In the following example, the user has defined two demand rates. During "Rate 2" (May through October), the demand charge will be $16.23 times the peak demand in kW for each month. During "Rate 1" (November through April), each month will have a demand charge equal to $8 times the peak demand in kW.



Rate Properties

Each demand rate can be defined in its properties window. Click on the Edit button to access the demand rate properties menu.

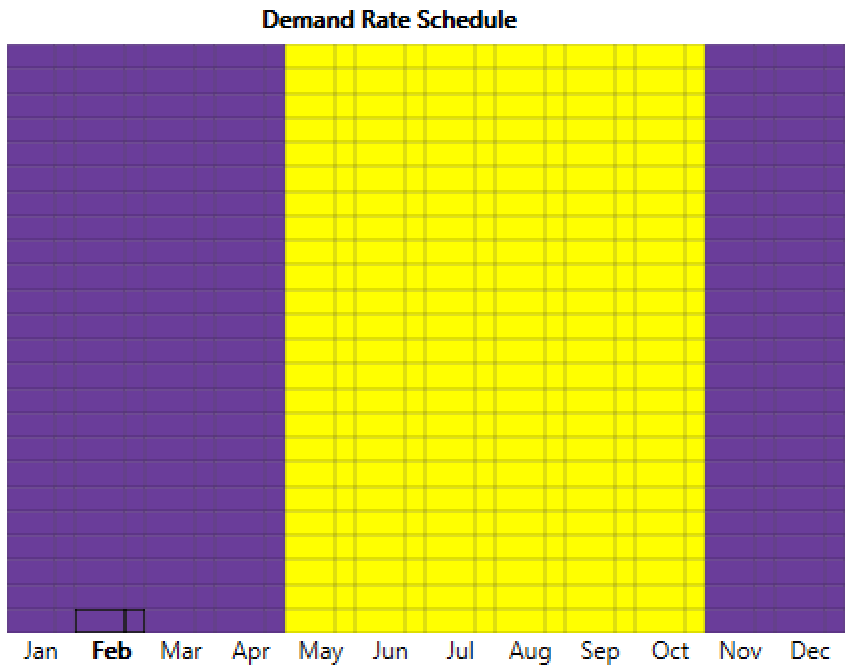


This window allows you to view and edit the properties of a demand rate, including:

Variable	Description
Name	The name HOMER uses to identify the rate
Demand Rate	The monthly fee charged by the utility on the monthly peak demand, in $/kW/month.
Override system dispatch strategy	If checked, HOMER will not use its economic decisions and instead will force the storage to maintain the state of charge selected below.
Keep storage fully charged	Keep the storage fully charged unless the energy is needed to avoid a capacity shortage.
Keep storage at minimum state of charge	Sell or use all storage energy whenever possible, and only charge the storage when there is excess electricity. This is most applicable in systems where renewable generation can exceed the grid sale capacity.

Schedule

The table at the bottom of the window shows the times at which each rate applies. If you define multiple rates, you can click and drag on the rate schedule chart to indicate when each rate applies. In the following example 'Rate 2' applies all days May through October. 'Rate 1' applies at all other times.

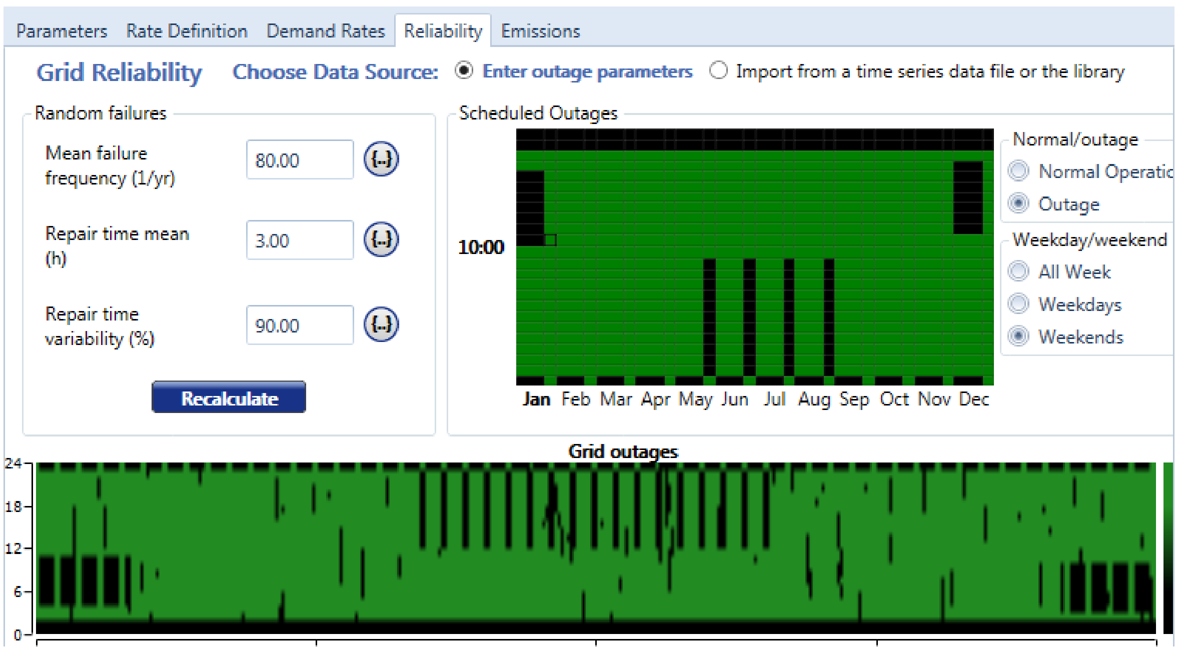


To draw the schedule shown above, you would add 'Rate 2' to the rate table and select it. Click on the first row in the rate schedule cell for May, and then holding the mouse button down, drag to the bottom cell for October and release the mouse button.

2.2.10.7 Reliability

This feature requires the Advanced Grid Module. Click for more information.

In "**Real time rates**" and "**Scheduled rates**" modes, there is a tab labeled Reliability. The settings in this tab allow you to specify grid outages to model an unreliable grid. You can schedule outages by time of day and month of the year, and you can set parameters to generate random outages throughout the year. Outages are modeled as one or more time steps in which no electricity can be purchased from or sold to the grid.



Scheduled Outages

You can draw the outage schedule on the "Scheduled Outages" grid by clicking or clicking and dragging the mouse on the grid. You can select "Outage" or "Normal Operation" with the radio buttons on the right. Select "Outage" to draw outages on the grid, and "Normal Operation" to "erase" outages. The thin columns on the grid represent weekends, and the thick columns represent weekdays for each month. Select "All Week", "Weekdays", or "Weekends" from the radio buttons on the right to change which columns you are drawing.

In the example screenshot above, there is an outage every night from midnight to 2 am and outages on January weekdays from 4 am to 11 am and December weekdays from 3 am to 11 am. There are outages on weekends in May through August from noon to 11 pm, and outages on weekdays from 11pm to midnight. The random outage schedule is overlaid on top of the scheduled outages.

Random Outages

Specify the failure frequency and duration using the inputs. HOMER will generate the outage time series, and display the outages in the DMap below. Outages will appear in black, and regular grid operation appears in green. The grid outage time series, as displayed here, will be used in all simulations.

Variable	Description
Mean failure frequency	Number of times the grid will fail per year.
Mean repair time	Mean duration of grid outages, in hours.
Variability in repair time	The standard deviation of a grid failure duration, expressed as a percentage of the mean. Percentages higher than 100% are allowed.

Algorithm

HOMER generates each random outage by picking a pseudo-random time step from the year-long simulation period. HOMER then chooses the duration of that outage by picking a pseudo-random number from a normal distribution specified by the "Mean repair time (h)" and Variability in repair time (%)" inputs.

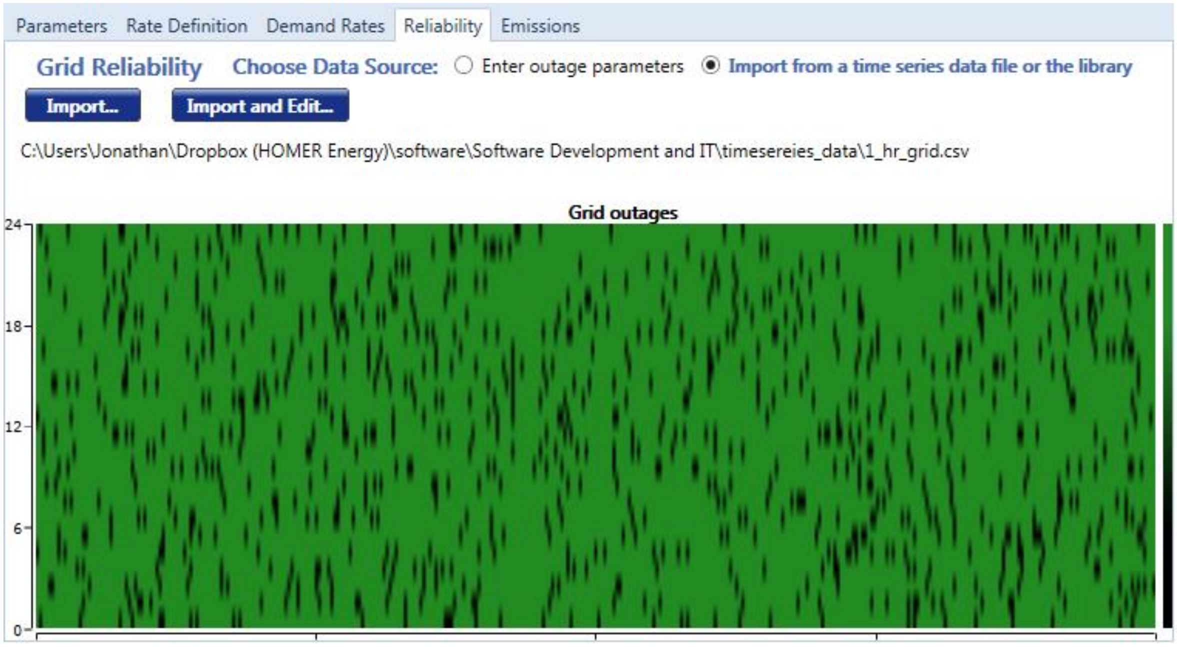
HOMER will try to generate distinct, non-overlapping outages equal to the number specified for "Mean failure frequency (1/yr)", not considering scheduled outages. As it chooses the time step index for each outage, it will only choose an index that will not overlap with an existing outage, if possible. If there are too many outages (or the durations are too long), some outages will overlap. This algorithm does not take the scheduled outages into consideration. The outages from this random algorithm are combined with those from the outage schedule to generate the final outage time series.

Import Time Series

You can import your own time series of grid outages. Select the option for "Import from a time series data file or the library" at the top of the Reliability menu. In this menu you are given the option to "Import..." or "Import and Edit...". You can use either of these functions to import your own text file time series of outages.

```
0
1
1
0
0
0
0
1
1
1
1
0
0
1
0
0
```

Your data file should contain a single column of zeros and ones, without any headers or row titles. A one (or any non-zero number) indicates that the grid is operational during the corresponding time step. The system can purchase from and sell to the grid. A zero indicates that the grid is off for the corresponding time step. During this time step where the grid is off, corresponding to an outage or failure, the system cannot buy from or sell to the grid.



For all data imported from a file, HOMER will infer the time step by the number of rows in the data file, and assume that the data is of one-year duration. For a file with 8,760 rows, HOMER will assume that it is hourly data (there are 8,760 hours per year). If the file contains 525,600 rows, HOMER will assume that it contains one-minute data. HOMER can read files with several integer time steps between one hour and one minute: 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, and 60 minutes are valid time step sizes.

Tip: In HOMER, January 1st is always a Sunday.

Since the HOMER standard year starts on a Sunday, you might need to adjust your price time series to match. If any part of your HOMER model is sensitive to weekdays versus weekends (i.e. a load that is higher on weekdays), you may need to modify your grid rate data so that the first day is a Sunday. You can usually adjust your data to start on a Sunday by cutting a few days from the beginning of the load profile and pasting them at the end (or vice-versa). Keep in mind that if you view the hourly time series plot for your simulation, your load will be shifted by the number of days you moved.

2.2.10.8 Emissions

The Emissions tab allows you to specify emissions factors for several pollutants.

Variable	Description
Carbon Dioxide	The amount of carbon dioxide released per kWh of grid power consumed by the system, in grams/kWh

Carbon Monoxide	The amount of carbon monoxide released per kWh of grid power consumed by the system, in grams/kWh
Unburned Hydrocarbons	The amount of unburned hydrocarbons released per kWh of grid power consumed by the system, in grams/kWh
Particulate Matter	The amount of particulate matter released per kWh of grid power consumed by the system, in grams/kWh
Sulfur Dioxide	The amount of sulfur dioxide released per kWh of grid power consumed by the system, in grams/kWh
Nitrogen Oxides	The amount of nitrogen oxides released per kWh of grid power consumed by the system, in grams/kWh

HOMER uses these emissions factors to calculate:

- the emissions of each pollutant resulting from grid power purchases
- the avoided emissions of each pollutant resulting from grid power sales

The values of these coefficients depend on the generation mix of the electricity in your area. In an area where the majority of the electricity is produced from coal, these values will be relatively high because burning coal results in large emissions of pollutants. Natural gas generation results in somewhat lower emissions, and nuclear and hydro generation result in virtually no emissions of these pollutants.

This help file contains a **table of US grid emissions factors**. For additional resources, see the article on **Finding data to run HOMER**.

See also:
5.3 How HOMER Calculates Emissions

2.2.10.9 Net Metering

Variable	Description
Net Metering	Select this option to base grid energy charges on net usage. See Net metering below for explanation.
Net purchases calculated monthly	With this option net usage is calculated monthly
Net Purchases Calculated Annually	With this option net usage is calculated annually

Net metering is a billing scheme by which the utility allows you to sell power to the grid at the retail rate. Effectively, and often literally, your electrical meter runs backwards when you are selling surplus power to the grid. At the end of the billing period (either monthly or annually) you are charged for the net amount purchased (purchases minus sales). If the 'net grid purchases' value is negative, meaning you sold more than you bought over the billing period, the utility pays you according to the sell back price, which is typically equal to the wholesale or 'avoided cost' of power, or zero.

Since the sellback price is often lower than the purchase price, generally net metering results in lower grid costs or greater income. For example, consider a scenario where the price is $0.20 per kWh, and the sell back price is $0.10 per kWh. The monthly usage is 1,000 kWh, and the monthly sales is 900 kWh. Without net metering, the cost is $200 purchased minus $90 sold, resulting in $110 cost. With net monthly net metering, we calculate the net usage for the month, which is 100 kWh. Then we calculate the cost which is now only $20.

If we use annual net metering, we have the rest of the year to return this 100 kWh to the grid. In other words: consider an example where six months out of the year we net 100 kWh of usage per month, and the other six months we net 110 kWh of sales to the grid. If we calculate net purchases monthly, we buy $120 of power and sell $66, resulting in $54 in annual cost. If we calculate net purchases annually, we use 600 kWh over the year, and sell 660 kWh, resulting in net sales of 60 kWh or $6 in income (and $0 purchased).

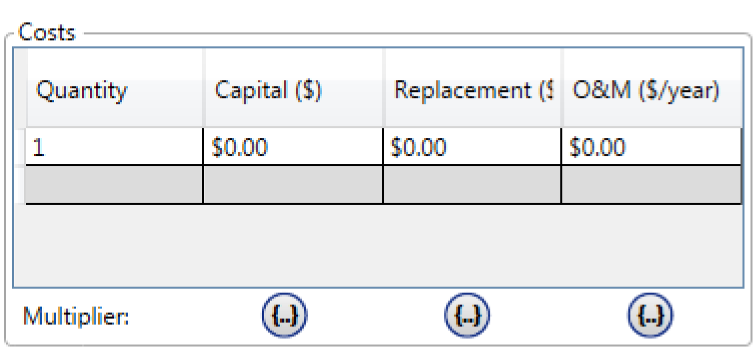
With multiple grid rates in "Scheduled Rates" mode, HOMER calculates net usage within each rate period separately, and then applies the purchase price or sell back price for that rate period. If you select monthly net metering, HOMER will find the net usage for each rate period for each month. If annual net metering is selected, HOMER will find the net usage for each rate for the entire year. Net metering is not applicable in real time rates mode.

See also:
5.3 How HOMER Calculates Emissions

2.2.11 Hydrogen Tank

This window gives access to the cost and performance inputs of the hydrogen storage tank.

Costs



In the hydrogen tank cost table, enter the hydrogen tank cost curve, meaning the way the cost varies with size. If you have a particular hydrogen tank in mind, you can enter its size and cost. In the example above, a 1 kg tank costs $1400 initially, $1200 to replace at the end of its life, and $30/yr for operation and maintenance.

Sizes to consider

Search Space

Size (kg)
100
0

In this table, enter the hydrogen tank sizes you want HOMER to consider as it searches for the optimal system. Be sure to include a zero size if you want to consider systems without a hydrogen tank. HOMER will use the information you entered in the cost table to calculate the costs of each tank size, interpolating and extrapolating as necessary.

Properties

Variable	Description
Lifetime	The number of years the hydrogen storage tank is expected to last before it needs replacement
Initial Tank Level	The level of the tank at the start of the simulation. You can specify the initial level as a percentage of the tank size, or as an absolute amount in kg.
Require year-end tank level to equal or exceed initial tank level	If you check this box, HOMER will consider any system whose year-end hydrogen tank level is lower than its initial level to be **infeasible**

Note: To the right of each numerical input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.2.12 Electrolyzer

This window gives access to the cost and performance inputs of the electrolyzer, which generates hydrogen from electricity.

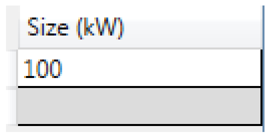
Costs

Quantity	Capital ($)	Replacement ($	O&M ($/year)
1	$0.00	$0.00	$0.00

Multiplier: {...} {...} {...}

In the electrolyzer cost table, enter the electrolyzer cost curve, meaning the way the cost varies with size. If you have a particular electrolyzer in mind, you can enter its size and cost. In the example above, a 0.7 kW electrolyzer costs $1400 initially, $1200 to replace at the end of its life, and $30/yr for operation and maintenance.

Sizes to consider



In this table, enter the electrolyzer sizes you want HOMER to consider as it searches for the optimal system. Be sure to include a zero size if you want to consider systems without an electrolyzer. HOMER will use the information you entered in the cost table to calculate the costs of each electrolyzer size, interpolating and extrapolating as necessary. You can see the results in the cost curve graph.

Properties

Variable	Description
Lifetime	The number of years the electrolyzer is expected to last before it requires replacement
Efficiency	The energy content (based on the higher heating value) of the hydrogen produced divided by the amount of electricity consumed
Minimum Load Ratio	The minimum power at which the electrolyzer can operate, as a fraction of its rated capacity
Type	Specifies whether the electrolyzer consumes alternating current (AC) or direct current (DC) power

> **Note:** To the right of each numerical input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.2.13 Reformer

A reformer generates hydrogen by reforming a hydrocarbon, typically natural gas. Use this window to define the costs and properties of the reformer.

> **Note:** HOMER cannot model a system where a reformer supplies a fuel cell with hydrogen. The only purpose of the reformer is to serve a **hydrogen load**.

Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$0.00	$0.00	$0.00

Multiplier: {..} {..} {..}

In the cost table, enter the reformer *cost curve*, meaning the way the cost varies with size.

Note that the **capital cost** is the initial purchase price, the **replacement cost** is the cost of replacing the reformer at the end of its lifetime (relevant only if the **project lifetime** exceeds the reformer lifetime), and the operating and maintenance cost is the annual cost of operating and maintaining the reformer.

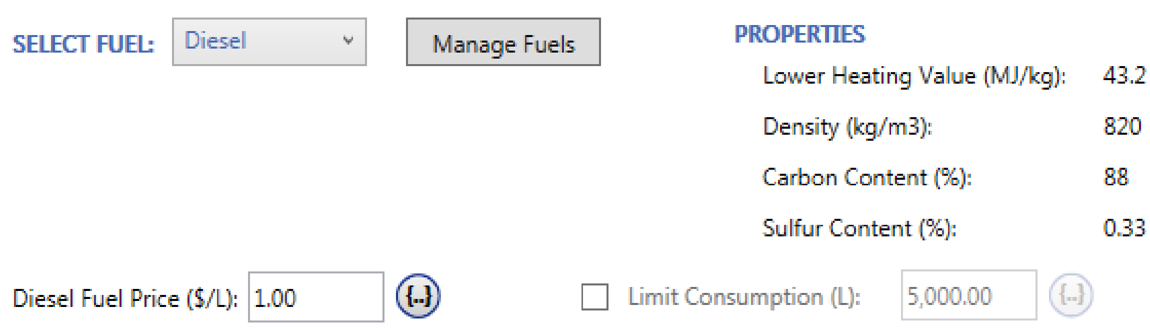
Sizes to consider

Size (kW)
100

In this table, enter the reformer sizes you want HOMER to consider as it searches for the optimal system. Be sure to include a zero size if you want to consider systems without a reformer. HOMER will use the information you entered in the cost table to calculate the costs of each reformer size, interpolating and extrapolating as necessary. You can see the results in the cost curve graph.

Tip: You can also access the values in this table using the **Search Space** window.

Performance parameters



The fuel drop-down box contains all the fuels stored in your **component library**. Choose the appropriate fuel from this list. To see the properties of the selected fuel, click the Details button.

You can create a new fuel type by clicking the New button. The new fuel type will be added to your component library. You can also remove a fuel type from the component library by clicking on the Delete button. Note that additions and deletions from the component library are canceled if you close the Reformer Inputs window with the Cancel button.

Variable	Description

Efficiency	The efficiency with which the reformer converts the fuel to hydrogen, in %

Economic parameters

Variable	Description
Lifetime	The number of years the reformer will last
Delivery Cost	The cost of transporting the hydrogen produced by the reformer to the site of use, in $/kg/km

Tip: You do not need to input cost data if you do not want to consider delivery cost. HOMER will assume the delivery cost to be zero if there is no delivery cost entered.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.2.14 Controller

The Controller component lets you specify how your HOMER system will operate during the simulation. Each controller has a unique control algorithm or "**dispatch strategy**". If you add multiple controller components to your model, HOMER will simulate and optimize the system with each controller, and present the results so you can compare the performance with each control algorithm.

You can specify a cost and and a lifetime for each controller, or you can leave the cost set to zero (with zero cost, the lifetime doesn't matter). Which controller (and dispatch strategy) is best depends on many factors, including the sizes of the generators and battery bank, the price of fuel, the O&M cost of the generators, the amount of renewable power in the system, and the character of the renewable resources. Before the Controller component existed in HOMER, only load following and cycle charging dispatch strategies existed. With the addition of the Controller component, we have added several more choices for the dispatch strategy. Load following and cycle charging are still good controllers to start with for many systems.

HOMER Pro includes the following controller choices:

- **Load Following**
- **Cycle Charging**
- **Merit Order**
- **MATLAB Link**

Note that the dispatch strategy is abbreviated "Dispatch" in the sensitivity and optimization results tables.

Variable	Description
Carbon Monoxide Emissions Factor	The quantity of carbon monoxide (in grams) emitted per unit of fuel consumed by the boiler
Unburned Hydrocarbons Emissions Factor	The quantity of unburned hydrocarbons (in grams) emitted per unit of fuel consumed by the boiler
Particulate Matter Emissions Factor	The quantity of particulate matter (in grams) emitted per unit of fuel consumed by the boiler
Proportion of fuel sulfur emitted as PM	The fraction of the sulfur in the fuel that is emitted as particulate matter (the rest is emitted as sulfur dioxide)
Nitrogen Oxides Emissions Factor	The quantity of nitrogen oxides (in grams) emitted per unit of fuel consumed by the boiler

See also:

5.3 How HOMER Calculates Emissions

2.2.14.1 Load Following

Under the **load following** strategy, whenever a generator is needed it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power, when the renewable power output sometimes exceeds the load. Load following is abbreviated "LF" in the results tables.

Select the option "Allow diesel-off operation" if the system can maintain stability without the generator running. This option only has an effect if there is a generator in the system which can sometimes be turned off. Some systems require a generator to maintain bus voltage and frequency. If the system includes a "grid-forming" component other than the generator, you can deselect this option, and HOMER will turn the generator off if the load can be supplied with other sources.

The check box "Allow generators to operate simultaneously" only affects the operation of systems that include two or more generators on the same bus. If you check this box, HOMER will allow multiple generators on the same bus to operate at once whenever necessary. Otherwise, multiple generators on the same bus must take turns operating.

See also:

2.2.14 Controller
2.2.14.2 Cycle Charging

2.2.14.2 Cycle Charging

Under the **cycle charging** strategy, whenever a generator has to operate, it operates at full capacity with surplus power going to charge the battery bank. Cycle charging tends to be optimal in systems with little or no renewable power. Cycle charging is abbreviated "CC" in the results tables.

If you can apply a **setpoint state of charge** to the cycle charging strategy, the generator(s) will not stop charging the battery bank until it reaches the specified state of charge. The sensitivity button to the right allows you to do a **sensitivity analysis** on this setpoint.

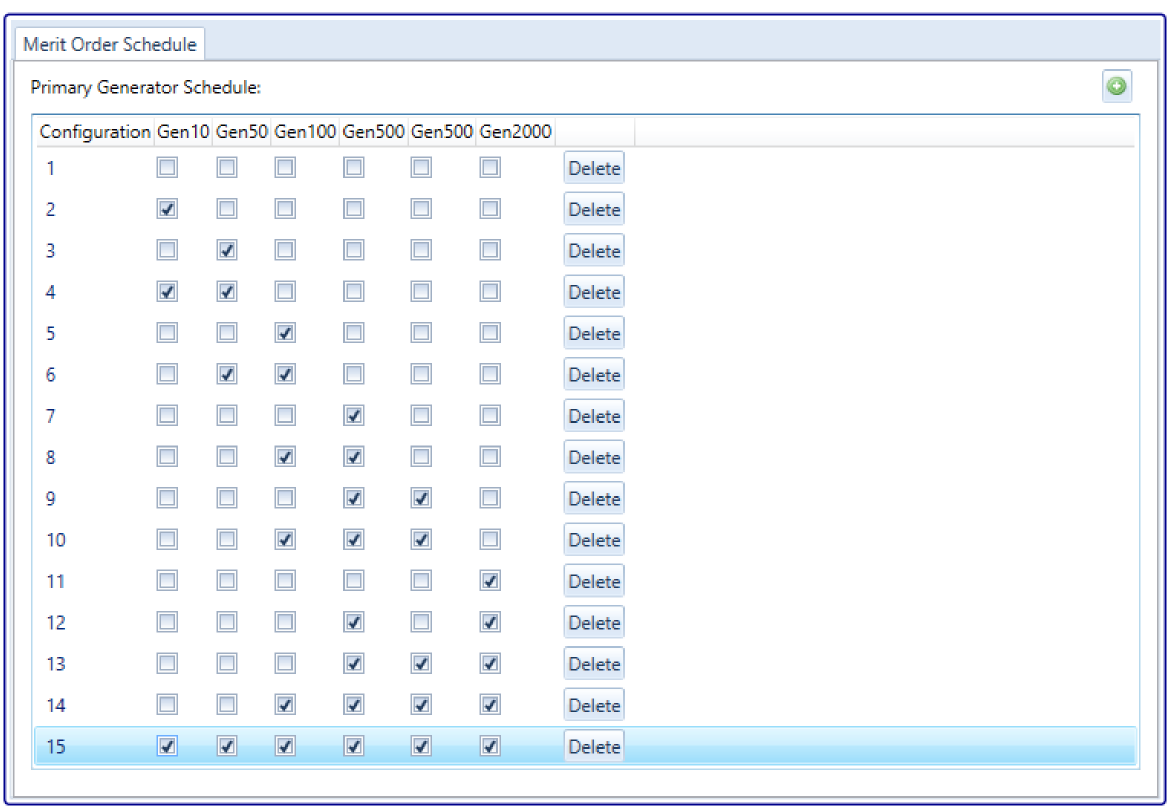
Select the option "Allow diesel-off operation" if the system can maintain stability without the generator running. This option only has an effect if there is a generator in the system which can sometimes be turned off. Some systems require a generator to maintain bus voltage and frequency. If the system includes a "grid-forming" component other than the generator, you can deselect this option, and HOMER will turn the generator off if the load can be supplied with other sources.

The check box "Allow generators to operate simultaneously" only affects the operation of systems that include two or more generators on the same bus. If you check this box, HOMER will allow multiple generators on the same bus to operate at once whenever necessary. Otherwise, multiple generators on the same bus must take turns operating.

See also:
2.2.14 Controller
2.2.14.1 Load Following

2.2.14.3 Generator Order

With the Generator Order dispatch strategy, HOMER follows a defined order of generator combinations, and uses the first combination in the list that meets the **Operating Capacity**. The generator order dispatch only supports systems with generators, PVs, wind turbines, a converter and/or storage components. The generator order dispatch will not run systems that include any thermal or CHP components, hydrogen components, the grid, the hydroelectric component, or the hydrokinetic component.



Configuration	Gen10	Gen50	Gen100	Gen500	Gen500	Gen2000	
1	☐	☐	☐	☐	☐	☐	Delete
2	☑	☐	☐	☐	☐	☐	Delete
3	☐	☑	☐	☐	☐	☐	Delete
4	☑	☑	☐	☐	☐	☐	Delete
5	☐	☐	☑	☐	☐	☐	Delete
6	☐	☑	☑	☐	☐	☐	Delete
7	☐	☐	☐	☑	☐	☐	Delete
8	☐	☐	☑	☑	☐	☐	Delete
9	☐	☐	☐	☑	☑	☐	Delete
10	☐	☐	☑	☑	☑	☐	Delete
11	☐	☐	☐	☐	☐	☑	Delete
12	☐	☐	☐	☑	☐	☑	Delete
13	☐	☐	☐	☑	☑	☑	Delete
14	☐	☐	☑	☑	☑	☑	Delete
15	☑	☑	☑	☑	☑	☑	Delete

You can specify the generator order with the table in the Generator Order Dispatch menu. Click the button with green circle and a plus sign in the upper-right corner of the table to add a row to the bottom. Click the Delete button next to any row to delete the row. A typical generator order table is pictured above.

In each time step, the generator order dispatch will try each combination, starting with the first row of the table and working down, until it finds one that can meet the required operating capacity in the current time step. Once HOMER finds a combination of generators which meet the required operating capacity, HOMER will choose the generator "setpoints" to meet the actual load in the lowest cost way possible.

For systems with a battery, the Generator Order Dispatch will use the battery to meet the load whenever possible. In other words, the battery maximum discharge power is subtracted from the required operating capacity before the generator order combination is chosen to meet the remaining required operating capacity. The generators that are turned on in the current time step (as chosen by the generator order) will charge the battery as much as possible (if the maximum generator output exceeds the load), or run at full load to minimize the amount of energy taken from the battery bank (if the generators can't meet the load without the battery).

See also:
2.2.14 Controller
2.2.14.2 Cycle Charging

2.2.14.4 MATLAB Link

The HOMER Pro MATLAB Link allows you to write your own dispatch algorithm for HOMER Pro using MATLAB. HOMER will interface with the MATLAB software to run your MATLAB functions during the simulation. In order to run a simulation with your own MATLAB dispatch algorithm you need:

1. HOMER Pro 3.7 or later installed
2. 32-bit version of MATLAB installed and licensed
3. Three MATLAB functions described below (these comprise your custom algorithm, example m-files are included below)
4. A HOMER model with the HOMER Pro MATLAB Link Controller selected in the Controller Set Up menu, with settings described below.

MATLAB Functions

You need three MATLAB functions, each in a separate M-file. The three M-files should be together in a directory. You will specify the location and name of these files in HOMER so that it knows how to run your functions. The functions must use the following syntax exactly:

```
[myErr, custom variables] =
   MatlabStartSimulation(simulation_parameters)

[simulation state, custom variables] =
   MatlabDispatch(simulation parameters, simulation state,
   custom variables)
```

```
myErrs = MatlabEndSimulation(simulation parameters,
    custom variables)
```

HOMER calls these three commands before, during, and after the simulation. To run a simulation with the MATLAB Link, HOMER performs the following steps:

1. The HOMER Pro MATLAB Link Controller opens an instance of MATLAB and sends the variable **simulation_parameters** to the MATLAB workspace.
2. HOMER runs the **MatlabStartSimulation** command in MATLAB.
3. HOMER gets the variable **myErr** back from MATLAB. If **myErr** contains an error, HOMER may stop the simulation or the entire calculate as described in **MatlabStartSimulation**.
4. The variable **custom_variables** is left in the MATLAB workspace and so it is accessible by all the following MATLAB function calls.
5. HOMER creates the variable **simulation_state** and sends it to MATLAB.
6. HOMER runs the command for **MatlabDispatch** in MATLAB.
7. HOMER reads the new values set by **MatlabDispatch** in the **simulation_state** variable and simulates the timestep according to these dispatch commands.
8. HOMER updates the values in **simulation_state** for the new time step. Steps 6, 7, and 8 are repeated until all the time steps are simulated.
9. Finally, after all time steps are simulated, HOMER calls **MatlabEndSimulation**, and any errors are reported back to the HOMER user interface.

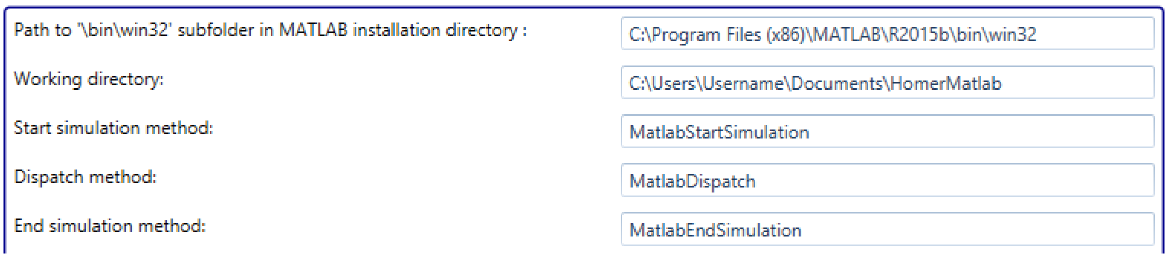
While the variable **simulation_parameters** is not changed throughout the simulation, the values in the variable **simulation_state** are changed in each time step to reflect how the system is operating. Each time step, **simulation_state** is updated in the MATLAB workspace, and the function **MatlabDispatch** is called. The function **MatlabDispatch** makes changes to **simulation_state** that are read by HOMER each time step.

Each MATLAB function must follow the syntax given in the grey boxes above. The topics below have more details and examples for each function.

- **MatlabStartSimulation**
- **MatlabDispatch**
- **MatlabEndSimulation**

Setting Up the HOMER Model

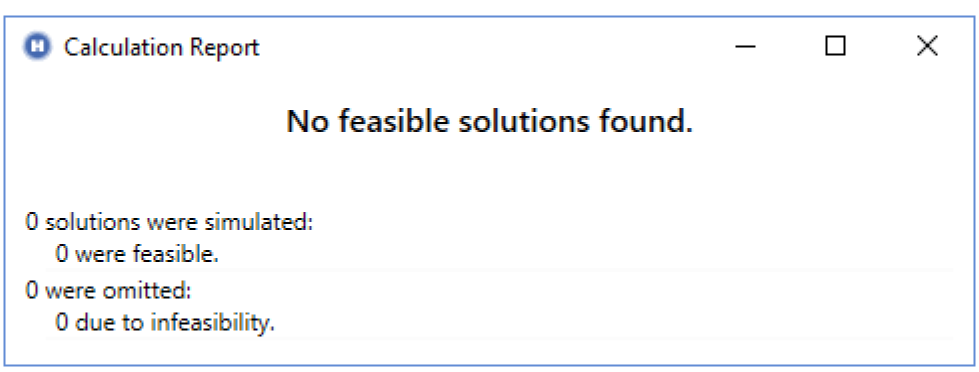
To run you MATLAB dispatch code, you need to have the MATLAB Link Controller set up in your model. First, select HOMER Pro MATLAB Link from the dropdown menu and click "Add" in the Controller menu. HOMER will add a new tab for the HOMER Pro MATLAB Link and take you to it.



Variable	Description
Path to '\bin\win32' subfolder in MATLAB installation directory	Enter the path to the installation of MATLAB on your computer, to the '\bin\win32' subfolder there. HOMER needs the 32-bit installation of MATLAB (you can have 32-bit and a 64-bit versions of MATLAB installed on your computer at the same time). A typical path might look like: C:\Program Files (x86)\MATLAB\R2015b\bin\win32
Working directory	This is the location of the m-files with the three functions defined above. HOMER will set this as the MATLAB working directory, and call the functions as described above.
Start simulation method	The name for your MatlabStartSimulation function that is called before the simulation. Throughout these help articles the function is called MatlabStartSimulation, but you can call it whatever you like, and specify that name here.
Dispatch method	The name for your MatlabDispatch function that is called each timestep. In this and related help articles, this function is called MatlabDispatch, but you can name this function something else if desired.
End simulation method	The name for you MatlabEndSimulation function that is called after the simulation. We call this function MatlabEndSimulation in the help, but you can choose a different name if you like.

Troubleshooting

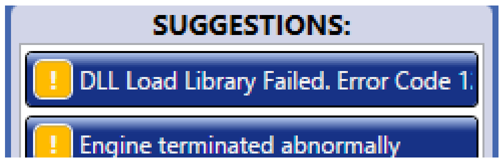
If errors occur while trying to run the MATLAB dispatch, you may get the message "No feasible solutions found".



First, you should be sure that your system does actually produce at least one feasible result. You can check that by running your system with one of the original HOMER dispatch algorithms like Cycle Charging or Load Following.

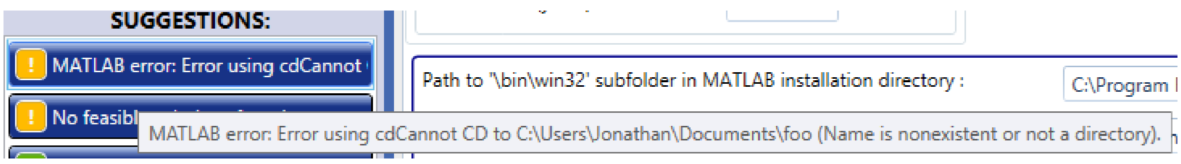
Look in the "Suggestions" in the lower-left corner of the HOMER window for specific error messages. You can hover your mouse over a message or click on it to see the full message text. The first problem that might occur is that HOMER might be unable to find your MATLAB installation.

If this is the problem, you will see an error message that says "DLL Load Library Failed."



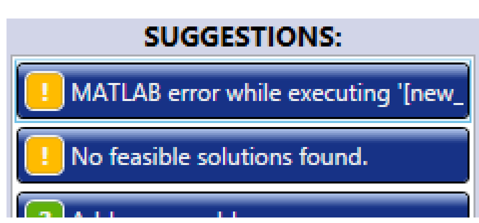
If you see this message, be sure that the path specified for the input "Path to '\bin\win32' subfolder in MATLAB installation directory" is correct, and points to the \bin\win32 subfolder inside your MATLAB installation. Also be certain that you are pointing to a 32-bit installation of MATLAB. You can tell this because 32-bit programs are always installed in "Program Files (x86)" and not in "Program Files" (if you have a 64-bit computer). If you need a 32-bit version of MATLAB, you can download it from the Mathworks website. You can have 32-bit and a 64-bit versions of MATLAB installed on your computer at the same time.

If HOMER was able to find your MATLAB installation, but it wasn't able to find the working directory you specified, you'll see the error message: "MATLAB error: Error using cd...".



Hover your mouse over the message to see the full text. If you get this error, double check the path you specified for the "Working directory" input. It is very likely that this path is spelled wrong or doesn't exist. HOMER gave MATLAB the command **`cd('C:\your\path')`** where "C:\your\path" is the path you specified for the "Working directory", and MATLAB gave an error. If it isn't clear by double checking the path name, you can open MATLAB and try the "cd" command to debug this step.

If those steps work, HOMER will send the **`simulation_parameters`** variable to the MATLAB workspace, and then call your **`MatlabStartSimulation`** command using the syntax listed in the gray box above. If any of the three functions are missing, or if the names are spelled wrong, HOMER will provide the corresponding error message in the Suggestions box in the lower left after calculate has finished. It may look like this:



You can hover your mouse over the message or click on it to see the full text of the error message. In this case, the full text of the message was:

```
MATLAB error while executing '[new simulation state,
   custom variables] =
   MatlabDispatchWrong(simulation parameters, simulation state,
```

```
   custom variables);': Undefined function 'MatlabDispatchWrong
   for input arguments of type 'struct'.
```

This message can be broken down into several parts to make it easier to understand. The first part of the message says: **MATLAB error while executing 'stuff':**. The **stuff** in quotes is the exact command that HOMER gave to MATLAB. In this case it was:

```
[new simulation state, custom variables] =
   MatlabDispatchWrong(simulation parameters, simulation state,
   custom variables);
```

We can look at this command closely to see what might be wrong. The second part of the error message is the exact message from MATLAB:

```
Undefined function 'MatlabDispatchWrong' for input arguments of
   type 'struct'.
```

We can recognize this as MATLAB's familiar but roundabout way of telling us that it couldn't find a function called **MatlabDispatchWrong**. By analyzing the error message carefully, we can get a pretty good idea of what went wrong.

In other cases, your m-file might cause an error while it's running. If that happens, the error message will be similar to the above example, except the second part of the message, which tells you MATLAB's exact error message, will be different. It will say what went wrong, and may give you the number of the line in your m-file where the error occured, for example:

```
MATLAB error while executing '[new simulation state,
   custom variables] = MatlabDispatch(simulation parameters,
   simulation state, custom variables);': Reference to non-
   existent field 'wrong field name'. Error in MatlabDispatch
   (line 30) simulation state.wrong field name;
```

We can see from the error message that my MatlabDispatch function tried to access a field of the simulation_state structure that doesn't exist, and it happened on line 30 of that function (which is written in the file MatlabDispatch.m). For details of the **simulation_state** and **simulation_parameters** variables, see their topics: **Listing of simulation_state** and **Listing of simulation_parameters**.

See also:
2.2.14 Controller

2.2.14.4.1 MatlabStartSimulation Function

```
[myErr, custom variables] =
   MatlabStartSimulation(simulation parameters)
```

HOMER will call **MatlabStartSimulation** before each simulation. The job of **MatlabStartSimulation** is to check the problem, return errors if needed, and initialize values in the **custom_variables** output if desired. In some cases, this function could be nearly empty. It must at least initialize the return arguments **myErr** and **custom_variables** to be a valid function.

The variable **simulation_parameters** contains all the information about the current system and the current simulation, such as information about each generator, PV, converter, or battery in the system, and information about the load. You can return errors in the variable **myErr**. For example, your dispatch algorithm might be designed to handle systems with only components on the AC bus, and no DC components or converter. You could check the **simulation_parameters** variable to see if each generator, PV, battery, and load in the system are on the AC bus. You could also check that there is no converter. If any of those conditions are not met, the function would return a "simulation" error with a message like: "This MATLAB dispatch can't handle DC components."

The variable **myErr** must be a structure with two fields: **error_description** and **severity_code**. The **error_description** is a text string that will be displayed to the user. The **severity_code** can be set to the text **DISPATCH_SIMULATION_ERROR** or **DISPATCH_CRITICAL_ERROR**. If the value is set to anything else, i.e. blank, there is no error. Depending on the severity code of the error returned, HOMER will skip the simulation, or the entire calculation run.

You can also set values for the output **custom_variables** here. HOMER won't do anything with the values in this variable, but you can use it to save values for use in **MatlabDispatch** and **MatlabEndSimulation**. You will also be able to change the values in **custom_variables** in each time step in the **MatlabDispatch** function.

Here are some examples of commands you might use in your **MatlabStartSimulation** function:

Command	Description
`myErr.error_description = 'Danger!';`	This text error message that will be displayed to the user in the Suggestions list in the lower-left part of the HOMER window. You must set one of the two severity codes below or the error won't do anything.
`myErr.severity_code = 'DISPATCH_SIMULATION_ERROR';`	Setting the severity code to this will skip the simulation.
`myErr.severity_code = 'DISPATCH_CRITICAL_ERROR';`	Setting the severity code to this will skip the rest of the calculate.
`custom_variables.anything = 0;`	You can add fields to custom_variables and use or modify them later in MatlabDispatch.

See also:

2.2.14 Controller
2.2.14.2 Cycle Charging

2.2.14.4.2 MatlabDispatch Function

```
[simulation_state, custom_variables] =
   MatlabDispatch(simulation_parameters, simulation_state,
   custom_variables)
```

HOMER will call **MatlabDispatch** at the beginning of each time step in the simulation. MatlabDispatch has three input variables:

1. **simulation_state**: this structure contains variables that may change in each time step of the simulation. Some of the values must be set by the user every time step (in the MatlabDispatch function) in order to control the operation of the system.
2. **simulation_parameters**: this structure contains variables that are defined by the HOMER Model. They are all read-only and they do not change during the course of the simulation.
3. **custom_variables**: this user-defined variable is not used by HOMER. You can use it to keep track of values needed for your algorithm over the course of a simulation if desired. This variable can be a structure, array, or scalar, depending on how you define it.

Here are some examples of commands you might use in your `MatlabDispatch` function:

1. Using a component (PV, Battery, Generator etc.)

Action	Command	Description
Check if the component is present	`simulation_parameters.has_generator`	Check if this variable is set to true before performing calculations for the component. Some optimization cases might exclude a component that was present in the model
Check if the component is on the AC or DC bus	`simulation_parameters.generator_list(i).is_AC`	Check if the component is on the AC or DC bus. All actions of this component will affect the buses accordingly
Set the power the component should be producing	`simulation_state.generator(i).power_setpoint = simulation_state.generator(i).power_available;`	This command will set generator number *i* to its maximum power output.
	`simulation_state.generator(i).power_setpoint = simulation_parameters.generator_list(i).minimum_load ;`	This command will set generator number *i* to its minimum load.

	`simulation_state.generator(i).power_setpoint = simulation_state.generator(i).power_available * 0.8`	Use only 80 % of the power produced by the generator
Add to Operating Capacity	`simulation_state.ac_bus.operating_capacity_served = simulation_state.ac_bus.operating_capacity_served + simulation_state.generator(i).power_available;`	Depending on which bus the component is, it contributes it maximum possible power available to the bus' operating capacity

2. Setting output parameters at each timestep

It is important to note that each of these parameters should be set on both the AC and DC bus separately.

In the below table,

- *load_supplied_ac* is the sum of all production on the AC bus.
- *operating_capacity_ac* is the sum of operating capacity of all components on the AC bus

Parameter	Command	Description
Load Served	`simulation_state.ac_bus.load_served = min(load_supplied_ac, simulation_state.ac_bus.load_requested);`	Takes the mimimum of the load produced on the AC bus and the AC load. If the load has been completely satisfied, then the load served should be equal to the load requested
Unmet Load	`simulation_state.ac_bus.unmet_load = max(simulation_state.ac_bus.load_requested - load_supplied_ac, 0);`	If the load requested on the AC bus has been completely met by the production on the AC bus, then the unmet load is 0
Excess Electricity	`simulation_state.ac_bus.excess_electricity = max(load_supplied_ac - load_requested_ac, 0);`	If production on the AC bus is more than requested, then the remaining amount will become excess electricity
Operating Capacity	`simulation_state.ac_bus.operating_capacity_served = operating_capacity_ac;`	The sum of the renewable generation, the maximum battery discharge power (DC

Served		bus only), and the power available from all operating generators. Should not exceed the operating_capacity_requested.
Capacity Shortage	`simulation_state.ac_bus.capacity_shortage = max(simulation_state.ac_bus.operating_capacity_requested - operating_capacity_ac, 0);`	The capacity shortage occurs when the operating capacity served is less than the operating capacity requested on that bus

Notice that HOMER won't check that your settings obey the laws of physics. You can set the value for capacity shortage each time step to whatever you like, independent of whether you acutally turn on a generator or produce any power. It is important to set these values correctly to ensure accurate results.

The article **Listing of simulation_state** lists the fields within the **`simulation_state`** variable; fields marked with an asterisk should be set by the MatlabDispatch function each time step. If your algorithm does not support a component, you don't need to set any values for that component's fields.

See also:

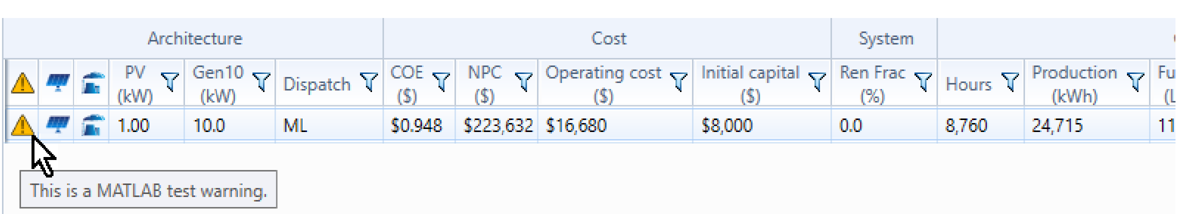
2.2.14 Controller

2.2.14.2 Cycle Charging

2.2.14.4.3 MatlabEndSimulation Function

```
myErrs = MatlabEndSimulation(simulation parameters,
    custom variables)
```

HOMER will call **`MatlabEndSimulation`** after all time steps have been simulated. **`MatlabEndSimulation`** should generate errors and/or warnings, and return them in the variable **`myErrs`**. **`myErrs`** has two fields, **`simulation_errors`** and **`simulation_warnings`**. Both of these fields are cell arrays of strings. If you set warnings in **`simulation_warnings`**, they will appear in the HOMER results table with a warning icon next to a simulation:



In the **simulation results** for that simulation, the warning will also appear as a larger yellow warning symbol at the bottom of the window. If you set any errors in the **`simulation_errors`**, the simulation will be infeasible and will not appear in the results.

Here are some examples of commands you might use in your **`MatlabEndSimulation`** function:

Command	Description
`myErrs.simulation_warnings = {'This is a MATLAB test warning.'};`	Adds an example warning to the myErrs variable.
`if custom_variables.total_energy < 1e4 myErrs.simulation_warnings = [myErrs.simulation_warnings {'Not very much energy.'}]; end`	You can use values set in custom_variables (in the MatlabDispatch function, for example) to trigger different warnings or errors.
`myErr.severity_code = 'DISPATCH_CRITICAL_ERROR';`	Setting the severity code to this will skip the rest of the calculate.

See also:

2.2.14 Controller
2.2.14.2 Cycle Charging

2.2.14.4.4 Listing of simulation_parameters

simulation_parameters.generator_list(i).emissions_factor_CO	double
simulation_parameters.generator_list(i).emissions_factor_NOx	double
simulation_parameters.generator_list(i).emissions_factor_PM	double
simulation_parameters.generator_list(i).emissions_factor_UHC	double
simulation_parameters.generator_list(i).emissions_sulfur_PM_ratio	double
simulation_parameters.generator_list(i).fuel.carbon_content	double
simulation_parameters.generator_list(i).fuel.cost	double
simulation_parameters.generator_list(i).fuel.density	double
simulation_parameters.generator_list(i).fuel.initial_fuel_available	double
simulation_parameters.generator_list(i).fuel.limit_consumption	double
simulation_parameters.generator_list(i).fuel.lower_heating_value	double
simulation_parameters.generator_list(i).fuel.name	string
simulation_parameters.generator_list(i).fuel.sulfur_content	double
simulation_parameters.generator_list(i).fuel_curve_intercept	double
simulation_parameters.generator_list(i).fuel_curve_slope	double
simulation_parameters.generator_list(i).lifetime_in_hours	double
simulation_parameters.generator_list(i).minimum_load	double
simulation_parameters.generator_list(i).minimum_runtime	double
simulation_parameters.generator_list(i).nonlinear_x0	double
simulation_parameters.generator_list(i).nonlinear_x1	double
simulation_parameters.generator_list(i).nonlinear_x2	double
simulation_parameters.generator_list(i).component_number	int
simulation_parameters.generator_list(i).cost.capital	double
simulation_parameters.generator_list(i).cost.operation_and_maintenance	double

simulation_parameters.generator_list(i).cost.replacement	double
simulation_parameters.generator_list(i).is_AC	bool
simulation_parameters.generator_list(i).name	string

simulation_parameters.primary_load_list(i).name	string
simulation_parameters.primary_load_list(i).peak_load	double
simulation_parameters.primary_load_list(i).is_AC	bool

simulation_parameters.pv_list(i).name	string
simulation_parameters.pv_list(i).component_number	int
simulation_parameters.pv_list(i).cost.capital	double
simulation_parameters.pv_list(i).cost.operation_and_maintenance	double
simulation_parameters.pv_list(i).cost.replacement	double
simulation_parameters.pv_list(i).is_AC	bool
simulation_parameters.pv_list(i).lifetime_in_years	double
simulation_parameters.pv_list(i).rated_capacity	double

simulation_parameters.battery_list(i).name	string
simulation_parameters.battery_list(i).component_number	int
simulation_parameters.battery_list(i).cost.capital	double
simulation_parameters.battery_list(i).cost.operation_and_maintenance	double
simulation_parameters.battery_list(i).cost.replacement	double
simulation_parameters.battery_list(i).is_AC	bool
simulation_parameters.battery_list(i).nominal_voltage	double
simulation_parameters.battery_list(i).nominal_capacity	double
simulation_parameters.battery_list(i).minimum_state_of_charge	double
simulation_parameters.battery_list(i).fractional_charge_efficiency	double
simulation_parameters.battery_list(i).wear_cost	double
simulation_parameters.battery_list(i).battery_bank_maximum_absolute_soc	double
simulation_parameters.battery_list(i).battery_bank_minimum_absolute_soc	double
simulation_parameters.battery_list(i).dedicated_converter	double
simulation_parameters.battery_list(i).has_dedicated_converter	bool

simulation_parameters.converter(i).name	string
simulation_parameters.converter(i).component_number	int
simulation_parameters.converter(i).cost.capital	double
simulation_parameters.converter(i).cost.operation_and_maintenance	double
simulation_parameters.converter(i).cost.replacement	double
simulation_parameters.converter(i).is_AC	bool
simulation_parameters.converter(i).inverter_capacity	double
simulation_parameters.converter(i).rectifier_capacity	double
simulation_parameters.converter(i).inverter_efficiency	double
simulation_parameters.converter(i).rectifier_efficiency	double
simulation_parameters.converter(i).lifetime_in_years	double
simulation_parameters.converter(i).able_to_parallel_with_ac_generator	bool

simulation_parameters.flywheel(i).name	string
simulation_parameters.flywheel(i).component_number	int
simulation_parameters.flywheel(i).cost.capital	double
simulation_parameters.flywheel(i).cost.operation_and_maintenance	double
simulation_parameters.flywheel(i).cost.replacement	double
simulation_parameters.flywheel(i).is_AC	bool
simulation_parameters.flywheel(i).charge_discharge_capacity	double
simulation_parameters.flywheel(i).parasitic_load	double
simulation_parameters.flywheel(i).quantity	int
simulation_parameters.flywheel(i).lifetime_in_years	double

simulation_parameters.emissions.emissions_penalty_CO	double
simulation_parameters.emissions.emissions_penalty_CO2	double
simulation_parameters.emissions.emissions_penalty_NOx	double
simulation_parameters.emissions.emissions_penalty_PM	double
simulation_parameters.emissions.emissions_penalty_SO2	double
simulation_parameters.emissions.emissions_penalty_UHC	double
simulation_parameters.emissions.max_emissions_CO	double
simulation_parameters.emissions.max_emissions_CO2	double
simulation_parameters.emissions.max_emissions_NOx	double
simulation_parameters.emissions.max_emissions_PM	double

simulation_parameters.emissions. max_emissions_SO2	double
simulation_parameters.emissions. max_emissions_UHC	double
simulation_parameters.emissions. use_max_emissions_CO	bool
simulation_parameters.emissions. use_max_emissions_CO2	bool
simulation_parameters.emissions. use_max_emissions_NOx	bool
simulation_parameters.emissions. use_max_emissions_PM	bool
simulation_parameters.emissions. use_max_emissions_SO2	bool
simulation_parameters.emissions. use_max_emissions_UHC	bool

simulation_parameters.operating_reserve.peak_load_requirement	double
simulation_parameters.operating_reserve.solar_requirement	double
simulation_parameters.operating_reserve.timestep_requirement	double
simulation_parameters.operating_reserve.wind_requirement	double

simulation_parameters.maximum_annual_capacity_shortage	double
simulation_parameters.minimum_renewable_fraction	double
simulation_parameters.timestep_size_in_seconds	int
simulation_parameters.number_of_timesteps	int
simulation_parameters.has_generator	bool
simulation_parameters.has_battery	bool
simulation_parameters.has_pv	bool
simulation_parameters.has_converter	bool
simulation_parameters.has_flywheel	bool

Grid: Scheduled rates

simulation_parameters.grid_list(i).technical_model.model_type	"SCHEDULED"
simulation_parameters.grid_list(i).technical_model.demand_rate(j).demand_rate	double
simulation_parameters.grid_list(i).technical_model.demand_rate(j).grid_label	string
simulation_parameters.grid_list(i).technical_model.demand_rate(j).grid_state	GridState (see definition below)
simulation_parameters.grid_list(i).technical_model.demand_rate_index	int
simulation_parameters.grid_list(i).technical_model.grid_rate(j).grid_label	double

simulation_parameters.grid_list(i).technical_model.grid_rate(j).grid_state	GridState (see definition below)
simulation_parameters.grid_list(i).technical_model.grid_rate(j).power_price	double
simulation_parameters.grid_list(i).technical_model.grid_rate(j).sellback_rate	double
simulation_parameters.grid_list(i).technical_model.grid_rate_index	int

Grid: Real time rates

simulation_parameters.grid_list(i).technical_model.model_type	"REAL_TIME"
simulation_parameters.grid_list(i).technical_model.demand_rate(j).demand_rate	double
simulation_parameters.grid_list(i).technical_model.demand_rate(j).grid_label	string
simulation_parameters.grid_list(i).technical_model.demand_rate(j).grid_state	GridState (see definition below)
simulation_parameters.grid_list(i).technical_model.demand_rate_index	int
simulation_parameters.grid_list(i).technical_model.realtime_power_price	double
simulation_parameters.grid_list(i).technical_model.realtime_sellback_rate	double

Grid: `GridState`

grid_state.grid_is_down	bool
grid_state.maintain_state_of_charge	bool
grid_state.maintain_state_of_charge_has_ended	bool
grid_state.maintain_state_of_charge_percent	double
grid_state.prohibit_any_battery_charging	bool
grid_state.prohibit_any_grid_sales	bool
grid_state.prohibit_battery_from_discharging	bool
grid_state.prohibit_grid_from_charging_battery	bool
grid_state.prohibit_grid_sales_from_battery	bool

All of the values in `simulation_parameters` are read-only.

See also:

2.2.14 Controller
2.2.14.4 MATLAB Link

2.2.14.4.5 Listing of simulation_state

Rows marked with a * asterisk should be set in the MatlabDispatch function

	simulation_state.generator(i).power_available	double
*	simulation_state.generator(i).power_setpoint	double
	simulation_state.generator(i).current_state	string

The value of current_state will be set to one of the following by HOMER: DISPATCH_DECIDES, FORCED_OFF_FOR_MAINTENANCE_EVENT, FORCED_OFF_FOR_SCHEDULE, FORCED_OFF_OUT_OF_FUEL, FORCED_ON_FOR_MINIMUM_RUNTIME, FORCED_ON_FOR_SCHEDULE

	simulation_state.pv(i).power_available	double
*	simulation_state.pv(i).power_setpoint	double
*	simulation_state.converter(i).inverter_power_input	double
*	simulation_state.converter(i).inverter_power_output	double
*	simulation_state.converter(i).rectifier_power_input	double
*	simulation_state.converter(i).rectifier_power_output	double
	simulation_state.primary_load(i).load_requested	double
*	simulation_state.primary_load(i).load_served	double
*	simulation_state.ac_bus.capacity_shortage	double
*	simulation_state.ac_bus. excess_electricity	double
	simulation_state.ac_bus. load_requested	double
*	simulation_state.ac_bus.load_served	double
	simulation_state.ac_bus. operating_capacity_requested	double
*	simulation_state.ac_bus. operating_capacity_served	double
*	simulation_state.ac_bus. unmet_load	double
*	simulation_state.dc_bus.capacity_shortage	double
*	simulation_state.dc_bus.excess_electricity	double
	simulation_state.dc_bus.load_requested	double
*	simulation_state.dc_bus.load_served	double
	simulation_state.dc_bus.operating_capacity_requested	double
*	simulation_state.dc_bus.operating_capacity_served	double
*	simulation_state.dc_bus.unmet_load	double
	simulation_state.current_timestep	int
*	simulation_state.grid(i).grid_purchases	double
*	simulation_state.grid(i).grid_sales	double
	simulation_state.grid(i).grid_state	GridState (see **simulation_parameters**)
	simulation_state.grid(i).max_grid_purchases	double

	simulation_state.grid(i).max_grid_sales	double
	simulation_state.grid(i).power_price	double
	simulation_state.grid(i).sellback_rate	double

See also:

2.2.14 Controller
2.2.14.4 MATLAB Link

2.3 Resources Tab

In HOMER, a "resource" is anything coming from outside the system.

Resource	Components
Solar GHI Resource	**PV (Flat Panel)**
Solar DNI Resource	**PV (Concentrating)**
Temperature Resource	**PV (Consider temperature effects)**
Wind Resource	**Wind Turbine**
Hydro Resource	**Hydro Component**
Fuel Resource	**Generator**, **Boiler**, **Reformer**
Biomass Resource	**Generator** (Biogas)

2.3.1 Solar GHI Resource

The Global Horizontal Irradiation (GHI) Resource is used to calculate flat panel PV array output. GHI is the sum of beam radiation (also called direct normal irradiance or DNI), diffuse irradiance, and ground-reflected radiation. For more details on the equations that determine the incident radiation based on the GHI, see **How HOMER Calculates the Radiation Incident on the PV Array**.

Note: For concentrating PV, enter a Solar DNI Resource, not GHI. Concentrating PV only captures DNI, the beam radiation component of GHI, and so uses the Solar DNI resource.

The Solar Resource inputs window can be reached by clicking the "Solar GHI" icon in the resources tab of the navigation ribbon at the top of the HOMER window.

Choose Locale

If you select a location on the map in the home page, the latitude and longitude will appear here. Otherwise, you can enter the latitude and longitude manually. Select the time zone by clicking the "Update" button or by choosing from the drop down menu. HOMER uses the location for several aspects of the PV power calculation, so it is important to specify this even if you are not downloading solar data.

Choose Data Source

The baseline data is a one-year time series representing the average global solar radiation on the horizontal surface, expressed in kWh/m^2, for each time step of the year. HOMER displays the monthly average radiation and **clearness index** of the baseline data in the solar resource table and graph.

There are two ways to create baseline data: you can use HOMER to synthesize hourly data from monthly averages, or you can import time series radiation data from a file. If you are looking for solar data, see **Finding data to run HOMER**.

Enter Monthly Averages

Solar resource data can be input via the monthly solar radiation table. You can enter the monthly data manually, or you can download it from the HOMER website.

To enter twelve average monthly values into the solar resource table manually, you can input either solar radiation (in kWh/m^2 per day) or clearness index. You do not have to enter both; HOMER calculates one from the other using the latitude.

To download solar data from the HOMER Energy website, simply click the "Download" button. This will automatically fill in the twelve monthly average values for you based on the latitude and longitude.

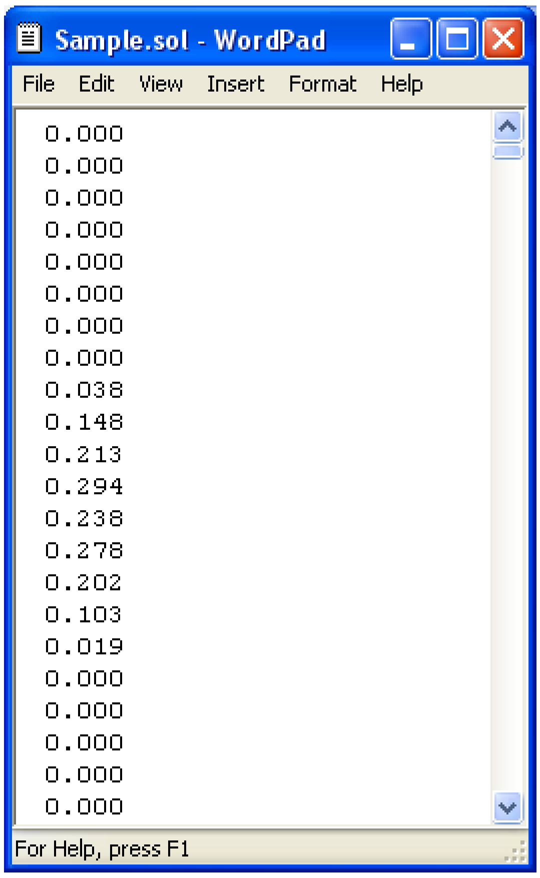
Once you have values in the monthly solar radiation table, either by manual entry or download, HOMER builds a set of 8,760 solar radiation values, or one for each hour of the year. HOMER creates the synthesized values using the **Graham algorithm**, which results in a data sequence that has realistic day-to-day and hour-to-hour variability and autocorrelation. For more information please see the article on **synthetic solar data**.

Import Solar Data

You can prepare your own text file that contains the solar radiation data in each time step for a complete year.

> **Tip:** You can import data with time steps of many sizes between 60 minutes and one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

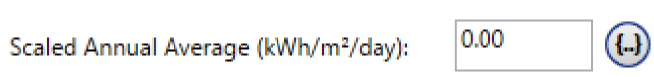
The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average solar radiation (in kW/m^2) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



Click Import... to open the text file. You can import a text file with any extension.

When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates monthly average radiation and clearness index values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the graph.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the values in the baseline data by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average solar radiation. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average solar radiation. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no solar radiation.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

An example of using the scaled annual average for unit conversion is to convert data from an imported file that contains solar radiation data expressed in Wh/m^2 rather than kWh/m^2. If the baseline annual average is 4800 Wh/m^2, you should enter 4.8 in Scaled Annual Average, so that the scaled data is equivalent to the baseline data, but expressed in kWh/m^2: 1 kWh/m^2 = 1000 Wh/m^2.

> **Note:** To the right of the Scaled Annual Average input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

5.16 Generating Synthetic Solar Data
6. Finding Data to Run HOMER
6.6 Recommended Reading

2.3.2 Solar DNI Resource

The Direct Normal Irradiance (DNI) Resource is used to calculate concentrating PV output. Concentrating PV uses optics to concentrate the solar radiation in a way that only captures the direct beam radiation (also called DNI) and does not capture the diffuse or reflected components of the incident solar radiation.

> **Note:** For a flat panel PV, enter a Solar GHI resource, not DNI. Flat panel PV captures direct, diffuse, and reflected radiation, and so uses the Solar GHI resource to calculate output.

The Solar DNI Resource window can be reached from the resources tab by clicking the icon in the resources tab of the navigation ribbon at the top of the HOMER window.

Choose Locale

You can select a location on the map in the home page.

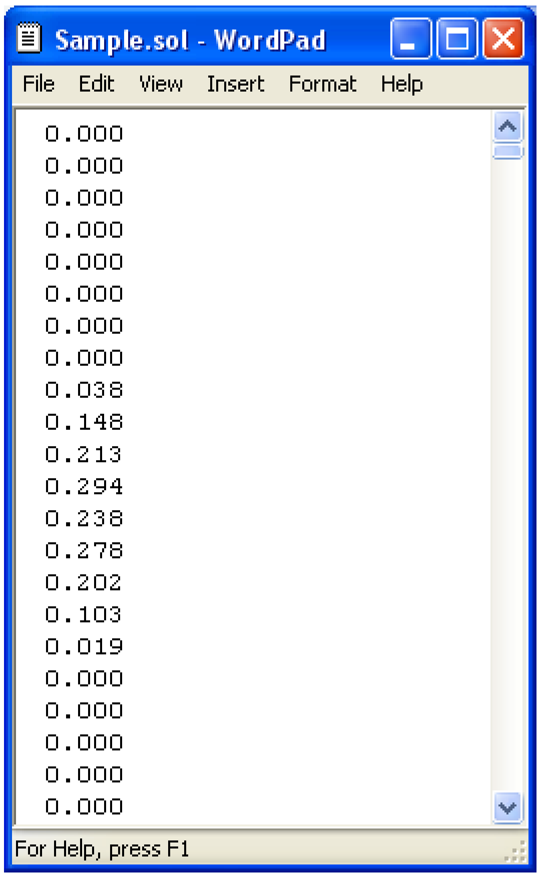
Importing Solar Data

The Solar DNI resource can only by specified by importing a time-series data file. See the help article **Finding data to run HOMER** for a list of sources for solar data.

You can prepare your own text file that contains the solar radiation data in each time step for a complete year.

> **Tip:** You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average solar radiation (in kW/m^2) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



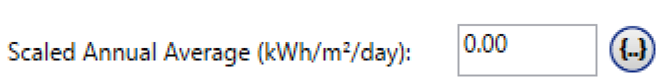
Click 

to open the text file. You can import a text file with any extension.

When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates monthly average radiation and clearness index values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the graph.

If you enter new monthly solar radiation values after importing data from a file, HOMER discards the data from the imported file and synthesizes new data based on the twelve new monthly averages. You can edit synthesized data by changing values in the solar resource table. To edit values from an imported file, you must edit the file directly and then import the modified file, as described above.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the values in the baseline data by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average solar radiation. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average solar radiation. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no solar radiation.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

An example of using the scaled annual average for unit conversion is to convert data from an imported file that contains solar radiation data expressed in Wh/m^2 rather than kWh/m^2. If the baseline annual average is 4800 Wh/m^2, you should enter 4.8 in Scaled Annual Average, so that the scaled data is equivalent to the baseline data, but expressed in kWh/m^2: 1 kWh/m^2 = 1000 Wh/m^2.

> **Note:** To the right of the Scaled Annual Average input is a sensitivity button ({...})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

5.16 Generating Synthetic Solar Data
6. Finding Data to Run HOMER
6.6 Recommended Reading

2.3.3 Temperature Resource

The Temperature Resources window can be reached by selecting the Resources tab and clicking the temperature icon.

Use this window to specify the ambient temperature for the year. Enter twelve monthly numbers or import a time series data file.

If you enter a scaled average different from the average of the baseline data, HOMER will offset the temperature data to correspond to the average value that you enter.

HOMER uses the ambient temperature to calculate the PV cell temperature, as described in the article on how HOMER calculates the PV cell temperature.

The Plot button allows you to view the scaled data in several graphical formats.

Choose Data Source

The baseline data is a time series representing the average temperature for each time step of the year. HOMER displays the monthly averages in the temperature resource table and graph.

There are two ways to create baseline data: you can use HOMER to synthesize hourly data from monthly averages, or you can import time series radiation data from a file.

Monthly Averages

Temperature resource data can be input via the monthly solar radiation table. You can enter the monthly data manually, or you can download it from the HOMER website.

To download solar data from the HOMER Energy website, first be sure that you have selected your project's location on the **Home Page**. Then, simply click the "Download" button. This will automatically fill in the twelve monthly average values for you based on the latitude and longitude.

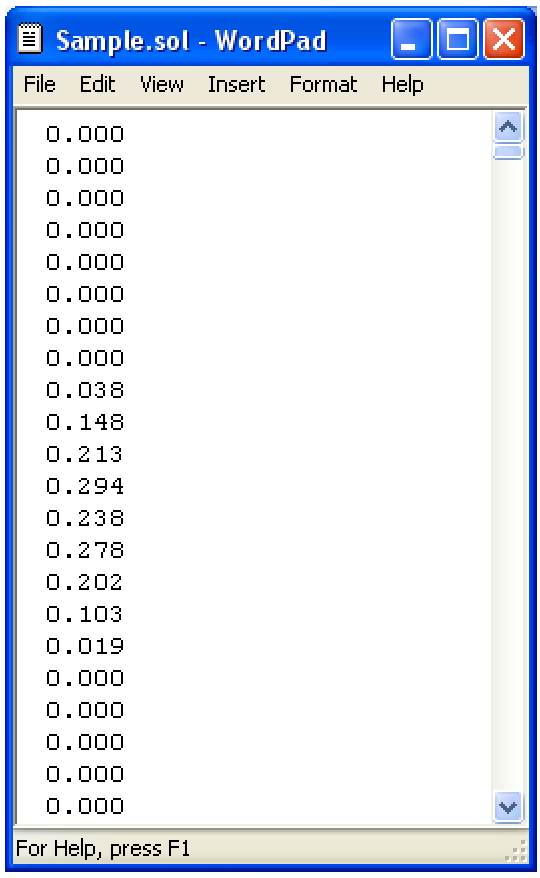
Once you have values in the monthly table, either by manual entry or download, HOMER builds a set of 8,760 temperature values, or one for each hour of the year. HOMER simply assumes a constant temperature throughout the month, and writes a time series where the temperature in each month is constant at the average value. This is a simplifying assumption; for a more precise representation of ambient temperature, you can import time series data from a file.

Import Solar Data

You can prepare your own text file that contains the temperature in each time step for a year.

> **Tip:** You can import data with time steps of many sizes between 60 minutes and one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the temperature (?C) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.

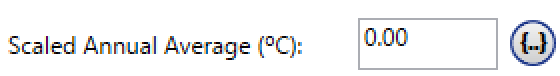


Click 

to open the text file. You can import a text file with any extension.

When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates monthly average values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the graph.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the values in the baseline data by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

An example of using the scaled annual average for unit conversion is to convert data from an imported file that contains temperature expressed in °F rather than °C. If the baseline annual average is 59 deg;F, you should enter 15 in Scaled Annual Average, so that the scaled data is equivalent to the baseline data, but expressed in °C: °F = 9/5 * (°C) + 32

See also:

5.8 How HOMER Calculates the PV Cell Temperature

2.3.4 Wind Resource

The Wind Resource window can be reached from the Resources tab by using the  button.

You can use this window to describe the available wind resource. HOMER will use this data to calculate the output of the wind turbine in each time step. This window also provides access to the following tabs:

- **Parameters**: Variables related to altitude
- **Variation with Height**: Parameters describing wind shear and the wind velocity's vertical profile
- **Advanced Parameters**: Parameters controlling variation of the wind over time

You can download monthly average wind resource data from the HOMER Energy website, or see **Finding data to run HOMER**

Baseline data

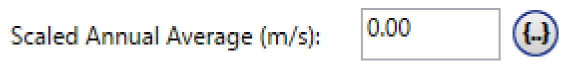
The baseline data is a one-year time series representing the average wind speed, expressed in meters per second, for each time step of the year. HOMER displays the monthly averages calculated from the baseline data in the wind resource table and graph.

You can create baseline data by downloading data from the HOMER Energy website, entering monthly average manually and using HOMER to synthesize time series data, or by importing time series data from a file.

To synthesize data, you must enter or download twelve average wind speed values: one for each month of the year. To download the monthly averages for synthesized wind data, be sure to first select your location on the **Home Page**. Then simply click "Download from Internet..." to download the averages from the HOMER website. Wind resource data comes with the anemometer height at which the wind speed was measured. Downloading a wind resource will automatically set this input to the correct value. Some regions have wind resource data available that includes values for the four **advanced parameters**. If that is the case, these four parameters will also be set when you download the wind resource. You can also edit the four advanced parameters by hand.

To input data manually, enter each month's average wind speed (m/s) in the table. As you enter values in the table, HOMER synthesizes time series data with the statistical characteristics you have specified. For more information please see the article on **synthetic wind data**.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in Scaled annual average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no wind resource.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

An example of using the scaled annual average for unit conversion is to convert data from an imported file that contains wind speed expressed in kilometers per hour. If the baseline annual average is 20 km/hr, you should enter 5.56 in Scaled Annual Average, so that the scaled data is equivalent to the baseline data, but expressed in m/s rather than km/hr: 1 m/s = 3.6 km/hr; 5.56 m/s = 20 km/hr.

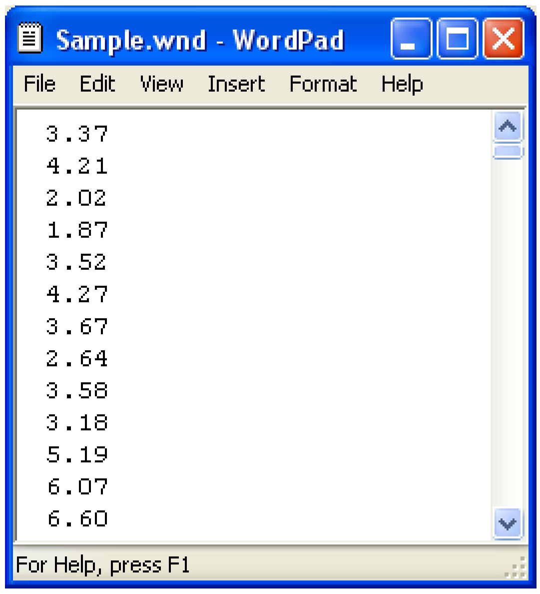
> **Note:** To the right of the Scaled Annual Averages input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

Importing Wind Speed Data

To import a file, you must prepare a text file that contains the wind speed in each time step for a complete year.

> **Tip:** You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average wind speed (in m/s) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates twelve monthly average wind speed values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the graph. HOMER calculates the four advanced parameters from the imported data and displays them (read-only) in the text boxes.

Pro: If you click Enter monthly averages after importing data from a file, HOMER discards the data from the imported file and synthesizes new data based on the twelve monthly average wind speed values and four advanced parameters it calculated from the imported data. You can edit synthesized data by changing values in the monthly wind speed table. To edit values from an imported file, you must edit the file directly and then import the modified file, as described above.

See also:

5.10 How HOMER Calculates Wind Turbine Power Output
5.17 Generating Synthetic Wind Data
6. Finding Data to Run HOMER
6.6 Recommended Reading

2.3.4.1 Wind Resource Parameters

The Parameters tab in the **Wind Resource** window gives you access to the following variables:

Variable	Description
Altitude	The altitude in meters above sea level
Anemometer Height	The height above ground at which the wind speed data were measured, in meters

2.3.4.2 Wind Resource Variation with Height

Use this window to describe the way the wind speed increases with height above ground. HOMER uses this information to calculate the wind speed at the hub height of the wind turbine.

Ground-level obstacles such as vegetation, buildings, and topographic features tend to slow the wind near the surface. Since the effect of these obstacles decreases with height above ground, wind speeds tend to increase with height above ground. This variation of wind speed with height is called *wind shear*. Wind energy engineers typically model wind shear using one of two mathematical models, the logarithmic profile or the power law profile.

Logarithmic profile

The logarithmic profile (or log law) assumes that the wind speed is proportional to the logarithm of the height above ground. The following equation therefore gives the ratio of the wind speed at hub height to the wind speed at anemometer height:

$$\frac{U_{hub}}{U_{anem}} = \frac{\ln(z_{hub}/z_0)}{\ln(z_{anem}/z_0)}$$

where
:

U_{hub} = the wind speed at the hub height of the wind turbine [m/s]

U_{anem} = the wind speed at anemometer height [m/s]

z_{hub} = the hub height of the wind turbine [m]

z_{anem} = the **anemometer height** [m]

z_0 = the surface roughness length [m]

ln(..) = the natural logarithm

The surface roughness length is a parameter that characterizes the roughness of the surrounding terrain. The table below contains representative surface roughness lengths taken from **Manwell, McGowan, and Rogers**:

Terrain Description	z_0
Very smooth, ice or mud	0.00001 m
Calm open sea	0.0002 m
Blown sea	0.0005 m
Snow surface	0.003 m
Lawn grass	0.008 m

Rough pasture	0.010 m
Fallow field	0.03 m
Crops	0.05 m
Few trees	0.10 m
Many trees, few buildings	0.25 m
Forest and woodlands	0.5 m
Suburbs	1.5 m
City center, tall buildings	3.0 m

Power law profile

The power law profile assumes that the ratio of wind speeds at different heights is given by the following equation:

$$\frac{U_{hub}}{U_{anem}} = \left(\frac{z_{hub}}{z_{anem}} \right)^{\alpha}$$

where:

U_{hub} = the wind speed at the hub height of the wind turbine [m/s]

U_{anem} = the wind speed at anemometer height [m/s]

z_{hub} = the hub height of the wind turbine [m]

z_{anem} = the **anemometer height** [m]

α = the power law exponent

The power law exponent is a dimensionless parameter. Foundational research in fluid mechanics showed that its value is equal to 1/7 for turbulent flow over a flat plate. Wind speed researchers have found that in practice the power law exponent depends on terrain roughness, atmospheric stability, and several other factors.

See also:
2.3.4 Wind Resource
5.10 How HOMER Calculates Wind Turbine Power Output
7.5 Anemometer Height
7.176 Wind Turbine Hub Height

2.3.4.3 Wind Resource Advanced Parameters

The Advanced Parameters tab in the **Wind Resource** window gives you access to the following variables:

Variable	Description
Weibull K	A measure of the long-term distribution of wind speeds

1 hr. autocorrelation factor	A measure of the hour-to-hour randomness of the wind speed
Diurnal pattern strength	A measure of how strongly the wind speed depends on the time of day
Hour of peak windspeed	The time of day that tends to be windiest on average

Some resource data, for certain regions, includes these parameters. If this is the case, HOMER will automatically set these parameters to the values specified in the downloaded resource information.

2.3.5 Hydro Resource

This feature requires the Hydro Module.
Click for more information.

Use the Hydro Resource window to describe the stream flow available to the hydro turbine. HOMER uses this data to calculate the output of the hydro turbine in each time step.

Baseline data

The baseline data is a one-year time series representing the average stream flow, expressed in liters per second, for each time step of the year. HOMER displays the monthly averages calculated from the baseline data in the stream flow table and graph.

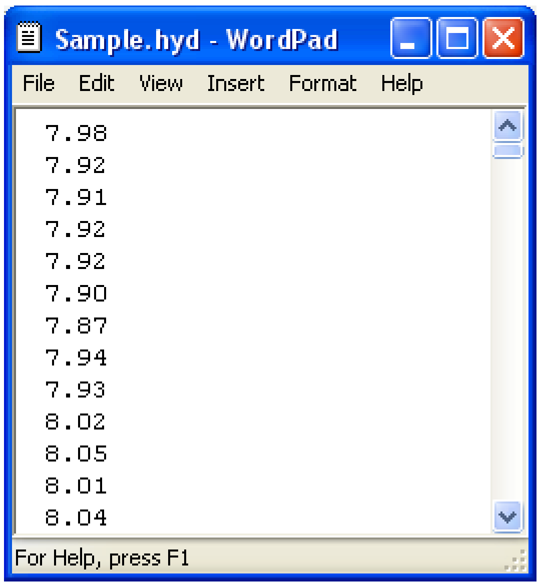
There are two ways to create baseline data: you can use HOMER to synthesize hourly data, or you can import time series data from a file.

To synthesize data, you must enter twelve average stream flow values: one for each month of the year. Enter each month's average stream flow (L/s) in the appropriate row on the stream flow table. As you enter values in the table, HOMER builds a set of 8,760 values, or one stream flow value for each hour of the year. HOMER creates the synthesized values by assuming that the stream flow is constant throughout each month; HOMER simply assigns the monthly average value to each hour in that month.

To import a file, you must prepare a text file that contains the stream flow in each time step for a complete year.

Tip: You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

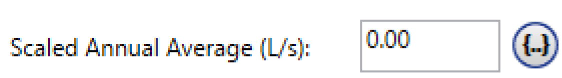
The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average stream flow (in L/s) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates twelve monthly average stream flow values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the stream flow graph.

If you click Enter monthly averages after importing data from a file, HOMER discards the data from the imported file and synthesizes new data based on the twelve monthly average values it calculated from the imported data. You can edit synthesized data by changing values in the stream flow table. To edit values from an imported file, you must edit the file directly and then import the modified file, as described above.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in Scaled annual average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no stream flow.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

An example of using the scaled annual average for unit conversion is to convert data from an imported file that contains stream flow data expressed in US gallons per minute. If the baseline annual average is 90 gal/min, you should enter 5.68 in Scaled Annual Average, so that the scaled data is equivalent to the baseline data, but expressed in L/s rather than U.S. gallons per hour: 1 L/s = 15.85 gal/min; 5.68 L/s = 90 gal/min.

Another reason to scale the baseline data is to do a **sensitivity analysis** on the hydro resource. Click the sensitivities button (to the right of the text box) to enter multiple values for a sensitivity analysis.

The Plot button allows you to view the scaled data in several graphical formats.

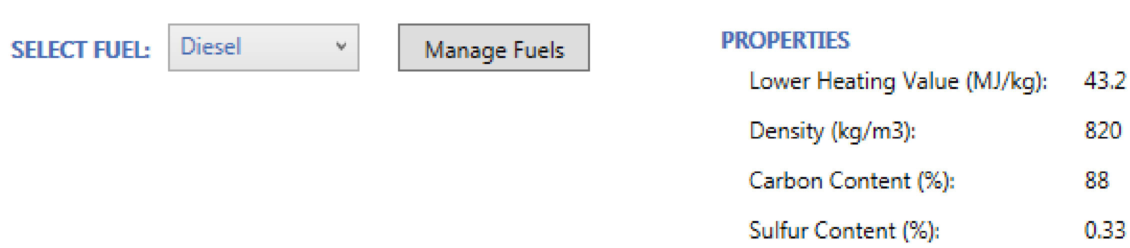
See also:

6.6 Recommended Reading

2.3.6 Fuels

When adding a generator, boiler, or reformer component, you must select a fuel. For the generic built-in components, the default fuel is diesel. You can leave diesel as the fuel or change to a different fuel in the library. Several common fuels are already built in to the library. You can also define your own custom fuel.

When you add a generator, boiler, or reformer, HOMER adds the corresponding fuel to your model by making a copy of the fuel from the library. You can add, remove, or modify fuels in the Fuels menu of the Resources tab. You can also access the fuels resource menu from the generator, reformer, or boiler component menus, through the "Manage Fuels" button that appears next to the fuel selection drop-down menu (screenshot below).



In the Fuels resource menu, you can change the properties of the fuel, as described in the table below. You can add any fuel from your library into the model by selecting it from the drop-down menu and clicking "Add". Changes to the fuel properties in this menu will not affect the fuel properties in the library. If you change the fuel properties and want to save the modified fuel in the library, you can click the "Copy to Library" button and the current fuel will be copied to your user library.

Properties

Variable	Description
Name	A unique name for the fuel

Lower Heating Value	The energy released per kg of fuel combusted
Density	Density in kg/m3 (the density of water is 1000 kg/m3)
Carbon Content	The mass-based carbon content of the fuel, in %
Sulfur Content	The mass-based sulfur content of the fuel, in %
Units	The preferred units for amount and price of the fuel. Liters, kg, and cubic meters are supported.
Fuel Type: Conventional	Typical fuels that are purchased at the specified price per unit from an external source (i.e. Diesel, Gasoline, etc.)
Fuel Type: Uses biomass resource	If this box is checked, this fuel can only be produced by the **Biomass Resource**.
Fuel Type: Stored Hydrogen	If this box is checked, the fuel can only be produced by the electrolyzer or reformer components, and it cannot be purchased. The fuel can only be used by components that can connect to the hydrogen bus.
Limit Quantity	Components using this fuel will not operate once the total system consumption exceeds the value set in "Quantity Available". This input is ignored if "Bio Fuel" or "Stored Hydrogen" is selected. Fuels with limited quantity cannot be used in boiler or reformer components.
Quantity available	The maximum quantity of fuel the system can use per year. This input is only used if "Limit quantity" is selected. This input is ignored if the fuel is not an "Conventional" type fuel. "Limit quantity" can only be used in the generator.
Fuel Price	Default price for this fuel. Once the fuel is added to a model, the fuel price or sensitivity values can be chosen for the scenario in the model.

You can also remove the fuel from the model by clicking the grey "x" in the corresponding row of the table of fuels available in the model. If you try to remove a fuel that is being used by any components in the model, you will see an error message telling you which components are using the fuel. To remove the fuel, you first need to change the components' fuels so that none of them are using the fuel you want to remove.

See also:

4.2.1 Create a New Fuel

2.3.7 Hydrokinetic Resource

Use the Hydrokinetic Resource window to describe the flow available to the hydrokinetic turbine. HOMER uses this data to calculate the output of the hydro turbine in each time step.

Baseline water speed data

The baseline data is a one-year time series representing the water speed, expressed in meters per second, for each time step of the year. HOMER displays the monthly averages calculated from the baseline data in the water speed table and graph.

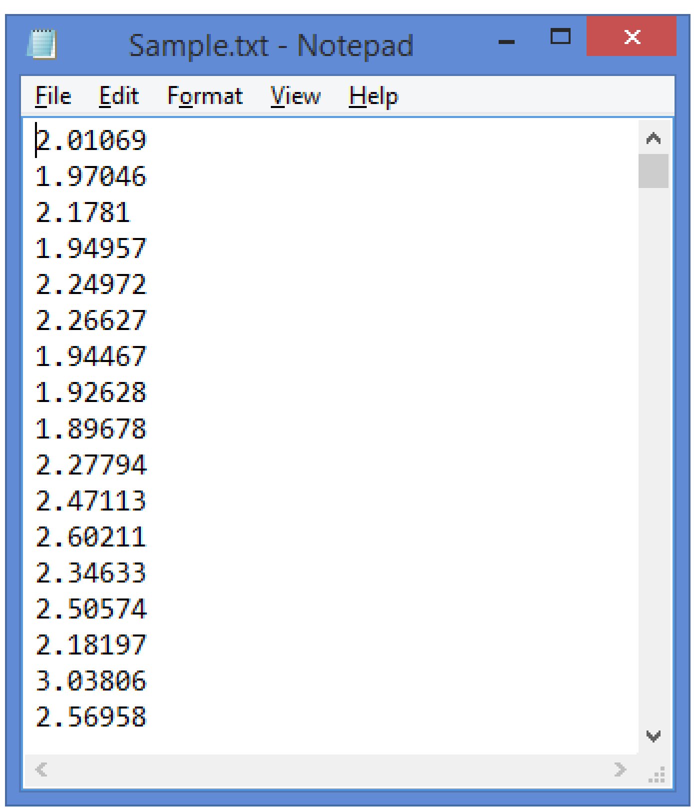
There are two ways to create baseline data: you can enter monthly averages, or you can import time series data from a file.

To enter twelve monthly averages, enter each month's average water speed (m/s) in the appropriate row on the water speed table. As you enter values in the table, HOMER builds a set of 8,760 values, or one water speed value for each hour of the year. HOMER creates the hourly values by assuming that the stream flow is constant throughout each month; HOMER simply assigns the monthly average value to each hour in that month.

To import a file, you must prepare a text file that contains the water speed in each time step for a complete year.

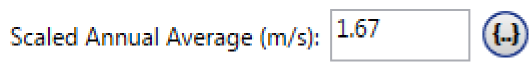
Tip: You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the average water speed (in m/s) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates twelve monthly average water speed values and displays them in the table and graph. You can view a plot of the time series data by clicking on the "Plot..." button at the bottom of the window.

Scaled data for simulation



HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in Scaled annual average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no stream flow.

You can use the scaled annual average for unit conversion. For example, you could convert data from an imported file that contains water speed data expressed in miles per hour. If the baseline annual average is 4 mi/hr, you should enter 1.79 in Scaled annual average, so that the scaled data is equivalent to the baseline data, but expressed in m/s rather than miles per hour: 1 m/s = 2.24 mi/hr; 1.79 m/s = 4 mi/hr.

Another reason to scale the baseline data is to do a **sensitivity analysis** on the hydro resource. Click the sensitivities button (to the right of the text box) to enter multiple values for a sensitivity analysis.

The Plot button allows you to view the scaled data in several graphical formats.

See also:

6.6 Recommended Reading

2.3.8 Biomass Resource

This feature requires the Biomass Module.
Click for more information.

HOMER assumes the biomass feedstock is fed into a gasifier to create **biogas** . One or more generators then consume the biogas to produce electricity (and optionally heat). Use the Biomass Resource window to describe the availability of biomass feedstock. HOMER uses this data to calculate (in each time step of the year) the amount of biogas that can be supplied by the gasifier to the biogas-fueled generator(s).

In each time step, HOMER will decide how to operate the biomass generator(s). If there is not enough feedstock available, HOMER may not be able to run the generator at full power, or might not be able to turn the generator on at all. Other than this constraint, the decision of how to run a biomass generator is similar to the logic used to control a normal generator.

Once HOMER decides the operating load for the biomass generator, the mass of biogas required is calculated from the fuel curve. The gasification ratio is used to convert the mass of biogas into a mass of biomass resource. This is the amount of biomass resource used (or purchased, if a price is assigned to the biomass feedstock) in the time step. If the available biomass feedstock is not all gasified and consumed in a given time step, the remainder is saved and can be used in future time steps.

Baseline data

The baseline data is a one-year time series representing the average biomass feedstock availability, expressed in kilograms, for each time step of the year. HOMER displays the monthly averages calculated from the baseline data in the biomass resource table and graph.

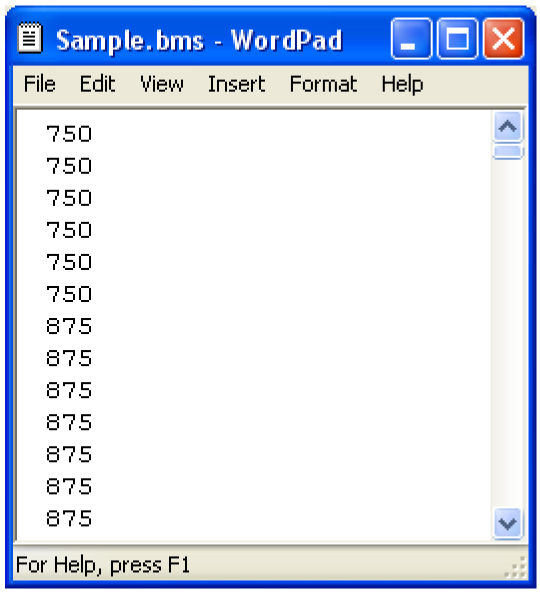
There are two ways to create baseline data: you can use HOMER to synthesize hourly data from monthly averages, or you can import time series data from a file.

To synthesize data, you must enter twelve average values of biomass availability: one for each month of the year. Enter each month's average biomass availability (in tonnes per day) in the appropriate row of the biomass resource table. As you enter values in the table, HOMER builds a set of 8,760 values, or one value for each hour of the year. HOMER creates the synthesized values by assuming that the biomass availability is constant throughout each month; HOMER simply assigns the monthly average value to each hour in that month.

To import a file, you must prepare a text file that contains the biomass feedstock availability in each time step for a complete year.

Tip: You can import data with any time step down to one minute. HOMER detects the time step when you import the data file. For example, if the data file contains 8760 lines, HOMER will assume that it contains hourly data. If the data file contains 52,560 lines, HOMER will assume that it contains 10-minute data.

The data file must contain a single value on each line, where each line corresponds to one time step. Each value in the file represents the biomass feedstock availability (in kilograms) for that time step. The first time step starts at midnight on January 1st. A sample input file appears below.



When you import data from a text file, HOMER makes a copy of the data set and integrates it with the HOMER (.homer) file. Once the data is part of the HOMER file, HOMER no longer refers to the original text file. If you modify data in the original file, you must import the modified file in order for the modification to be included in the HOMER file. After you import a data file, HOMER calculates twelve monthly average biomass availability values and displays them in the table and graph. HOMER also displays the name of the imported data file in the title of the biomass resource graph.

If you click Enter monthly averages after importing data from a file, HOMER discards the data from the imported file and synthesizes new data based on the twelve monthly average values it calculated from the imported data. You can edit synthesized data by changing values in the biomass resource table. To edit values from an imported file, you must edit the file directly and then import the modified file, as described above.

Properties

Variable	Description
Average cost	The average cost per tonne of the biomass feedstock.
Carbon content	The carbon content of the biomass feedstock as a mass-based percentage.
Gasification ratio	The ratio of **biogas** generated to biomass feedstock consumed in the gasifier.
LHV of biogas	The energy content (lower heating value) of the biogas produced by the gasifier.

Scaled data for simulation

HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in

Scaled annual average. To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical. HOMER interprets a scaled annual average of zero to mean that there is no biomass resource.

Two reasons to use a scaled annual average that is different from the baseline annual average are for unit conversion or to perform a sensitivity analysis.

The Plot button allows you to view the scaled data in several graphical formats.

> **Note:** To the right of each numerical input is a sensitivity button ({..})which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why would I want to do a sensitivity analysis?**

See also:
6.6 Recommended Reading

2.4 Project Tab

In the Project tab you can set options that apply to your entire model. They are grouped onto the following menus:

- **Economics**
- **System Control**
- **Emissions**
- **Constraints**

See also
Definition of **7.148 Sensitivity Variable**

2.4.1 Economics

The Economics menu in the **Project** tab gives access to the following variables:

Variable	Description
Real discount rate	The discount rate used to convert between one-time costs and annualized costs, in %
Nominal discount rate	The rate at which you could borrow money, in %
Expected inflation rate	The inflation rate that is expected over the project life, in %
Project lifetime (years)	The number of years over which the **net present cost** of the project should be calculated

System fixed capital cost	The fixed capital cost that occurs regardless of the size or architecture of the system, in $
System fixed O&M cost	The fixed annual costs that occur regardless of the size or architecture of the system, in $/yr
Capacity shortage penalty	A penalty applied to the system for any **capacity shortage**, in $/kWh

> **Note:** To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

2.4.3 Constraints

The Constraints menu in the **Project** tab allows you to modify system constraints which are conditions the **systems** must satisfy. HOMER discards systems that do not satisfy the specified constraints, so they do not appear in the optimization results or sensitivity results.

Variable	Description
Maximum annual capacity shortage	The maximum allowable value of the **capacity shortage fraction**, which is the **total capacity shortage** divided by the total annual electric load, in %
Minimum renewable fraction	The minimum allowable value of the annual **renewable fraction**, in %

Operating reserve

> **Note:** Under most circumstances you do not need to change the values of these advanced inputs. Their default values are appropriate for most systems.

Operating reserve is surplus **operating capacity** that ensures reliable electricity supply even if the load suddenly increases or renewable power output suddenly decreases. HOMER defines the required amount of operating reserve using four inputs, two related to the variability of the electric load and two related to the variability of the renewable power. These four inputs are described in the article on **required operating reserve**. The total required operating reserve is the sum of the four values resulting from these four inputs. In its simulation, HOMER operates the power system so as to keep the operating reserve equal to or greater than the required operating reserve. It records any shortfall as a **capacity shortage**.

Variable	Description
As a percent of the current load	HOMER adds this percentage of the primary load in the current time step (AC and DC separately) to the **required operating reserve** in each time step. A value of 10% means that the system must keep

	enough spare capacity operating to serve a sudden 10% increase in the load.
As a percent of annual peak load	HOMER adds this percentage of the peak primary load (AC and DC separately) to the **required operating reserve** in each time step. It therefore defines a constant amount of operating reserve. For example, if the peak AC primary load is 40 kW and you want to ensure at least 8 kW of operating reserve on the AC bus at all times (maybe to cover an 8 kW motor starting load), set this input to 20%.
As a percent of wind power output	HOMER adds this percentage of the wind turbine power output to the **required operating reserve** in each time step. A value of 60% means that the system must keep enough spare capacity operating to serve the load even if the wind turbine output suddenly decreases 60%. The more variable you expect the output of the wind turbine to be, the higher you should set this input.
As a percent of solar power output	HOMER adds this percentage of the PV array power output to the **required operating reserve** in each time step. A value of 25% means that the system must keep enough spare capacity operating to serve the load even if the PV array output suddenly decreases 25%. In most cases, the output of the PV array should be less variable than the output of a wind turbine, so this input will usually be set at a lower value than the previous one.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

7.115 Operating Reserve
7.138 Required Operating Reserve

2.4.4 Emissions

The Emissions menu in the **Project** tab allows you to specify a cost penalty associated with a pollutant, or a limit on the emissions of a pollutant.

Emissions Penalties

If you specify a non-zero cost penalty for a particular pollutant, HOMER will add the corresponding cost to the total annual cost of the power system. For example, if you specify a cost penalty for CO_2 emissions of $10 per tonne and the power system produces 15 tonnes of CO_2 per year, HOMER will penalize the system by adding $150/yr to its total annual cost. The emissions cost appears in the "other O&M cost" column of the in the **Costs** page of the Simulation Results window.

You can specify a penalty for any of the six pollutants that HOMER tracks. To the right of each input is a sensitivity button which allows you to do a **sensitivity analysis** on that variable.

In its dispatch logic, HOMER takes emissions penalties into account when comparing the costs of different dispatchable generation sources.

For a simple example, consider a system containing two generators whose properties are identical except that one has a higher NOx emissions factor. If the user specifies a non-zero cost penalty for NOx emissions, then whenever HOMER must choose between operating one generator or the other, it will choose the one with the lower NOx emissions factor.

Variable	Description
CO_2 Emissions Penalty	A cost penalty HOMER applies to the system's emissions of carbon dioxide, in $/ton
CO Emissions Penalty	A cost penalty HOMER applies to the system's emissions of carbon monoxide, in $/ton
HC Emissions Penalty	A cost penalty HOMER applies to the system's emissions of unburned hydrocarbons, in $/ton
PM Emissions Penalty	A cost penalty HOMER applies to the system's emissions of particulate matter, in $/ton
SO_2 Emissions Penalty	A cost penalty HOMER applies to the system's emissions of sulfur dioxide, in $/ton
NO_x Emissions Penalty	A cost penalty HOMER applies to the system's emissions of nitrogen oxides, in $/ton

Limits on Emissions

If you specify a limit to the emissions of a particular pollutant, HOMER will reject as infeasible any system that emits more than the allowed amount of that pollutant. You can constrain the emissions of any of the six pollutants that HOMER tracks. To the right of each input is a sensitivity button which allows you to do a **sensitivity analysis** on that variable. You can use such a sensitivity analysis to determine the cost of limiting emissions to a range of values.

Variable	Description
CO_2 Emissions Limit	A limit on the system's annual emissions of carbon dioxide, in kg/yr
CO Emissions Limit	A limit on the system's annual emissions of carbon monoxide, in kg/yr
UHC Emissions Limit	A limit on the system's annual emissions of unburned hydrocarbons, in kg/yr
PM Emissions Limit	A limit on the system's annual emissions of particulate matter, in kg/yr
SO_2 Emissions Limit	A limit on the system's annual emissions of sulfur dioxide, in kg/yr
NO_x Emissions	A limit on the system's annual emissions of nitrogen oxides, in

Limit	kg/yr

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also:

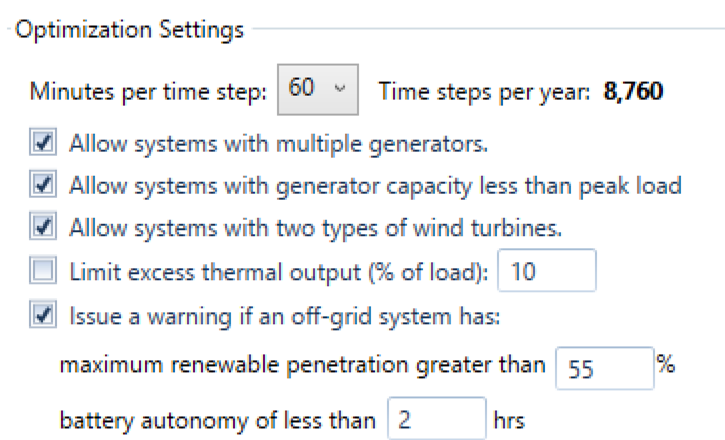
5.3 How HOMER Calculates Emissions

2.4.5 Optimization

The Optimization menu in the **Project** tab allows you to control how HOMER finds the optimal system. The Optimization menu is divided into two parts. On the left are the **"Optimization Settings"**, where you can apply rules to exclude some kinds of systems from the optimization. On the right side are **"Optimizer Settings"** which control some aspects of the numerical optimization.

Optimization Settings

The **simulation time step** is the time step that HOMER uses to simulate the operation of each system configuration. You can set the simulation time step to one of several possible values between one hour and one minute. The simulation time step does not have to match the time step of any time series load or resource data you may have imported. See the **article on the simulation time step** for details.



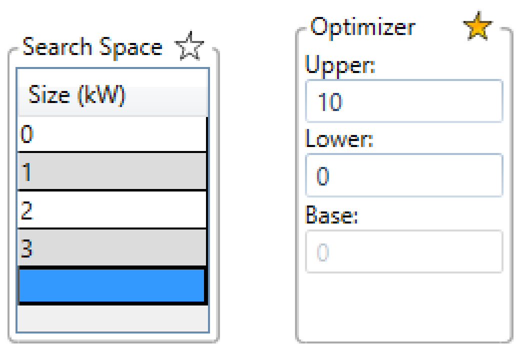
The rest of the options in this section let you exclude systems that meet certain criteria, or flag certain systems with a warning.

Allow systems with multiple generators	This check box controls whether HOMER considers systems that contain more than one generator. It has no effect if you are considering only one generator.
Allow systems with generator capacity less than peak load	This check box controls whether HOMER will consider systems whose total generator capacity is less than the annual peak primary load
Allow systems with two types of wind turbines	This check box controls whether HOMER will simulate system configurations that contain more than one type of wind turbine. If you add two types of wind turbine to the schematic and you

	simply wish to choose between them, then leave this checkbox unchecked. If you want HOMER to simulate systems that contain both types of turbine, then check this checkbox.
Limit excess thermal output	If you check this checkbox, HOMER will prevent the system from producing more than the allowable amount of excess thermal energy
Issue a warning if an off-grid system has ...	If you check this checkbox, HOMER will issue warnings in the results for systems that meet the criteria you specify here.

The Optimizer

You can enable the "Optimizer" by clicking on the star icon above the search space table in the converter, storage, PV, and wind turbine components.



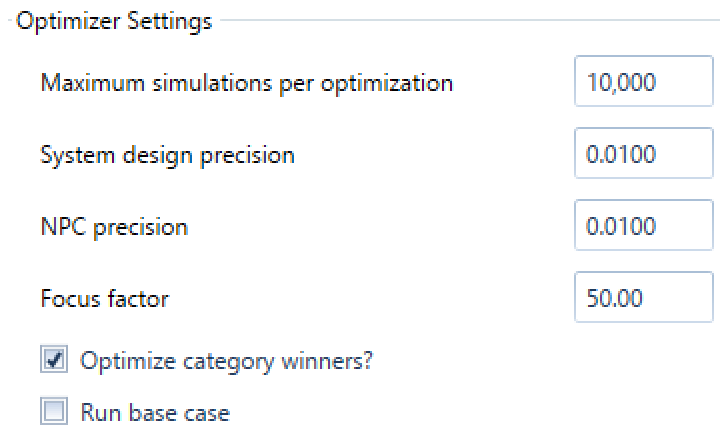
If you enable the optimizer for a component then you will not need to enter a search space for that component, only the lower and upper limits of the range to consider. HOMER will find the optimal size or quantity for you. You can optimize up to four components at a time. You can also mix some components that are optimized with some that have a regular search space together in one model. In that case, HOMER will run one optimization for each combination in the search space.

Using the Optimizer with a Search Space

For example, if you leave a PV with a regular search space like the image above and left, and have several other components with the optimizer enabled (like the above, right), HOMER will run an optimization with each value of the search space on the left. That is, you will get the optimal system configuration for the system with no PV, and with PV capacity of 1 kW, 2 kW and 3 kW. All the optimization results will be listed together in the optimization results table of the results view. You can compare the optimal systems with each size of PV, and find the best overall system this way. You can also sort and filter on PV size to see only results from one optimization at a time.

Tip: If you are considering a small number of wind turbines (i.e. 0, 1, or 2 turbines) it can be better to just enter the quantities in the search space, and not use the optimizer. The same applies to batteries. If you are considering four or more different quantities of wind turbines or batteries, the optimizer can be a good choice.

Optimizer Settings



The Optimizer Settings section of the Optimization menu contains inputs that affect how the numerical optimization algorithm operates.

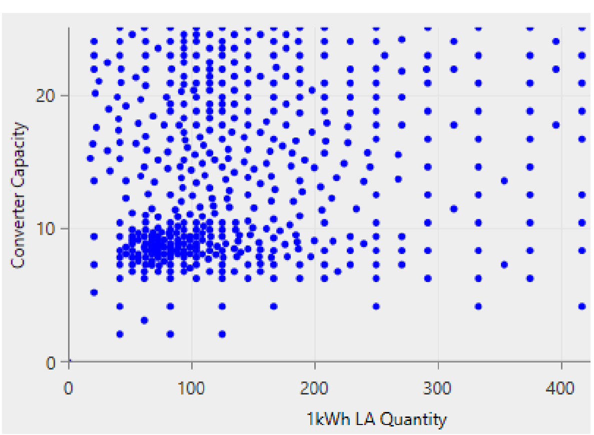
Variable	Description
Maximum simulations per optimization	HOMER will run one optimization for each combination of search space variables (explained above). HOMER will also run an optimization for each system category if "Optimize category winners?" (below) is selected. This option limits the number of simulations for each optimization.
System design precision	The maximum relative precision of **decision variables** allowed for convergence. There must be at least N systems closer than this from the best system, where N is the number of dimensions in the optimization. Distance is calculated as a fraction of the total range you specify for each decision variable (upper limit minus the lower limit).
NPC precision	The maximum relative error in net present cost (NPC) required for convergence. The average NPC of the N systems closest to the best system must be within the specified fraction of the best system's NPC, where N is the number of dimensions in the optimization. This input is interpreted as a fraction of NPC
Focus factor	This setting controls how evenly HOMER will cover the optimization space with points (where each point is a system configuration). A low focus factor will cover the space more evenly. A high focus factor will concentrate points near existing points with a low net present cost. Optimizing with a higher focus factor will tend to converge more quickly, with fewer total simulations needed, but can risk getting stuck in a local optimum.
Optimize category winners?	Run additional optimizations with and without each component in the system; if this is not selected, only the overall winner is optimized, and category winners may not be good.
Run base case	Enables the "Base Case" inputs in each component using the optimizer. HOMER will run a single extra simulation with these search space values in addition to the optimization.

The **system design precision** specifies the relative error in the decision variables (i.e. PV array capacity) below which convergence is allowed. If the NPC precision criterion is also satisfied, the optimization is finished. The system design precision is specified as a fraction of the total range of each component. For example, consider a system where the PV capacity (minimum 0 kW, maximum 100 kW) and the storage quantity (minimum 0, maximum 300) are both being optimized. A precision setting of 0.01 means plus or minus 1 kW of PV, and plus or minus 3 batteries.

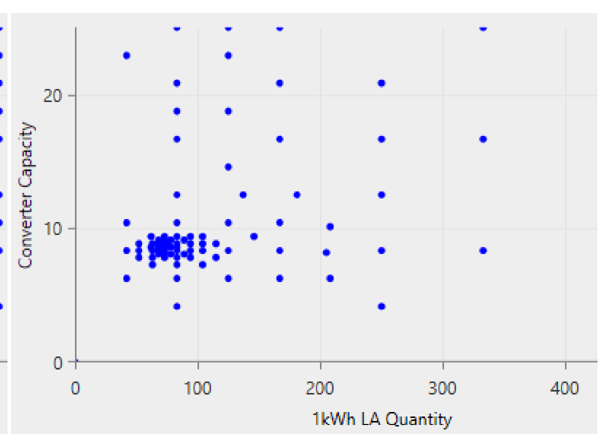
The **NPC precision** convergence criterion must also be met for convergence. Once both criteria are met, the optimization is finished. The NPC precision is relative to the best system's NPC. Consider an example where the current best system has an NPC of $67,000, and the NPC precision is 0.01. If average difference in NPC of the nearest N points is less than $670, the NPC precision criterion is satisfied.

The **Maximum simulations per optimization** prevents the optimization from running forever if it can't converge. For example, imagine we want to optimize four variables with the default system design and NPC precision of 0.01. If we choose a low focus factor, the guess points will be evenly distributed over the 4-dimensional space. With the system design precision of 0.01, we would need on the order of 100 points in each dimension. For four dimensions, that's 100^4 or 100 million points. The maximum simulations per optimization prevents the optimization from trying to do that.

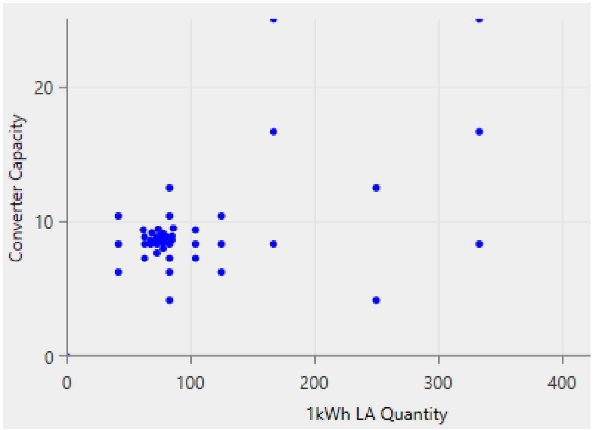
Increasing the **Focus Factor** causes the points evaluated during optimization to be clustered more around the optimal system. A typical point distribution for a 2-dimensional optimization is pictured below for different values of the focus factor. On the plots below, each point represents a system that was evaluated. There is no data plotted about the resulting NPC for each system, but you can guess where the lower NPC systems are because the points are clustered together around the optimal point.

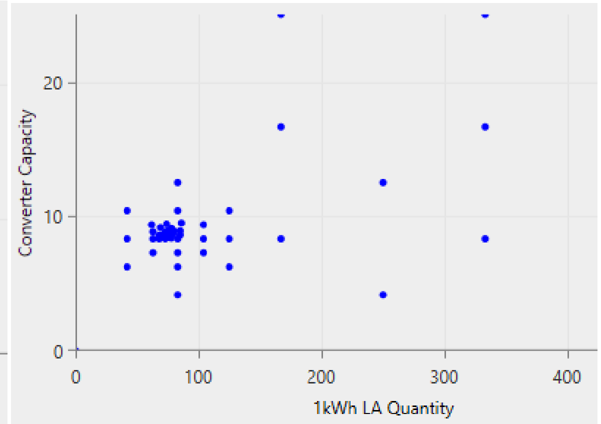


Focus factor = 1



Focus factor = 3



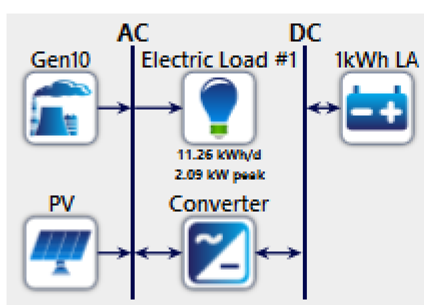


Focus factor = 15 **Focus factor = 50**

The default setting for the focus factor is 50. This will produce results rapidly, and is good for designing and iterating. Before finalizing a design, you may want to try a lower focus factor (i.e. 5 or 10) and run the optimization again. It will take longer, but you can be more confident that the solution reported is the global optimum. You might consider increasing the maximum simulations per optimization input to accommodate a lower focus factor.

Running Calculate with the Optimizer

When you click the "Calculate" button, HOMER may perform many optimizations: one optimization for each search space combination, and also for each system category. The theoretical maximum number of simulations per calculate can be many times more than the maximum number you specify in **maximum simulations per optimization**. Consider a system with a generator, storage, converter, and PV. We set the optimizer for the storage and converter, and PV. We also set the optimizer to optimize the category winners (the default). We put 0 and 10 kW in the generator search space.



HOMER will run an optimization with the storage, converter, PV, and 10 kW generator (since we put a 10 in the generator search space). If "Optimize category winners?" is selected, HOMER will also try to optimize the system with and without each of the storage, converter, and PV (all with the 10 kW generator still included). It will run an optimization with no storage, converter, or PV (generator only) and will quickly realize that there isn't much to optimize (but the generator-only result will still be included in the results). Then it will optimize the PV only, then the converter only, then PV and converter, then storage only, and so on (there are 2^3 combinations here). Then it will repeat the whole process without the generator, for a total of 2^3 * 2 (=16) optimizations.

If the **maximum simulations per optimization** is set to 10,000, then it would be possible to run up to 160,000 simulations in this example. This wouldn't actually happen, since many of these combinations are silly (i.e. storage but no converter, nothing in the system at all, etc.). In these cases, none of the systems in the optimization space will be feasible, and it will give up quickly. In the viable combinations, each optimization will run to convergence. We expect that will happen well before we hit 10,000 simulations, so the total number of simulations will be much lower than 160,000.

If you are running a sensitivity analysis, HOMER will repeat the entire process for each sensitivity case. When you add a sensitivity analysis to your HOMER model, the time HOMER takes to calculate will be multiplied by the number of sensitivity cases you add. For more information on this, see **Why would I do a sensitivity analysis?**

See also:

5.3 How HOMER Calculates Emissions

3.3.1 Why Would I Do a Sensitivity Analysis?

2.5 System Tab

The System tab gives you access to all of the menus where you can review your project and model as a whole. It is a good place to review your model and inputs before you calculate results. The system tab contains the following menus:

Name	Description
Project Set Up	Options that apply to the entire model: **economics**, **system control**, **emissions**, and **constraints**
Input Report	create an HTML-format report summarizing all the model inputs, and display it in a browser
Search Space	View and edit the system parameters HOMER simulates to find the optimal system configuration
Sensitivity Inputs	View and modify all the sensitivity variables in the model

2.5.1 Input Summary Report

HOMER will create an HTML-format report summarizing all the relevant inputs, and display it in a browser. From the browser, you can save or print the report, or copy it to the clipboard so that you can paste it into a word processor or spreadsheet program.

2.5.2 Search Space

The Search Space optimization values table gives access to the search space for the whole system. You can view and edit the values for any component in your model. HOMER will simulate all combinations of these values to determine the most efficient system configuration.

See also
Definition of **7.143 Search Space**

2.5.3 Sensitivity Inputs

This window gives convenient access to all the sensitivity variables. You can view and edit the values in tabular format.

See also
7.148 Sensitivity Variable

2.5.4 Estimate

The estimate button provides a quick calculation of the amount of time it will take to complete calculation for the current project. You do not need to estimate before running the calculation, but it can be useful for determining compute time. The number of simulations and estimated compute time will display in the space to the right of the buttons.

2.5.5 Multi-Year Inputs

This feature requires the Multi-Year Module. Click for more information.

The multi year feature allows you to model changes that occur over the lifetime of the project. It does this by running a simulation for every year in the project life. Without multi-year, HOMER runs a single simulation and extrapolates the results over the rest of the project lifetime. Multi-year mode significantly increases the calculation time, but allows you to model some important phenomena that can't be captured in a single year simulation.

Some of the phenomena that the multi-year function can model are:

- **Component degradation:** Photovoltaics panels degrade over time. Battery degradation can also be modeled when multi-year is combined with the Advanced Storage Module.
- **Price fluctuations:** Prices of fuel, the grid, and other components might not stay the same over the course of a project.

Multi-year allows you to input anticipated percentage changes in diesel prices or grid prices year by year.

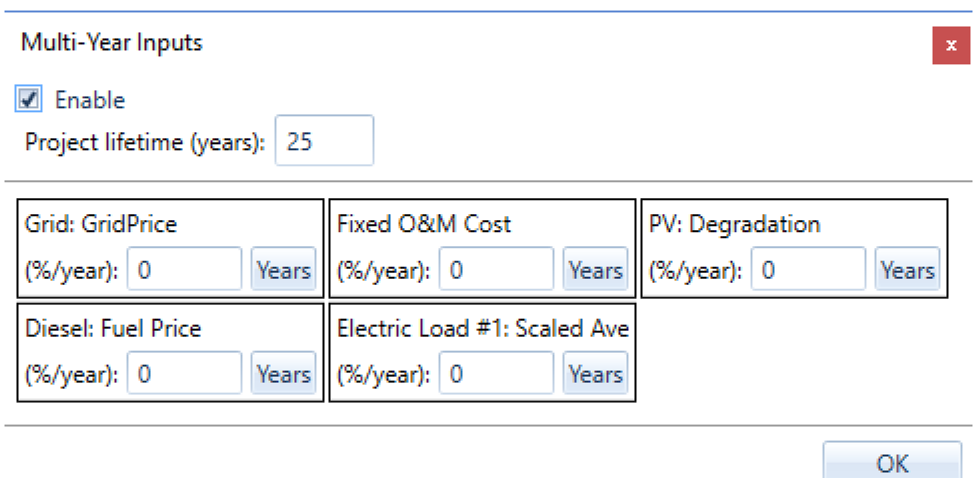
- **Load growth:** The primary demand might increase or decrease over the project lifetime. The multi year feature allows you to input a year by year percentage change in the load.
- **Other costs:** You can set a value for the System Fixed O&M Cost, and then use the multi-year multipliers to add a custom cash flow profile to the economics calculations.

Tip: Battery degradation is modeled automatically if you include a battery with the **Modified Kinetic Battery Model** in your model and enable multi-year mode.

Note: Multi-year mode does not work with the HOMER Optimizer.

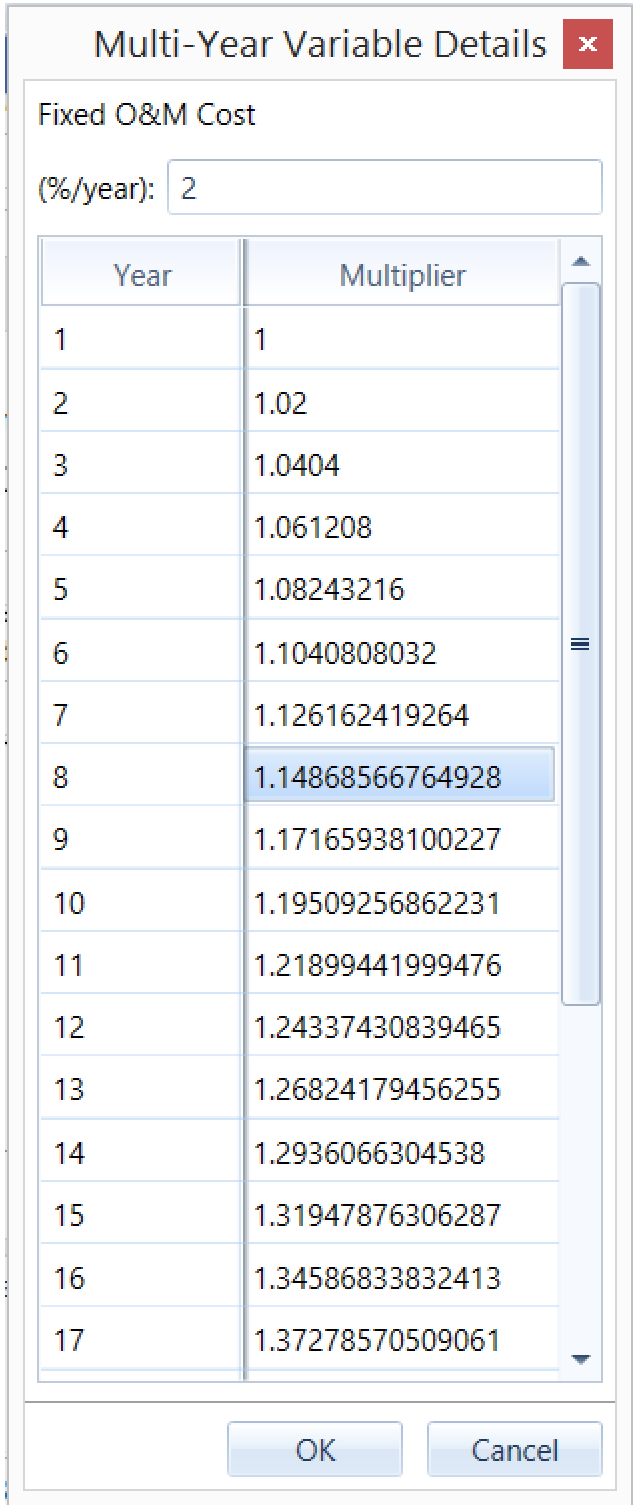
Using the Multi-Year Feature

To use the multi-year feature, click the System tab on the HOMER menu bar. Click on the multi-year button. This will open the multi-year menu. The variables that appear will depend on your formulated system.



Check the box to enable this feature, and specify the project lifetime. You can then choose to take into account the fluctuations in the O&M costs, PV degradation, Diesel fuel prices, and primary load changes. If you do not want to model changes in a certain variable over the project life time, leave the change rate (%/year) set to zero.

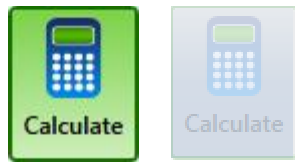
If you decide to model changes in a certain variable, you can set a constant percentage by which that component could change every year. You can also click the Years button to display the year-by-year table, and modify the relative value of the variable for each year individually. When you first open the year-by-year table, the multipliers will be calculated based on the percentage entered in the change rate input box.



Note: Calculate takes longer with multi-year mode on. The calculation time is increased over the normal calculate by a factor of the number of years in the project life, plus significant extra overhead associated with the multi-year calculations. When you use multi-year mode, keep your search space and sensitivity analysis small.

2.6 Calculate Button

The calculate button appears on the right end of the toolbar, and is visible from all menus. It changes color depending on the status of the current design:



If the current design contains all the necessary components and resources, the calculate button will appear green. If the design is obviously incomplete (i.e. if a PV is added and no solar resource is defined, or if there are both AC and DC components but no system converter) the calculate button will appear gray.

Note: It is possible for the calculate button to appear green, but still find no feasible solutions after calculating.

3. Results View

In the Results view, HOMER displays two tables. The top table is the **Sensitivity Cases** table. It shows a list of the best feasible systems for each sensitivity case entered. You can click a sensitivity case to view all feasible systems for that case in the lower, **Optimization Results** table. Double click on a system in the Optimization Cases table (the lower table) to see its details in a **Simulation Results** window.

Click the  button to view the results summary pop-up. This window explains the calculation results by providing the total number of simulations, number of feasible and infeasible systems, and number of systems omitted due to disallowed configuration (i.e. a non-zero converter with all components on one bus).

You can also click the Column choices... button to change which columns are listed in the results tables. The same columns are displayed for both tables. The Export... buttons above each of the two tables save the corresponding table to a csv file. Only the displayed columns, set in "Column Choices..." will be exported.

3.1 Simulation Results

Double click a row in the **Optimization Results** table to open the Simulation Results window for that system. At the top of the window will be displayed the system **Net Present Cost**, the system Architecture which lists the components of the system, and Sensitivities which is the **sensitivity case** that was used.

The Simulation Results window always contains the following tabs:

- The **Cost Summary** tab displays the total cash flow, categorized either by component or by cost type
- The **Cash Flow** tab displays the year-by-year cash flows in a customizable graphical format
- The **Electrical** tab displays details about the production and consumption of electricity by the system

- The **Emissions** tab displays the annual pollutants emitted by the system

The Simulation Results window may also contain the following tabs, if the equipment is included:

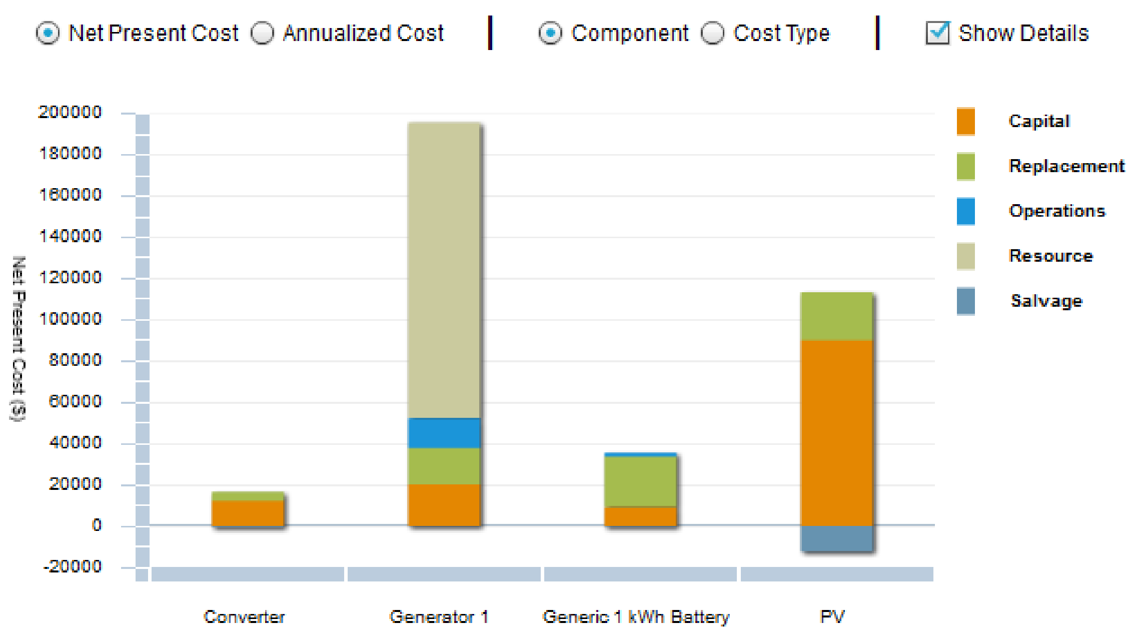
- The **PV** tab shows details about the operation of the PV array
- The **Wind Turbine** tab shows details about the operation of the wind turbine
- The **Generator** tab shows details about the operation of the generator
- The **Fuel Summary** tab gives a summary of fuel usage for each fuel type in the model.
- The **Storage** tab shows details about the use and expected lifetime of the storage
- The **Grid** tab shows details about the purchases from and sales to the grid if the system is grid-connected, or information about the **break-even grid extension** if you are considering extending the grid
- The **Converter** tab shows details about the operation of the inverter and rectifier, including capacity, electrical input and output, hours of operation, and losses
- The **Thermal** tab shows details about the production and consumption of thermal energy by the system
- The **Thermal Load Controller** tab shows details about the heat production of the thermal load controller component
- The **Boiler** tab shows details about the operation of the boiler. Systems with thermal loads will always contain boilers.
- The **Hydro** tab shows details about the operation of the hydro turbine
- The **Hydrokinetic** tab shows details about the operation of the hydrokinetic component
- The **Hydrogen** tab shows details about the operation of the hydrogen components of the system
- The **Hydrogen Tank** tab shows details about the operation of the hydrogen tank
- The **Electrolyzer** tab shows details about the operation of the electrolyzer
- The **Reformer** tab shows details about the operation of the reformer

In addition to the tabs, the Simulation Results also contains several buttons along the bottom of the window:

- The **Time Series data** buttons allow you to analyze those variables that HOMER stores for each time step of the simulation. Buttons for time series analysis are: plot, scatter plot, delta plot, table, and export.
- The **Report** button allows you to print out a report with basic information about the system to easily share your simulation results with others.
- The **Copy** button copies the results from this view to your clipboard. You can paste the results into a spreadsheet application. The copied data is structured so that the outputs will generally stay in the same place from one simulation to another, so that you can integrate these outputs into your own workbook tools.

3.1.1 Cost Summary Outputs

The Cost Summary tab in the **Simulation Results** window displays cash flows as either a present value or annualized cost, categorized by component or cost type. It also provides access to the **Compare Economics** window.



You can choose among several options for displaying the cash flow summary:

- Net Present Cost displays the cost breakdown in terms of **net present costs**.
- Annualized Cost displays the cost breakdown in terms of **annualized costs**.
- Component causes HOMER to categorize costs by component.
- Cost Type causes HOMER to categorize costs according to type: capital, O&M, replacement, resource, and salvage value.
- Show details causes HOMER to categorize costs both by component and type in a single graph.

The table below the graph displays the cash flow summary broken down by component and by cost type. The values displayed in the graph appear highlighted in the table.

Tip: The Compare button opens the **Compare Economics** window, which allows you to compare two systems and calculate payback or internal rate of return.

Tip: For systems connected to the grid, HOMER puts the costs and revenues associated with buying and selling power from the grid into the grid O&M cost.

Note that the **total net present cost** appears on the Cost Summary tab and in the top right corner of the Simulation Results window.

See also

3.1 Simulation Results
3.1.2 Cash Flow Outputs
3.1.1.1 Compare Economics Window
7.105 Net Present Cost

7.6 Annualized Cost

3.1.1.1 Compare Economics Window

This window allows you to compare the economic merits of the current system and a base case system. The window displays cash flow graphs and a table of economic metrics. To open the window, choose a system to be the current system in **optimization results**, and then click Compare on the **Cost Summary** page of the **Simulation Results** window.

You must choose a base case system to compare with the current system to make the economic metrics meaningful. The metrics show you the value of the difference between two options, taking into account the life-cycle costs of both systems. You can compare the current system to any other system in the optimization results. For example:

- Compare a PV-wind-diesel hybrid system with a diesel-only base case system for an off-grid project to find the present worth of fuel saved by installing a hybrid system instead of a diesel-only system, taking into account the cost of installing, operating, and maintaining each system.
- Compare a grid-connected PV system to a grid-only system to find the payback period required for grid sales to recover the cost of installing the PV system.

The table at the top of the window displays a list of systems from the optimization results from which you can choose a base case. You can display the list as a categorized list to display only the top-ranked system in each category, or as an overall list to display all systems.

The system summary table shows the component sizes, capital cost and net present cost of the base case system and current system.

The display options control what appears in the cash flow graph.

Tip: Click and drag or click and press Ctrl+A to select the table. Then press Ctrl+C to copy the data to your clipboard. You can then paste the data into another program like Microsoft Excel or MATLAB.

When you choose a base case system, the metric table shows economic measures representing the value of the difference between the two systems:

- The present worth is the difference between the **net present costs** of the base case system and the current system. The sign of the present worth indicates whether the current system compares favorably as an investment option with the base case system: A positive value indicates that the current system saves money over the project lifetime compared to the base case system.
- The annual worth is the present worth multiplied by the **capital recovery factor**.
- To see how HOMER calculates return on investment (ROI), choose the following display options: Graph, Difference, Cumulative. Subtract the cumulative nominal cash flow in year zero from the cumulative nominal cash flow in the final year. Divide that number by the lifetime and then again by the cumulative nominal cash flow in year zero. Note that the cumulative nominal cash flow in year zero is equivalent to the base case capital cost minus the current system capital cost.

- Internal rate of return (IRR) is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.
- Payback is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system. You can see a visual representation of the payback by choosing the following display options: Graph, Difference, and Cumulative. The simple payback is where the nominal cash flow difference line crosses zero. The discounted payback is where the discounted cash flow difference line crosses zero.

3.1.1.2 Calculating Payback, Internal Rate of Return (IRR) and Other Economic Metrics

HOMER calculates payback by comparing one system with another. In general, payback tells you how many years it will take to recover an investment. You invest a certain amount of money up front, then earn income from that investment, and the payback is the number of years it takes for the cumulative income to equal the value of the initial investment. HOMER can also calculate other economic metrics such as IRR, present worth, and return on investment.

Sometimes, the "income" of a power system can be defined intrinsically, without a reference for comparison. If, for example, a grid-sales system does not need to serve any load, but simply sells power to the grid, then you can define the income of the system as the money it makes by selling power to the grid minus the expense of operating the system. In that case, you could compare the initial cost of the system with its income to calculate the payback.

For distributed power systems, it's usually not that simple, and the income must be defined relative to some alternative. Say you are designing a system to provide electricity to an off-grid house. A pure diesel system might have low capital cost and high operating cost, whereas a PV-diesel-storage system might have high capital cost and low operating cost. Neither system produces any income. In both cases you spend money up front to build the system, then you keep spending money each year to operate the system. The concept of payback has meaning only if you compare one system to the other. You can define the payback of the additional investment required for the PV-diesel-storage system by comparing the difference in capital cost with the difference in operating cost. HOMER does exactly that in the **Compare Economics** window.

So, to calculate the payback of one alternative, we must compare to another alternative. Even to calculate the payback of the simple grid-sales system mentioned above involves an implicit comparison with the base case, which is to do nothing. The do-nothing alternative is easy to compare to, since all its costs are zero, but if we have an electric load to serve, the do-nothing alternative is not an acceptable one.

A renewable power system designer will often use a non-renewable power system as the base case, but HOMER lets you choose any base case you want. You could compare a system with two wind turbines to a system that has one wind turbine to calculate the payback of the second wind turbine. Or you could compare a PV-diesel-storage system with a PV-diesel system to calculate the payback of the storage.

3.1.1.3 Grid Costs

The grid cost in HOMER Explorer is based on a levelized electricity cost in $/kWh. All grid electricity purchases will be at this rate.

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Since the grid is unlike any other component, HOMER calculates the costs associated with the grid in a unique way. This article explains how HOMER calculates each of the grid cost outputs.

Grid capital cost

If the system is connected to the grid and contains some other power producing device (such as a microturbine, a fuel cell, a PV array, or a wind turbine), the grid capital cost is equal to the interconnection charge. Otherwise, the grid capital cost is zero.

Grid replacement cost

The replacement cost of the grid is always zero.

Grid O&M cost

The grid O&M cost is equal to the annual cost of buying electricity from the grid (energy cost plus demand cost) minus any income from the sale of electricity to the grid. For grid-connected systems that contain some other power producing device (such as a microturbine, a fuel cell, a PV array, or a wind turbine), the grid O&M cost also includes the **grid standby charge**.

Grid fuel cost

The fuel cost of the grid is always zero.

See also

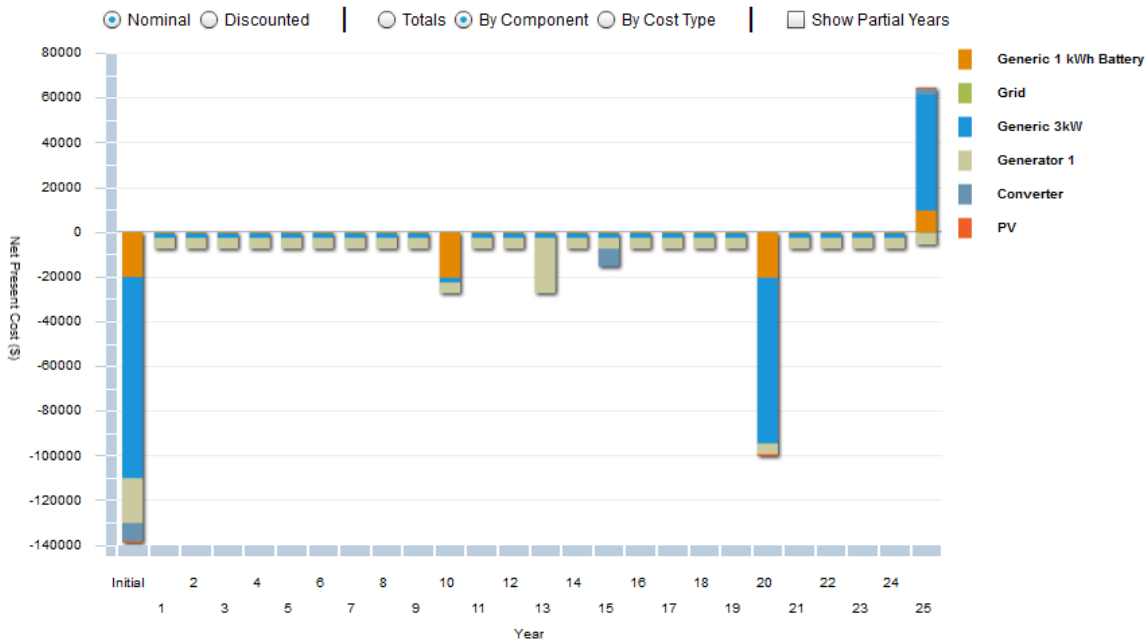
- **7.31 Capital Recovery Factor**
- **7.82 Grid Interconnection Charge**
- **7.83 Grid Standby Charge**
- **7.122 Project Lifetime**

3.1.2 Cash Flow Outputs

The Cash Flow tab in the **Simulation Results** window displays the system cash flow in either **graphical** or **tabular** form. You can choose the display with the radio buttons at the top of the window. Both views are described below.

Bar Chart

Each bar in the graph represents either a total inflow or total outflow of cash for a single year. The first bar, for year zero, shows the **capital cost** of the system, which also appears in the **optimization results**. A negative value represents an outflow, or expenditure for fuel, equipment replacements, or operation and maintenance (O&M). A positive value represents an inflow, which may be income from electricity sales or the salvage value of equipment at the end of the project lifetime.



You can choose to display the cash flows as either nominal or discounted values. A nominal cash flow is the actual income minus cost that HOMER anticipates in a particular year. A discounted cash flow is the nominal cash flow discounted to year zero. HOMER calculates the discounted cash flow by multiplying the nominal cash flow by the **discount factor**.

You can choose among two options for displaying the cash flow graph:

- By Cost Type shows each cash flow as a stacked bar, with each color representing one of five cost types: capital, replacement, salvage, O&M, and fuel. Note that the salvage value appears as a positive value at the end of the project lifetime. For grid connected systems that sell electricity to the grid, grid sales are included in the O&M cost type.
- By Component displays each cash flow as a stacked bar, with a different color representing each of the components in the system. Note that penalties and system fixed costs appear in the graph as "other" costs.

More detailed cash flow information can be found under the "Cash Flow" tab, which displays a table of cash flows broken down by year and by component.

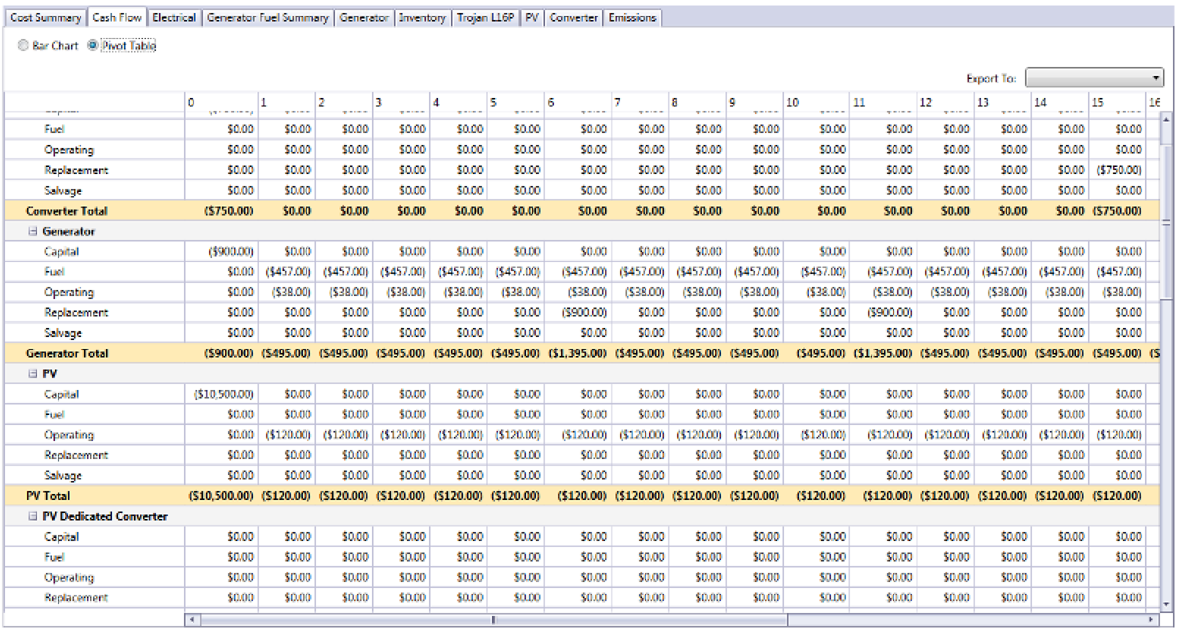
Pivot Table

Choose "Table" from the radio buttons at the top of the cash flow window. The cash flow details table shows a detailed breakdown of all the costs that occur throughout the project lifetime.

An example of the cash flow details table appears below. Each year of the project lifetime appears as a column. The rows list the capital cost, replacement cost, salvage value, O&M cost, fuel cost, and total cost for each component. Nominal costs appear in the top half of the table, and discounted costs appear in the bottom half. The discount factors, which

HOMER uses to calculate discounted costs from nominal costs, appear in between.

> **Tip:** Using the controls at the top of the window, you can choose to display a breakdown of the costs by component or by cost type, or to display nominal or discounted costs.



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fuel	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operating	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Replacement	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	($750.00)
Salvage	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Converter Total	**($750.00)**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**($750.00)**
Generator																
Capital	($900.00)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Fuel	$0.00	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)	($457.00)
Operating	$0.00	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)	($38.00)
Replacement	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	($900.00)	$0.00	$0.00	$0.00	$0.00	($900.00)	$0.00	$0.00	$0.00	$0.00
Salvage	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Generator Total	**($900.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($1,395.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($1,395.00)**	**($495.00)**	**($495.00)**	**($495.00)**	**($495.00)**
PV																
Capital	($10,500.00)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Fuel	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operating	$0.00	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)	($120.00)
Replacement	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Salvage	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Total	**($10,500.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**	**($120.00)**
PV Dedicated Converter																
Capital	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Fuel	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operating	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Replacement	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

The example above shows the cash flows for a system comprised of a diesel generator and a wind turbine. The project lifetime is ten years. The diesel generator needs to be replaced at a cost of $5,500 every two years, and the wind turbine needs to be replaced at a cost of $12,000 every eight years.

Capital Costs

Capital costs occur only at the beginning of the project, meaning at the end of year zero. No capital costs occur after year zero.

Replacement Costs

Replacement costs occur whenever a component needs a replacement. Note that replacement costs may not necessarily occur at integer year numbers. For example, if a generator requires replacement every 3.25 years, HOMER will assign replacement costs at 3.25 years, 6.5 years, and so on. Use the controls at the top of the window if you want to see the precise timing of these cash flows.

Salvage Value

Salvage value occurs as a positive cash flow at the end of the project lifetime, for any component that has some remaining life at this point. In the example above, the wind turbine requires replacement after eight years, so the second wind turbine is only two years old at the end of the ten-year project lifetime, meaning it has six years remaining in its lifetime. HOMER assumes linear depreciation, so it calculates a salvage value of 6/8 = 75% of the replacement cost of the wind turbine. Since the wind turbine replacement cost is $12,000, that leads to a salvage value of $9,000 for the wind turbine at the end of the project lifetime.

Operating and Maintenance Costs

For many components, such as the PV array and the wind turbine, you enter the O&M costs in dollars per year. For other components, such as the generator, you enter the O&M cost in dollars per operating hour, and HOMER multiplies that number by the operating hours per year to calculate the resulting annual O&M cost in dollars per year. Note that the number HOMER reports for the grid O&M cost is actually the annual cost of buying power from the grid minus the annual revenue gained from sales of power to the grid.

Fuel Costs

For components that consume fuel, HOMER calculates the annual fuel cost by multiplying the fuel price by the annual fuel consumption.

> **Tip:** The bottom row of the table, when displaying discounted costs, shows the total discounted cost for each year of the project lifetime. The sum of these numbers, which appears in the bottom right corner of the table, equals the total net present cost of the system.

See also

3.1 Simulation Results
3.1.1 Cost Summary Outputs
7.46 Discount Factor

3.1.3 Electrical Outputs

The Electrical tab in the **Simulation Results** window shows details about the annual production and consumption of electrical energy by the system.

Production

This table lists the total annual energy output of each electrical energy producing component of the power system, plus the **total electrical production**.

Consumption

This table lists the total amount of electrical energy that went to serve each of the system's electrical loads. Values that appear here when applicable include:

Variable	Description
AC Primary Load Served	The amount of energy that went towards serving the AC primary load(s)
DC Primary Load Served	The amount of energy that went towards serving the DC primary load(s)
Deferrable Load Served	The amount of energy that went towards serving the deferrable load
Electrolyzer Load	The amount of electrical energy consumed by the electrolyzer

Served	
Grid Sales	The total amount of electricity sold to the grid during the year
Total Load Served	The total amount of electrical load served during the year

Note: The total production can exceed the sum of the total consumption and the excess electricity because of losses in the storage and converter.

Excess and Shortage

This table lists the following values:

Variable	Description
Excess Electricity	The total amount of **excess electricity** that occurred during the year, as well as the **excess electricity fraction** expressed as a percentage of the total electrical production
Unmet Electric Load	The total amount of **unmet load** that went unserved because of insufficient generation during the year, as well as the **unmet load fraction** expressed as a percentage of the total electrical demand
Capacity Shortage	The total amount of **capacity shortage** that occurred during the year, as well as the **capacity shortage fraction** expressed as a percentage of the total electrical demand

Other Outputs

The final table lists the following variables:

Variable	Description
Renewable Fraction	The fraction of the total electrical production that is produced by renewable sources
Maximum **Renewable Penetration**	The maximum value of the renewable penetration that occurs over the year

See also

2.4.3 Constraints
3.1 Simulation Results

3.1.4 Emissions Outputs

The Emissions tab in the **Simulation Results** window shows the total amount of each pollutant produced annually by the power system in kg/yr. Pollutants originate from the consumption of fuel and biomass in generators, the boiler, and the reformer, as well as from the consumption of grid power.

Sales of power to the grid result in reduced grid emissions, and HOMER credits the power system with these reductions. The system can even achieve negative emissions of one or more pollutants if it sells a lot of low-emissions electricity to the grid.

See also

5.3 How HOMER Calculates Emissions

3.1.5 PV Outputs

The PV tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Rated Capacity	The rated capacity of the PV array under standard conditions, in kW
Mean Output	The average power amount of the PV array over the year, in kW and kWh/day
Capacity Factor	The average power output of the PV array (in kW) divided by its rated power, in %
Total Production	The total power output of the PV array over the year, in kWh/yr
Minimum Output	The minimum power output of the PV array over the year, in kW
Maximum Output	The maximum power output of the PV array over the year, in kW
PV Penetration	The average power output of the PV array divided by the average primary load, in %
Hours of Operation	The number of hours of the year during which the PV array output was greater than zero
Levelized Cost	The levelized cost of energy of the PV array, in $/kWh

In the bottom half of the page a **DMap** appears showing the power output of the PV array in each time step of the year.

3.1.6 Wind Turbine Outputs

The Wind Turbine tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Total Rated Capacity	The highest possible power amount from the wind turbine(s), in kW
Mean Output	The average power amount of the wind turbine over the year, in kW
Capacity Factor	The average power output of the wind turbine(s) divided by the total wind turbine capacity, in %
Total Production	The total power output of the wind turbine(s) over the year, in

	kWh/yr
Minimum Output	The minimum power output of the wind turbine over the year, in kW
Maximum Output	The maximum power output of the wind turbine over the year, in kW
Wind Penetration	The average power output of the wind turbine(s) divided by the average primary load, in %
Hours of Operation	The number of hours of the year during which the wind turbine output was greater than zero
Levelized Cost	The levelized cost of energy of the wind turbine(s), in $/kWh

In the bottom half of the page a **DMap** appears showing the power output of the wind turbine(s) in each time step of the year.

3.1.7 Generator Outputs

The Generator tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Hours of Operation	The total run time of the generator during the year, in hr/yr
Number of Starts	The number of times the generator was started during the year
Operational Life	The number of years the generator will last before it requires replacement
Capacity Factor	The average power output of the generator divided by its total capacity
Fixed Generation Cost	The fixed cost of running the generator, in $/hr
Electrical Production	The total power output of the generator over the year, in kWh/yr
Mean Electrical Output	The average electrical power output of the generator over the hours that it runs, in kW
Minimum Electrical Output	The lowest electrical power output of the generator over the year, in kW
Maximum Electrical Output	The highest electrical power output of the generator over the year, in kW
Average Thermal Output	The average thermal power output of the generator over the hours that it runs
Minimum Thermal Output	The lowest thermal power output of the generator over the year

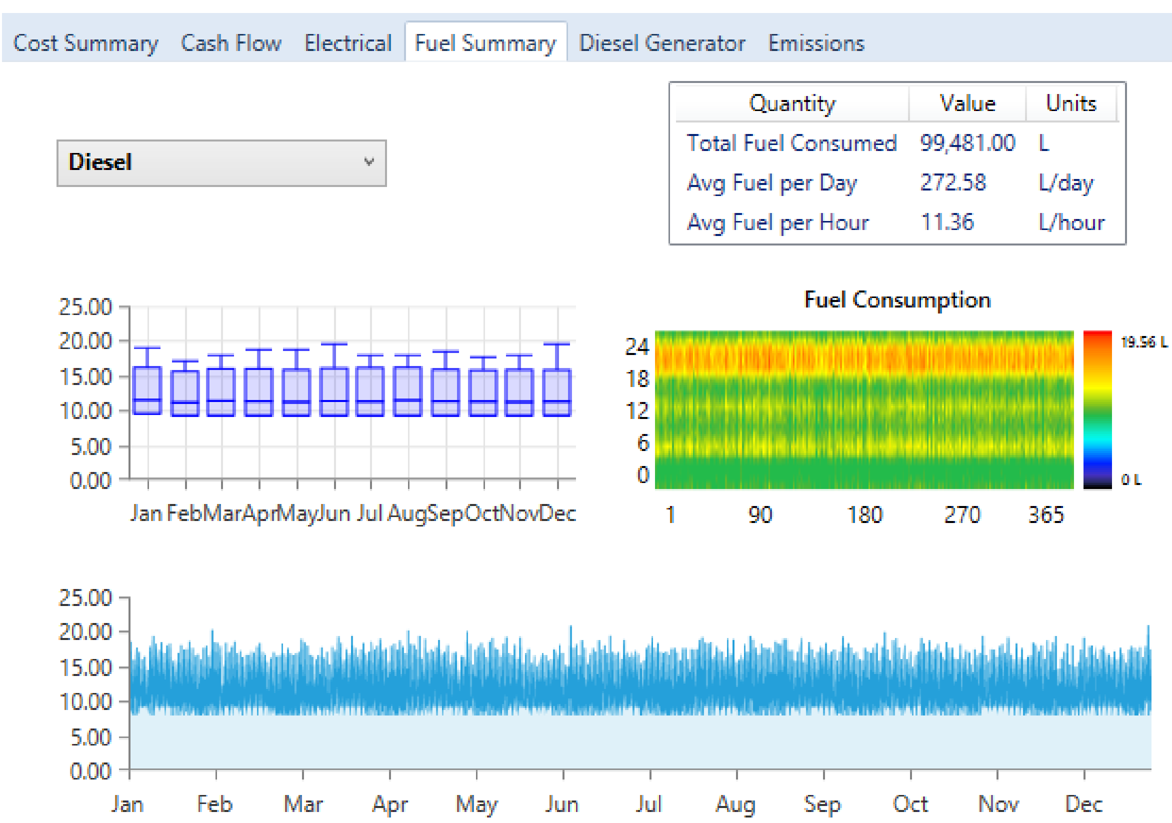
Maximum Thermal Output	The highest thermal power output of the generator over the year
Fuel Consumption	The total amount of fuel consumed by the generator during the year, in L/yr
Specific Fuel Consumption	The average quantity of fuel consumed per kWh of energy produced by the generator, in L/kWh
Fuel Energy Input	The total amount of energy in the fuel consumed by the generator during the year in kWh/yr
Mean Electrical Efficiency	The average electrical efficiency of the generator during the year, in %

Note: The thermal output variables appear only if the **heat recovery ratio** is nonzero.

In the bottom half of the page a **DMap** appears showing the power output of the generator in each hour of the year.

3.1.8 Fuel Summary

To view a report summarizing the fuel or fuels used in simulation, click the Fuel Summary of the **Simulation Results** window. The fuel summary tab appears whenever your model includes components that use a fuel resource.



The fuel summary includes a drop-down menu where you can select one of the fuels you used in your model. For each fuel, the fuel summary tab reports the total quantity consumed, the average consumption per day, and per hour. The fuel summary also includes a box-and-whisker plot of monthly consumption statistics, a DMap, and a line plot of hourly usage.

3.1.9 Battery Outputs

The Storage tab in the **Simulation Results** window contains the following output variables:

Variable	Description
String Size	The number of batteries connected in series in each string
Strings in Parallel	The number of storage strings connected in parallel
Batteries	The number of batteries in the array is the string size multiplied by the number of strings
Bus Voltage	The voltage of the storage array, calculated by multiplying storage voltage by string size, in volts
Nominal Capacity	The amount of energy that could be withdrawn from the storage at a particular constant current, starting from a fully charged state, in kWh
Usable Nominal Capacity	The storage capacity adjusted to exclude all capacity below the minimum state of charge of the storage, in kWh
Autonomy	The capacity of the storage bank divided by the average electrical load, in hours
Lifetime Throughput	The total amount of energy that can be cycled through the storage before it needs to be replaced, in kWh
Storage Wear Cost	The cost of cycling energy through the storage bank, in $/kWh
Average Energy Cost	The average cost of the energy that goes into the storage, in $/kWh
Energy In	The total amount of energy charged to the storage, in kWh
Energy Out	The total amount of energy discharged from the storage, in kWh
Storage Depletion	The difference in the storage state of charge at the beginning and end of the year, in kWh/yr
Losses	Annual energy losses due to storage inefficiency, in kWh/yr
Annual Throughput	The total amount of energy that cycled through the storage bank during the year, in kWh/yr
Expected Life	The number of years the storage bank will last before it requires replacement

In the bottom half of the page a **DMap** appears showing the state of charge of the storage bank in each time step of the year.

Modified Kinetic Storage Model Output

--- To be filled ---

3.1.10 Grid Outputs

The Grid tab in the **Simulation Results** window displays details about the buying and selling of electricity from and to the grid, and the resulting costs. The outputs table contains the following variables:

Variable	Description
Energy Purchased	The total amount of electricity purchased from the grid, in kWh
Energy Sold	The total amount of electricity sold to the grid, in kWh
Net Purchased	The net electricity purchased from the grid, in kWh
Peak Demand	The peak power demand serviced by the grid, in kW
Energy Charge	The total amount paid in energy charges, in $
Demand Charge	The total amount paid in demand charges, in $

Pro: If you defined more than one rate in the **Grid Inputs** window, a combo box will appear allowing you to choose a rate, or select All to see the summation over all rates.

Energy Charge

If net metering does not apply, HOMER calculates the total annual energy charge using the following equation:

$$C_{grid,energy} = \sum_{i}^{rates} \sum_{j}^{12} E_{gridpurchases,i,j} \cdot c_{power,i} - \sum_{i}^{rates} \sum_{j}^{12} E_{gridsales,i,j} \cdot c_{sellback,i}$$

where
:

$E_{grid\text{-}purchases,i,j}$	=	the amount of energy purchased from the grid in month j during the time that rate i applies [kWh]
$c_{power,i}$	=	the grid power price for rate i [$/kWh]
$E_{grid\text{-}sales,i,j}$	=	the amount of energy sold to the grid in month j during the time that rate i applies [kWh]
$c_{sellback,i}$	=	the sellback rate for rate i [$/kWh]

If net metering applies and net generation is calculated monthly, HOMER calculates the total annual energy charge using the following equation:

$$C_{grid,energy} = \sum_{i}^{rates} \sum_{j}^{12} \begin{cases} E_{netgridpurchases,i,j} \cdot c_{power,i} & if\ E_{netgridpurchases,i,j} \geq 0 \\ E_{netgridpurchases,i,j} \cdot c_{sellback,i} & if\ E_{netgridpurchases,i,j} < 0 \end{cases}$$

where

:

$E_{net\text{-}grid\text{-}purchases,i,j}$	=	the net grid purchases (grid purchases minus grid sales) in month j during the time that rate i applies [kWh]
$c_{power,i}$	=	the grid power price for rate i [$/kWh]
$c_{sellback,i}$	=	the sellback rate for rate i [$/kWh]

If net metering applies and net generation is calculated annually, HOMER calculates the total annual energy charge using the following equation:

$$C_{grid,energy} = \sum_{i}^{rates} \begin{Bmatrix} E_{netgridpurchases,i} \cdot c_{power,i} & if\ E_{netgridpurchases,i} \geq 0 \\ E_{netgridpurchases,i} \cdot c_{sellback,i} & if\ E_{netgridpurchases,i} < 0 \end{Bmatrix}$$

where
:

$E_{netgridpurchases,i}$	=	the annual net grid purchases (grid purchases minus grid sales) during the time that rate i applies [kWh]
$c_{power,i}$	=	the grid power price for rate i [$/kWh]
$c_{sellback,i}$	=	the sellback rate for rate i [$/kWh]

Demand Charge

HOMER calculates the total annual grid demand charge using the following equation:

$$C_{grid,demand} = \sum_{i}^{rates} \sum_{j}^{12} P_{grid,peak,i,j} \cdot c_{demand,i}$$

where
:

$P_{grid,peak,i,j}$	=	the peak hourly grid demand in month j during the time that rate i applies [kWh]
$c_{demand,i}$	=	the grid demand rate for rate i [$/kW/month]

3.1.11 Converter Outputs

The Converter tab in the **Simulation Results** window displays the following variables for both the inverter, which converts DC to AC electricity, and the rectifier, which converts AC to DC electricity:

Variable	Description
Capacity	The maximum possible power output, in AC kW for the inverter and DC kW for the rectifier
Mean, Min and Max	The inverter values are in terms of AC kW, and the rectifier values

Output	are in terms of DC kW
Capacity Factor	The mean output divided by the capacity, in %
Hours of Operation	The number of hours of non-zero power output
Energy In	The total amount of energy into the device, in DC kWh/yr for the inverter and AC kWh/yr for the rectifier
Energy Out	The total amount of energy out of the device, in AC kWh for the inverter and DC kWh for the rectifier
Losses	The total energy lost in the device, in kWh/yr

In the bottom half of the page a **DMap** appears showing the power output of the inverter and/or rectifier in each time step of the year.

3.1.12 Thermal Outputs

This feature requires the Combined Heat and Power Module. Click for more information.

The Thermal tab in the **Simulation Results** window shows details about the annual production and consumption of thermal energy by the system.

Annual Thermal Energy Production

This section lists the total annual output of each thermal energy producing component of the power system, as well as the **total thermal production**.

Annual Thermal Load Served

This section shows the total **total thermal load served** over the year, plus any surplus.

3.1.13 Thermal Load Controller Outputs

This feature requires the Combined Heat and Power Module. Click for more information.

The Thermal Load Controller tab in the **Simulation Results** view shows details about the annual conversion of energy by the thermal load controller component.

Operating hours	Hours per year that the thermal load controller is operational.
Mean output	The average heat output of the thermal load controller, including all hours of the year (not just operating hours).

Max. output	The peak output of the component, that is an average over one time step.
Min. output	The lowest output average over any time step in the simulation.

Thermal Load Controller Output

This section shows a DMap of the thermal load controller heat output, in kW, for each time step in the year-long simulation.

3.1.14 Boiler Outputs

This feature requires the Combined Heat and Power Module. Click for more information.

The Boiler tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Hours of Operation	The total run time of the boiler during the year, in hr/yr
Total Production	The total amount of thermal energy produced by the boiler per year, in kWh/yr
Mean Output	The average thermal power output of the boiler over the hours that it runs, in kW
Min. Output	The lowest thermal power output of the boiler over the year, in kW
Max. Output	The highest thermal power output of the boiler over the year, in kW
Fuel Consumption	The total amount of fuel consumed by the boiler during the year, in L/yr
Specific Fuel Consumption	The average quantity of fuel consumed per kWh of thermal energy produced by the boiler, in L/kWh
Mean Efficiency	The total annual thermal energy production divided by the total annual fuel energy consumption, in %

In the bottom half of the page a **DMap** appears showing the thermal power output of the boiler in each time step of the year.

3.1.15 Hydro Outputs

This feature requires the Hydro Module. Click for more information.

The Hydro tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Average Output	The average power amount of the hydro turbine over the year, in kW
Minimum Output	The minimum power output of the hydro turbine over the year, in kW
Maximum Output	The maximum power output of the hydro turbine over the year, in kW
Hydro Penetration	The average power output of the hydro turbine divided by the average primary load
Capacity Factor	The average power output of the hydro turbine divided by its nominal capacity
Hours of Operation	The number of hours of the year during which the hydro turbine output was greater than zero

In the bottom half of the page a **DMap** appears showing the power output of the hydro turbine in each time step of the year.

3.1.16 Hydrokinetic Outputs

The Hydrokinetic tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Total rated capacity	The nominal power output of the hydrokinetic component, in kW
Mean Output	The average power output of the hydrokinetic component over the year, in kW
Capacity Factor	The average power output of the hydrokinetic component divided by its nominal capacity
Total production	The total number of kWh produced by the hydrokinetic component over the year.
Minimum Output	The minimum power output of the hydrokinetic component over the year, in kW
Maximum Output	The maximum power output of the hydrokinetic component over the year, in kW
Hydrokinetic Penetration	The average power output of the hydrokinetic component divided by the average primary load
Hours of Operation	The number of hours of the year during which the hydro turbine output was greater than zero
Levelized Cost	The total annual production of the hydrokinetic component divided by its annualized cost.

In the bottom half of the page a **DMap** appears showing the power output of the hydrokinetic component in each time step of the year.

3.1.17 Hydrogen Outputs

The Hydrogen tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Electrolyzer Production	The total amount of hydrogen produced by the electrolyzer, in kg/yr
Reformer Production	The total amount of hydrogen produced by the reformer, in kg/yr
Total Hydrogen Production	The total amount of hydrogen produced by the system, in kg/yr
Unmet Hydrogen Load	The total hydrogen demand that the system was unable to supply, in kg/yr
Electrolyzer Capacity Factor	The average production of the electrolyzer divided by its rated production capacity
Reformer Capacity Factor	The average production of the reformer divided by its rated production capacity

3.1.18 Hydrogen Tank Outputs

The Hydrogen Tank tab in the **Simulation Results** window contains the following output variables:

Variable	Description
Hydrogen Production	The total amount of hydrogen produced annually by the system
Hydrogen Consumption	The total amount of hydrogen consumed annually by the system
Hydrogen Tank Autonomy	The energy capacity of the hydrogen tank divided by the average electrical load

This page also contains three graphs showing the amount of hydrogen in the tank over the year.

3.1.19 Electrolyzer Outputs

The Electrolyzer tab in the **Simulation Results** window contains the following output variables:

Variable	Description

Rated Capacity	The maximum electrical input power the electrolyzer can accept
Mean Input	The average electrical input power to the electrolyzer over the year
Minimum Input	The minimum electrical input power to the electrolyzer over the year
Maximum Input	The maximum electrical input power to the electrolyzer over the year
Total Input Energy	The total electrical energy that the electrolyzer consumes annually
Capacity Factor	The mean input power divided by the rated capacity
Hours of Operation	The number of hours per year that the electrolyzer produces hydrogen
Mean Output	The average rate of hydrogen production over the year
Minimum Output	The minimum rate of hydrogen production over the year
Maximum Output	The maximum rate of hydrogen production over the year
Total Production	The total amount of hydrogen produced annually by the electrolyzer
Specific Consumption	The average quantity of fuel consumed per kWh of thermal energy produced by the electrolyzer

In the bottom half of the page a **DMap** appears showing the electrical power consumption of the electrolyzer in each time step of the year.

3.1.20 Reformer Outputs

3.1.21 Time Series Outputs

Plot

The time series plot can graph a number of model variables over the duration of the simulation.

Scatterplot

The scatterplot graph allows you to plot any variable against any other variable. This kind of graph can often help you to understand how the system operates. For example, plotting diesel power output versus storage state of charge may reveal that the diesel only operates when the storage is at or near its minimum state of charge.

Deltaplot

The deltaplot shows the frequency of changes in any variable over some length of time. Choose the variable from the drop-down box, and choose the length of time using the slider control.

Table

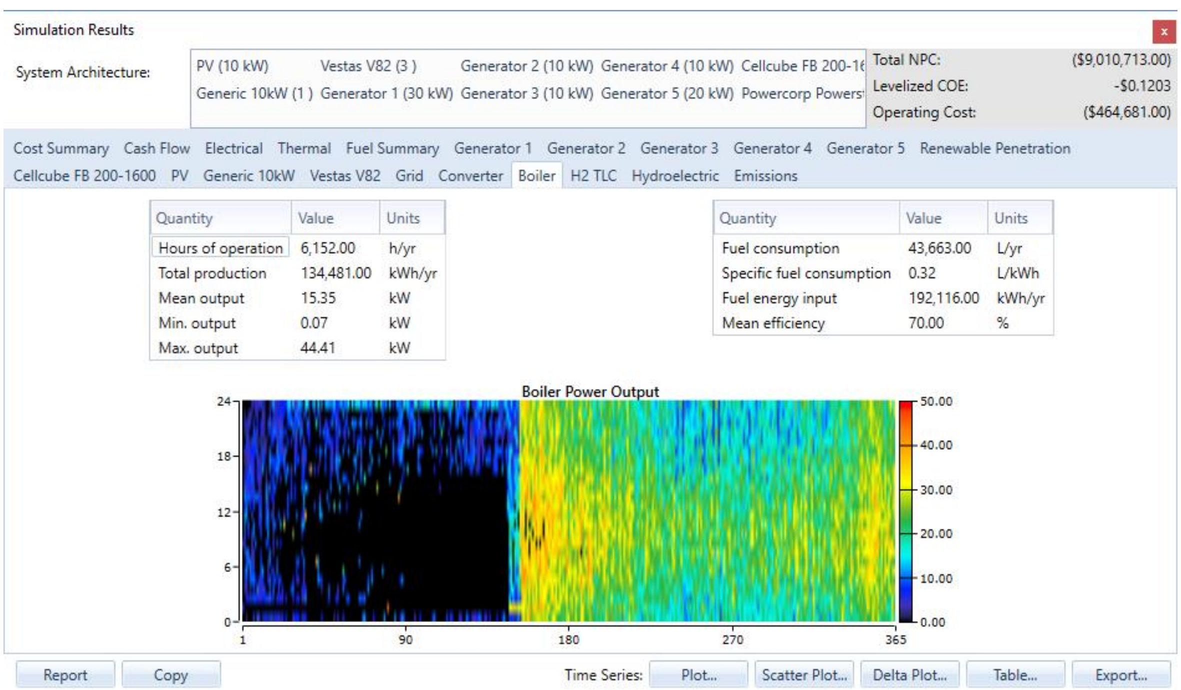
The table displays all of the time series data generated by the simulation for each time step.

Export

The export function writes all time series data from the selected simulation to a csv file. You will be prompted for a location and name for the output file.

3.1.22 Report Summarizing the Simulation Results

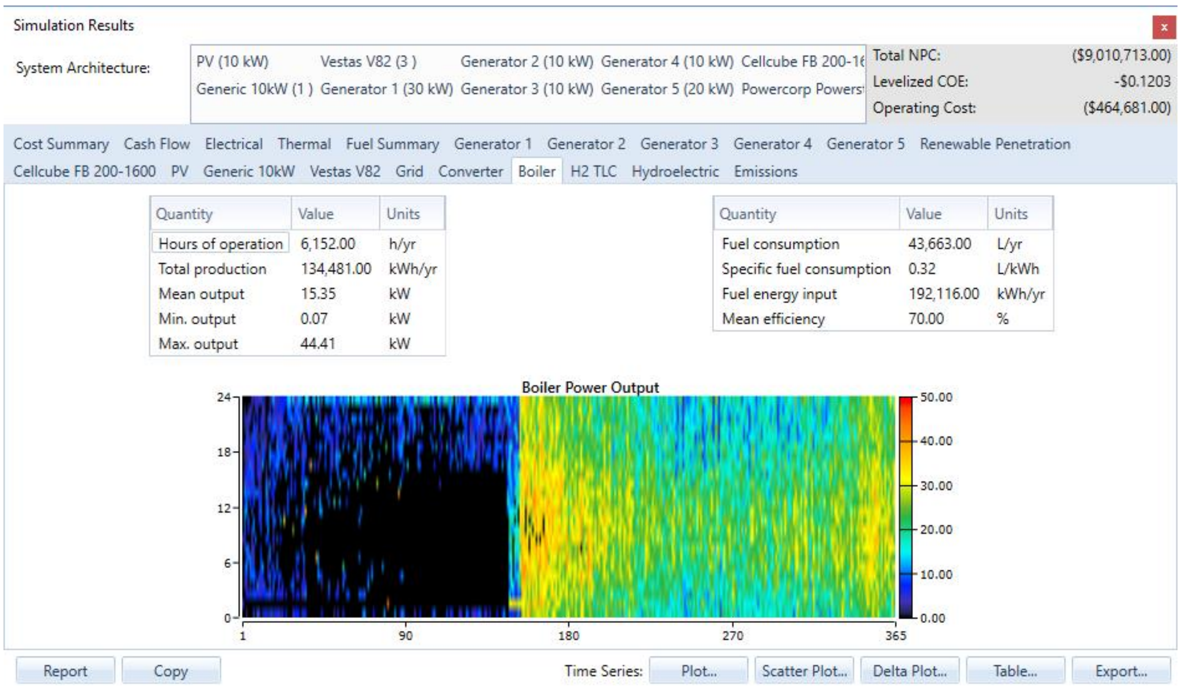
To view a report summarizing the results of a simulation, click the Report button in the bottom left corner of the **Simulation Results** window:



HOMER will create an HTML report containing all the information shown in the various pages of the Simulation Results window. You can print the report or save it to a file by clicking the Print button at the bottom of the window.

3.1.23 Copy Simulation Results to the Clipboard

Click the Copy button in the bottom left corner of the **Simulation Results** window to copy the simulation results to the clipboard.



The results data for this simulation will be copied to the clipboard in a format that you can paste into a spreadsheet application like Microsoft Excel (tab delimited text). The arrangement of the data is described in the table below. The locations described assume that you paste the data beginning with cell A1. Each piece of result data will generally appear in the same cell location, even with different simulations or different HOMER models. This makes it easier for other spreadsheets to reference the pasted results data by referencing specific cells.

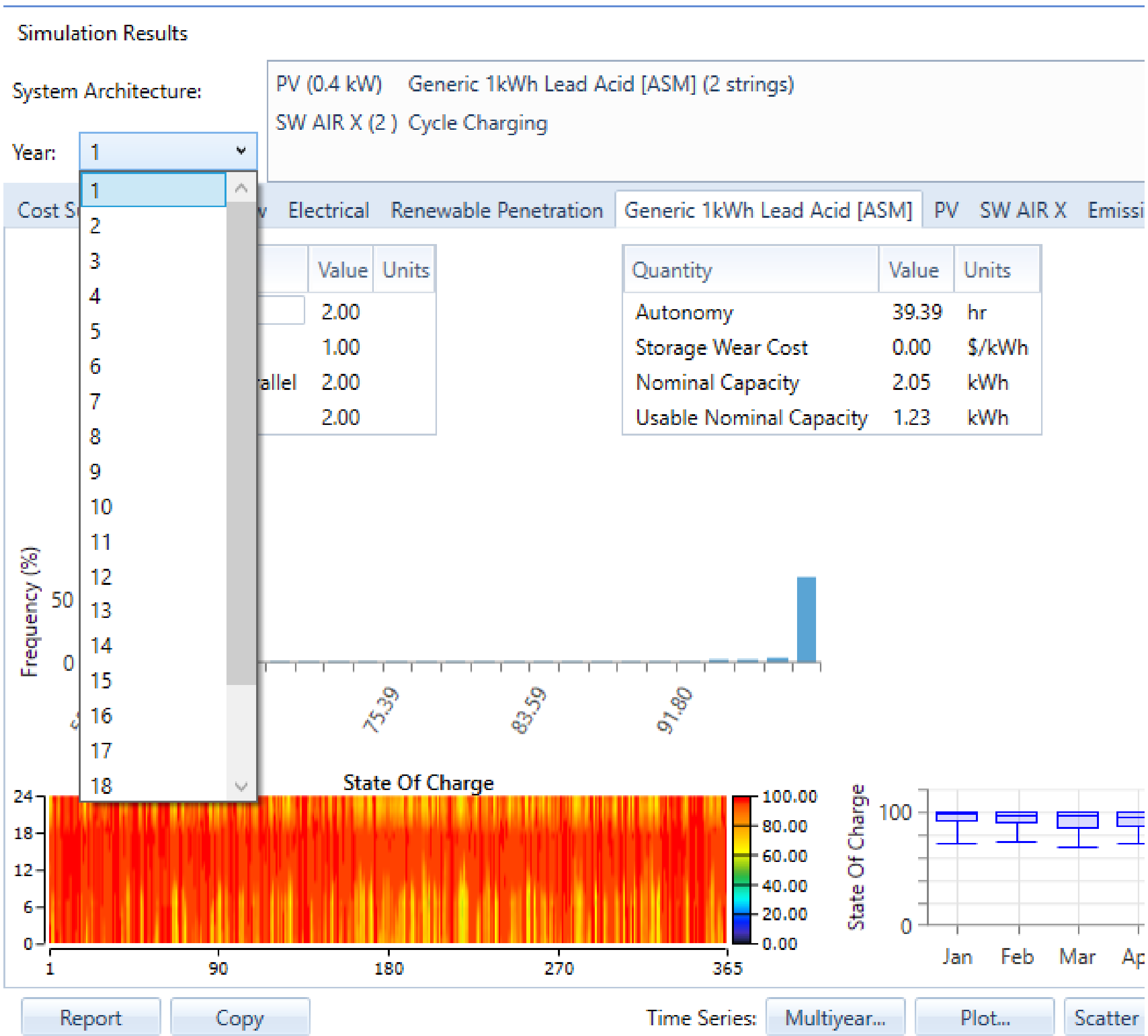
Spreadsheet row number	Contents
1	Title, description, filename
2	Project notes
3	Total NPC
4	LCOE
6-9	System architecture
11-12	Sensitivity case parameters
14-20	Cost summary table (Net present dollars)
22-28	Cost summary table (Annualized dollars)
30-32	Electrical summary
34-36	Other outputs
38-40	Thermal summary
42-46	Fuel summary

48-50	Emissions summary
60-89	Generators
90-109	PVs
110-129	Wind turbines
130-159	Batteries
160-179	Converter
180-199	Boiler
200-219	Hydro
220-239	Reformer
240-259	Electrolyzer
260-269	Hydrogen tank
270-289	Hydrokinetic
290-309	Grid
310-319	Thermal load controller

3.1.24 Multi-Year Outputs

**This feature requires the
Multi-Year Module.
Click for more information.**

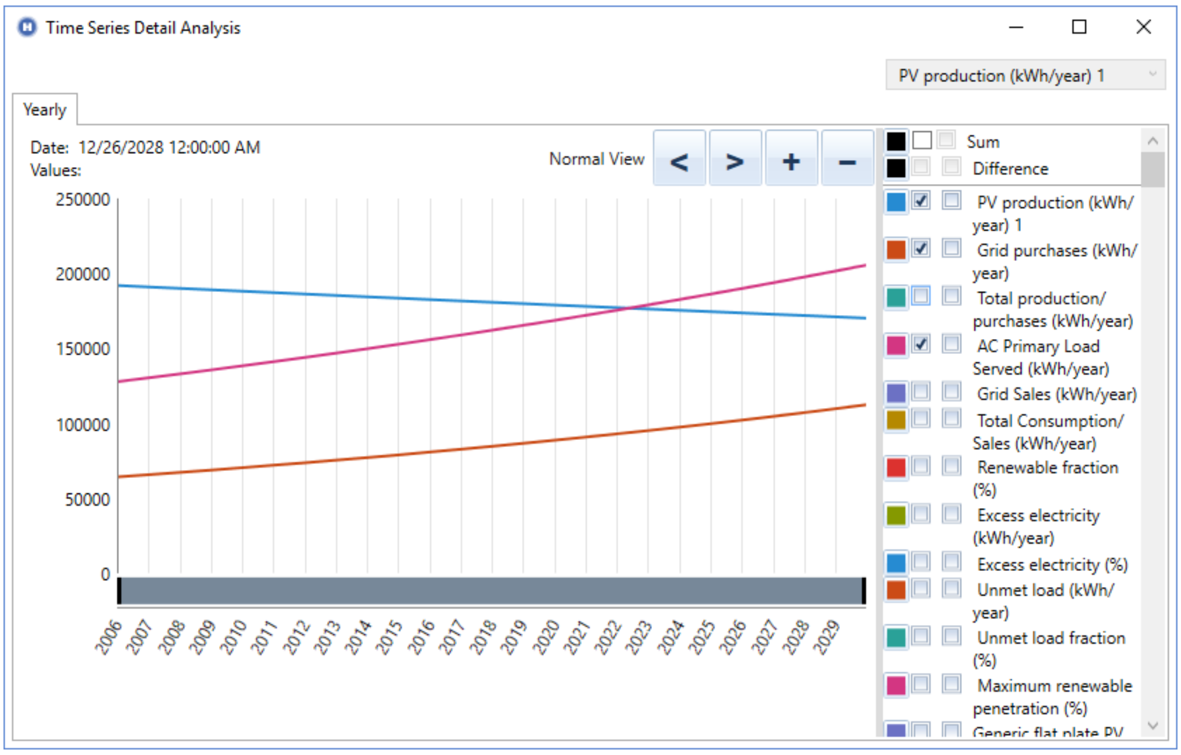
There are a number of ways to view the results for a multi-year model. The summary tables displayed in the Results view for **Sensitivity** and **Optimization** are largely unchanged, although the results will reflect the effects of the multi-year simulation. When you run a multi-year calculation, the Simulation Results window will include options to allow you to view year-by-year outputs from the multi-year simulation.



Use the drop-down menu in the upper-left of the results window to select a different year to view in the results. By switching between different years, you can see how the outputs vary over the years of the project life time. In the **Cost Summary** and **Cash Flow** tabs, the year selector drop-down is disabled, since these screens show outputs that are an aggregate of all the years in the simulation.

Yearly Plot

When you run a multi-year analysis, you'll find the Multiyear button along the bottom of the Simulation Results window. Click this button to bring up the yearly plot, which can plot many different output values over the lifetime of the simulation.

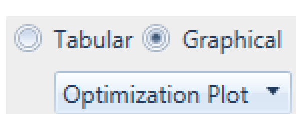


In the example above, several output metrics vary over the course of the 20 year project. The load increases, the PV output degrades, and the battery losses increase (and are reduced briefly when the batteries are replaced after year 14).

3.2 Optimization Results

For each **sensitivity case** that it solves, HOMER simulates every system in the **Search Space** and ranks all the **feasible** systems according to increasing **net present cost**. The Results tab of HOMER's main window displays that list of systems in the **Sensitivity Results** table.

When **calculate** is complete, HOMER will automatically display the results view in **tabular** mode. You can select the sensitivity case in the upper table, called the **sensitivity results** table. You can then view, sort, and filter all the feasible simulations that were run for the selected sensitivity case. For more information about the optimization table and how to use it, see **3.2.1 Tabular View**.



You can also view the optimization results as a plot. Click the **graphical** option of the radio buttons at the top right to view plots of the results. The graphical view includes plots of the **sensitivity results** and the optimization results. To learn more about the optimization plots and how to visualize the optimization space, see **3.2.2 Graphical View**.

See also

3.2.1 Tabular View
3.2.2 Graphical View
3.3 Sensitivity Results

3.2.1 Tabular View

The optimization results table lists all the feasible simulations for the selected sensitivity case. When you fist see the optimization table, the results are categorized and filtered by system type. See "Overall" and "Categorized", below, for how to change this. The optimization table only displays systems that were feasible in simulation.

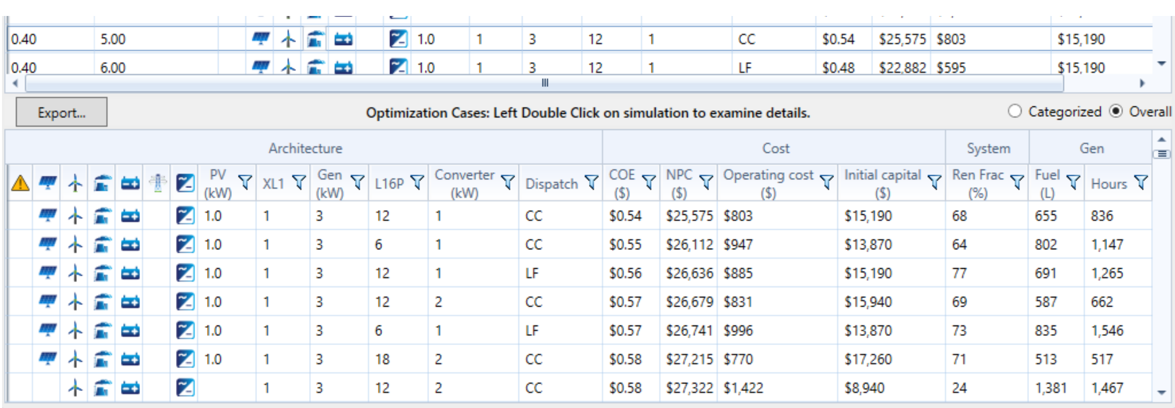
You can choose which sensitivity case to view in the `Optimization Results` table by clicking on a row in the `Sensitivity Results` table. Sensitivity variables appear in the left-most columns of the `Sensitivity Results` table. HOMER updates the list of systems in the `Optimization Results` each time you make a selection from the `Sensitivity Results` table.

The radio buttons above the Optimization Results table let you filter the list of feasible systems according to system type. The two choices, `Overall` and `Categorized`, are explained below.

Overall

If you choose to display the overall system rankings, HOMER shows the top-ranked **system configurations** according to net present cost. An example is shown below. If you look closely, you'll see that the numbers under the `Architecture` section indicate the presence of each type of component under consideration. In this example, the icons indicate the presence of, from left to right: PV, wind turbines, diesel generator, batteries, a grid connection, and the converter. To the right are several columns that indicate a few summary values drawn from the simulation results of the least-cost system, such as the initial capital cost, operating cost, and total net present cost.

Tip: Double click any system in the list to see detailed **Simulation Results**.



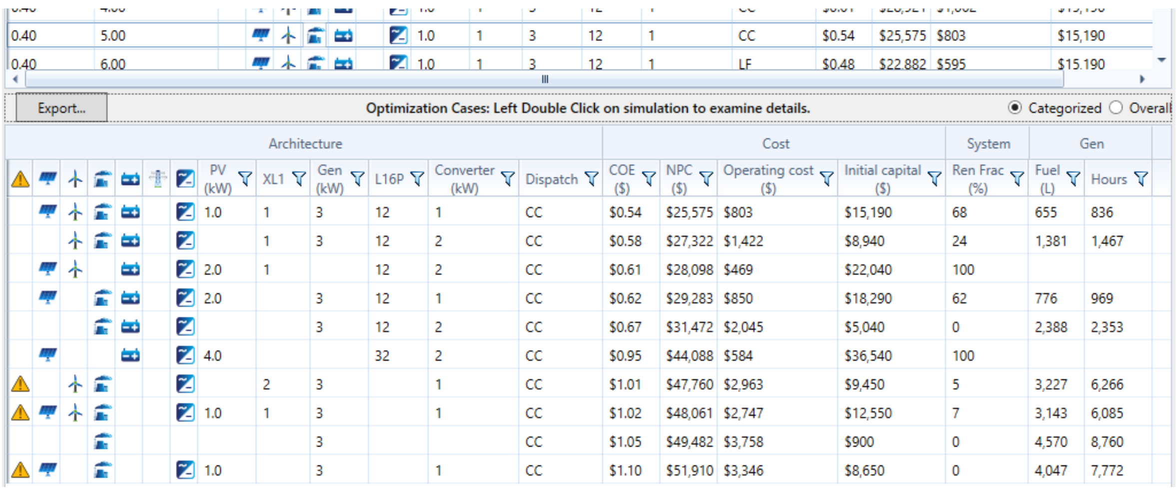
Architecture										Cost				System	Gen	
PV (kW)	XL1	Gen (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours				
1.0	1	3	12	1	CC	$0.54	$25,575	$803	$15,190	68	655	836				
1.0	1	3	6	1	CC	$0.55	$26,112	$947	$13,870	64	802	1,147				
1.0	1	3	12	1	LF	$0.56	$26,636	$885	$15,190	77	691	1,265				
1.0	1	3	12	2	CC	$0.57	$26,679	$831	$15,940	69	587	662				
1.0	1	3	6	1	LF	$0.57	$26,741	$996	$13,870	73	835	1,546				
1.0	1	3	18	2	CC	$0.58	$27,215	$770	$17,260	71	513	517				
	1	3	12	2	CC	$0.58	$27,322	$1,422	$8,940	24	1,381	1,467				

Categorized

The overall rankings are typically dominated by two or three **system types**. In the above example, the top systems are all either wind/generator/storage or PV/wind/generator/storage systems. For a broader comparison, select `Categorized` from the drop-down menu above `Filter by Architecture`. The categorized rankings show the least-cost system of each type. In the example shown below, the top-ranked system corresponds to the top-ranked system in the overall rankings shown above. But the second system listed corresponds to the seventh-place system in the overall rankings, because the second-place system in the overall rankings was of the same type as the first-place system.

The second system from the bottom in the categorized rankings is interesting for comparison because it represents the least-cost pure diesel system. This system would both appear so far down the overall rankings that it would be hard to see. But the categorized rankings makes it easy to compare this system with the other alternatives.

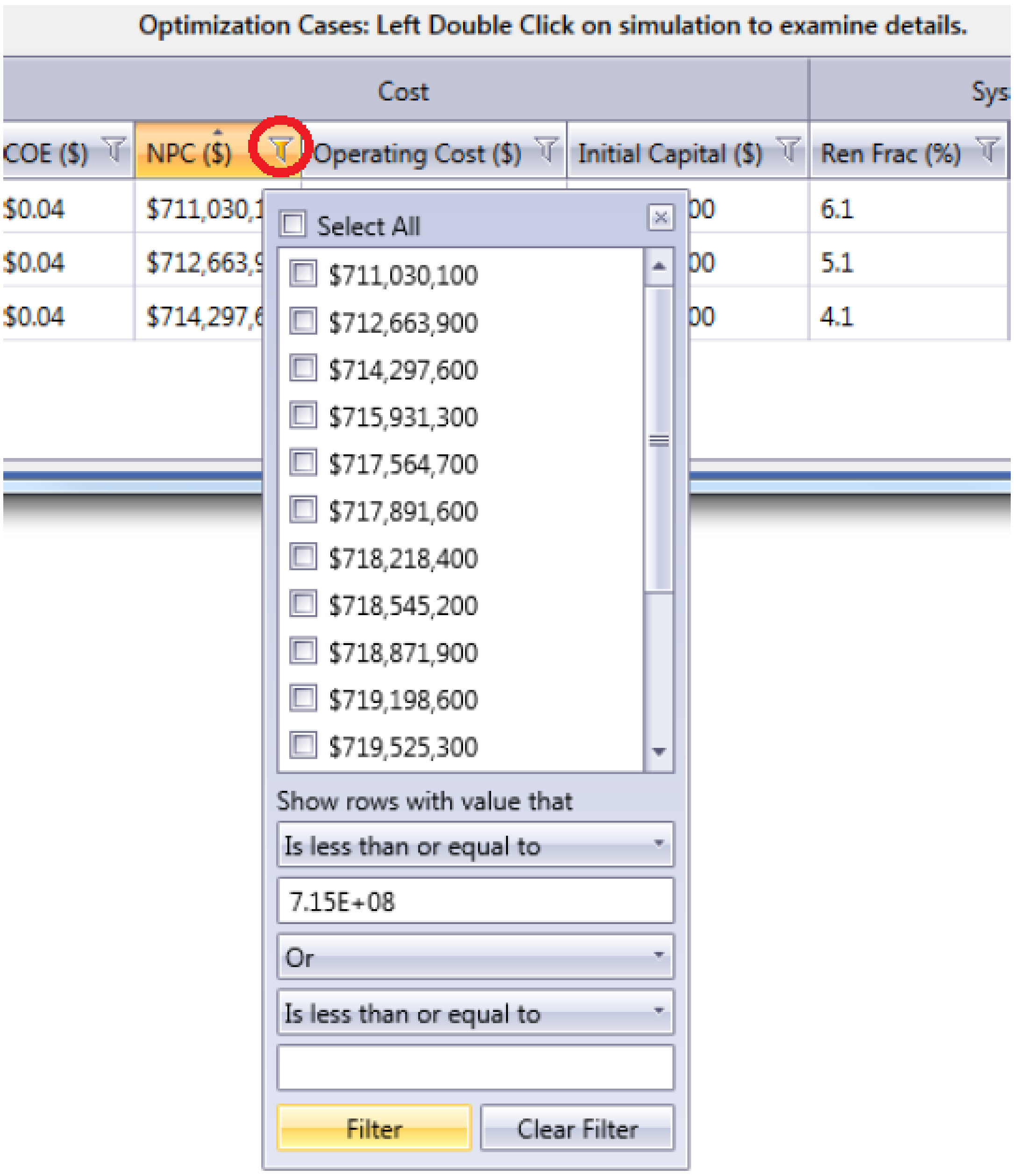
Tip: Double click any system in the list to see detailed **Simulation Results**.



PV (kW)	XL1	Gen (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Fuel (L)	Hours
1.0	1	3	12	1	CC	$0.54	$25,575	$803	$15,190	68	655	836
	1	3	12	2	CC	$0.58	$27,322	$1,422	$8,940	24	1,381	1,467
2.0	1		12	2	CC	$0.61	$28,098	$469	$22,040	100		
2.0		3	12	1	CC	$0.62	$29,283	$850	$18,290	62	776	969
		3	12	2	CC	$0.67	$31,472	$2,045	$5,040	0	2,388	2,353
4.0			32	2	CC	$0.95	$44,088	$584	$36,540	100		
	2	3		1	CC	$1.01	$47,760	$2,963	$9,450	5	3,227	6,266
1.0	1	3		1	CC	$1.02	$48,061	$2,747	$12,550	7	3,143	6,085
		3			CC	$1.05	$49,482	$3,758	$900	0	4,570	8,760
1.0		3		1	CC	$1.10	$51,910	$3,346	$8,650	0	4,047	7,772

Sorting and Filtering Results

You can sort your results table by any column in the table. To filter the results, click on the heading of the column on the "funnel" icon (pictured below) and specify the values of the selected column that you would like to see.



When the filter is active, the funnel icon will turn yellow.

To sort the results, click on the heading of a column. One click will sort the results by that column in ascending order. Click again, and the sorting will switch to descending order for that column. If you click a third time, the sorting will be removed, and the table will go back to the default sorting, which is by net present cost (NPC), ascending.

See also

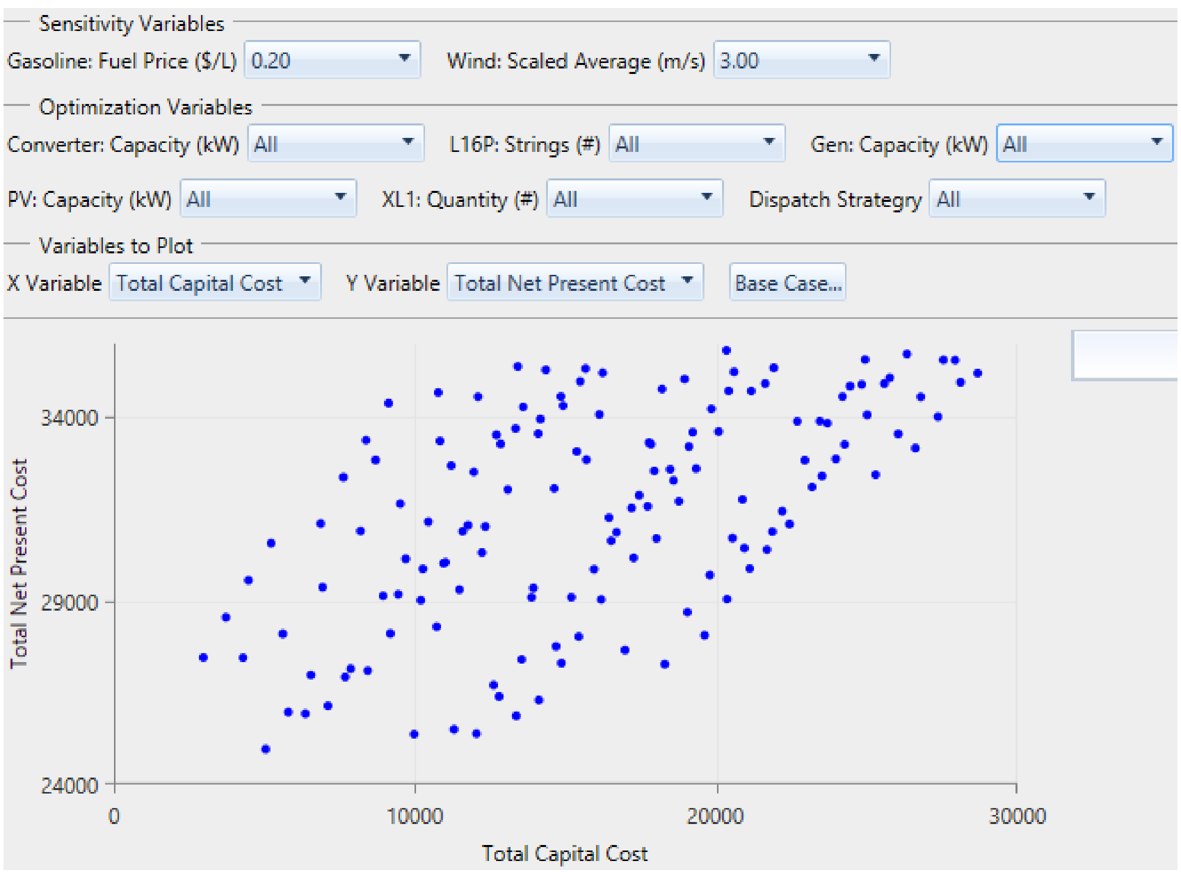
3.2.1 Tabular View
3.2.2 Graphical View
3.3 Sensitivity Results

3.2.2 Graphical View

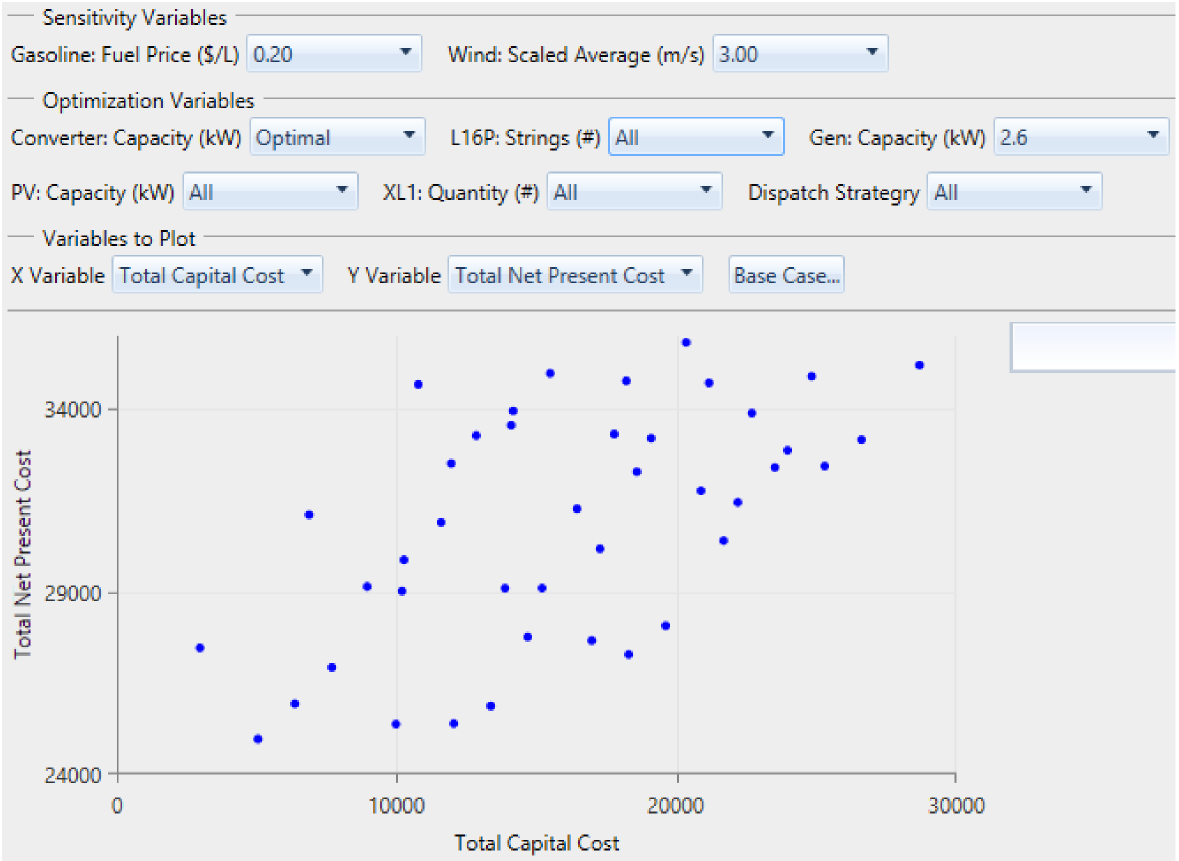
The graphical results view contains several plot types that let you visualize the results in different ways. Beneath the "tabular"/"graphical" radio buttons is a drop-down menu where you can select the plot that you would like to see. The first four options, the "Optimal System Type Plot", "Surface Plot", "Line Plot", and "Spider Plot" all give a graphical representation across the sensitivity results. The last two plots, the "Optimization Plot" and the "Optimization Surface Plot" allow you to visualize the optimization for a sensitivity case you select. See **3.3 Sensitivity Results** for more information on the first four options.

Optimization Plot

The optimization plot graphs each simulation as a single point on a set of axes you can choose. You'll first need to choose which sensitivity case to view with the drop-down menus under the heading "Sensitivity Variables". Then you can choose which values of the optimization variables you would like to see. By default, "All" will be selected for all of the optimization variables, and so you will see a dot for every simulation that was feasible for this sensitivity case.



The screenshot above is in the file "Sample-OffGridHouseInMontana.homer" which is available from the "Samples" section of HOMER's file menu. The x-axis represents total capital cost, and the y-axis represents the total net present cost. The winning system for this sensitivity case is the lowest dot on the plot, corresponding to the lowest net present cost. This system has a capital cost of $5,040 and a net present cost of $24,963. This system is a good balance of capital cost and operating cost, which results in the lowest net present cost in this scenario.



We can filter and group the points in this plot by changing the settings in the drop-down menus for each optimization variable under the "Optimization Variables" section. In the plot above, we've set the generator size to 2.6 and the converter size to "Optimal". Now there is a point for every combination of batteries ("L16P"), wind turbines ("XL1") and PV capacity. For each of these combinations, (i.e. 6 batteries, 1 kW of PV, and 2 wind turbines), we are only considering systems with the 2.6 kW generator (all the zero-size generator systems are infeasible anyway) and the optimal converter size for that case.

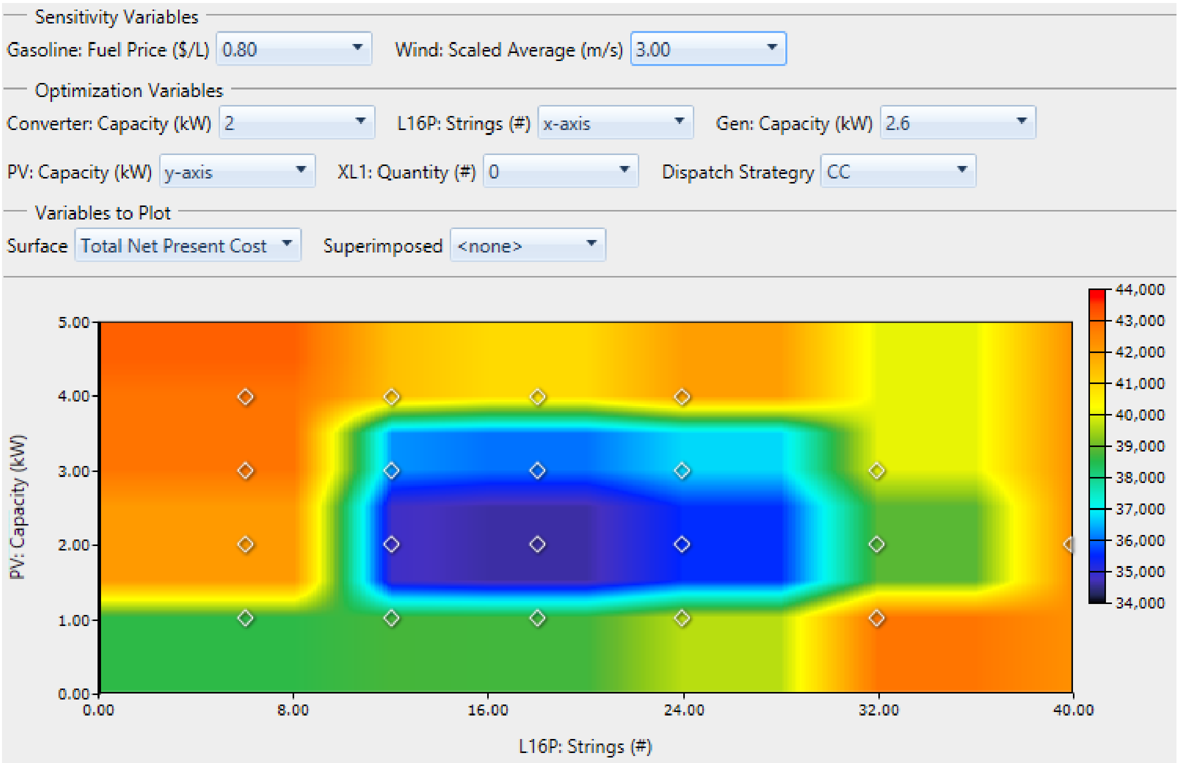
Now we've selected "line series" for the storage ("L16P"). You can only select "line series" for one of the variables at a time. With this configuration, there is a line for each combination of PV capacity and wind turbine ("XL1") quantity. At one end of each line is the minimum quantity of batteries (zero), and at the other end is the maximum number of batteries. Each line is a different color, corresponding to the legend entry which lists the PV capacity and wind turbine quantity for that line. You can also hover your mouse over any point to see the system architecture for it.

We would expect 18 lines (6 sizes of PV and 3 quantities of wind turbine) but we only see ten. When HOMER runs any optimization, it only saves the 2,000 best (lowest NPC) simulation results. This is the default setting which you can change in the File menu, under the "Settings" option there. For a large search space like we have in "Off-grid house in Montana", some simulations will be left out from the plot, unless you increase the number of simulations to save. HOMER always chooses which simulations to save by NPC, so only poor systems (according to NPC) are discarded. We can be confident that the optimization plot includes the most important simulations, but some trivial systems might be left off.

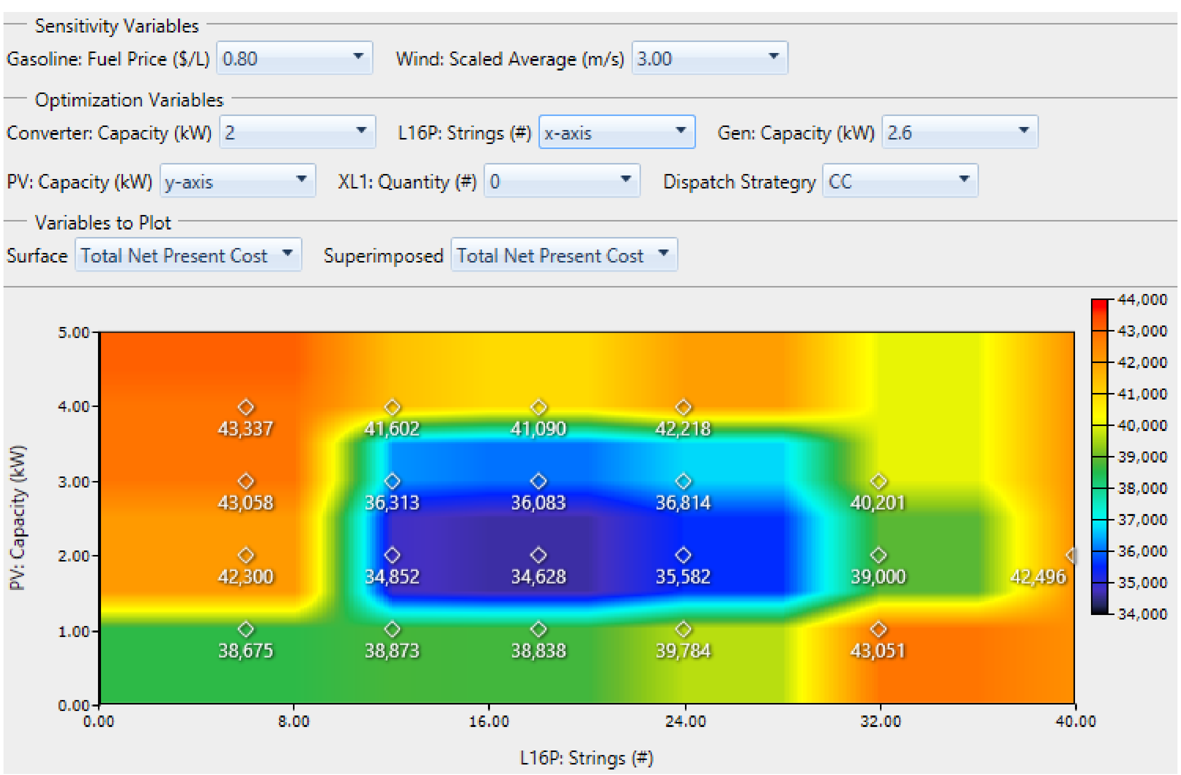
The "Base Case..." button, to the right of the "X Variable" and "Y Variable" drop down menus, allows you to choose a single simulation to compare with. This is required to compute some economic quantities. Outputs marked with "(*)" in the drop down lists for "X Variable" and "Y Variable" require you to select a base case. Once you have chosen a base case, a text summary of the selection will appear to the right of the "Base Case..." button.

Optimization surface plot

The optimization surface plot allows you to view how the value of one result variable changes over the range of two optimization variables. Typical inputs for this plot might be: PV capacity and storage quantity on the x and y axes, and net present cost as the result variable to plot. Like the optimization plot (above), first select the sensitivity case with the drop-down menus under "sensitivity variables". Then choose an optimization variable to plot on the x-axis and one for the y-axis, and then choose fixed values for the remaining optimization variables. You can only set x-axis for one variable, and y-axis for another variable. If you make an invalid selection (i.e. select x-axis for more than one variable), the plot will not refresh until you fix the selection.



The drop down menu labeled "Superimposed" allows you to choose a second results variable to print on the plot at each point of simulation on the plot. In the image below, we've selected "Total Net Present Cost" to superimpose. This is the same quantity that is drawn as the surface, and it lets us see what points were actually simulated, and how the plot interpolates and extrapolates to draw the surface. Of course, you can also choose to superimpose a different variable than the one plotted on the surface.



See also

3.2.1 Tabular View

3.2.2 Graphical View

3.3 Sensitivity Results

3.3 Sensitivity Results

A **sensitivity analysis** can result in a huge amount of output data. Every simulation that HOMER performs results in several dozen summary outputs (like the annual fuel consumption and the total capital cost) plus about a dozen arrays of time series data (e.g. the output of the wind turbine). HOMER typically performs hundreds or thousands of these simulations per **sensitivity case**, and a sensitivity analysis can easily involve hundreds of sensitivity cases. We designed HOMER's graphic and tabular output capabilities to let you efficiently analyze all that data.

Tabular

The tabular sensitivity results consist of a list showing the least-cost **system** for each sensitivity case. In the example shown below, the first two columns display the values of the two sensitivity variables: the diesel fuel price and the wind speed. The next five columns contain values indicating in the least-cost system the presence and size of the five components under consideration. From left to right, they are batteries, the diesel generator, wind turbines, PV panels, and the converter. Following are several columns with summary values drawn from the simulation results of the least-cost system including initial capital, operating cost, and total net present cost.

Sensitivity		Architecture						Cost			
Gasoline Fuel Price ($/L)	Wind Scaled Average (m/s)	PV (kW)	XL1	Gen (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)
0.40	3.00	2.0		3	12	1	CC	$0.62	$29,283	$850	$18,290
0.40	4.00	1.0	1	3	12	1	CC	$0.61	$28,921	$1,062	$15,190
0.40	5.00	1.0	1	3	12	1	CC	$0.54	$25,575	$803	$15,190
0.40	6.00	1.0	1	3	12	1	LF	$0.48	$22,882	$595	$15,190
0.40	7.00		1	3	12	2	CC	$0.42	$19,958	$852	$8,940

You can click on any row in the table to jump to the **optimization results** for that sensitivity case. That lets you see the sub-optimal systems (the ones that were not least cost) and view the **simulation results** for any of the ranked systems.

Sensitivity		Architecture						Cost			
Interest	Fuel Cost	PV	15/50	Gen100	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating Cost ($)	Initial Cap
10.00	0.60	1.0	2	100	5	100	LF	$3.13	$207,643	$4,919	$163,000
10.00	0.80	1.0	2	100	5	100	LF	$3.19	$211,635	$5,358	$163,000

Export...

Optimization Cases: Left Double Click on simulation to examine details.

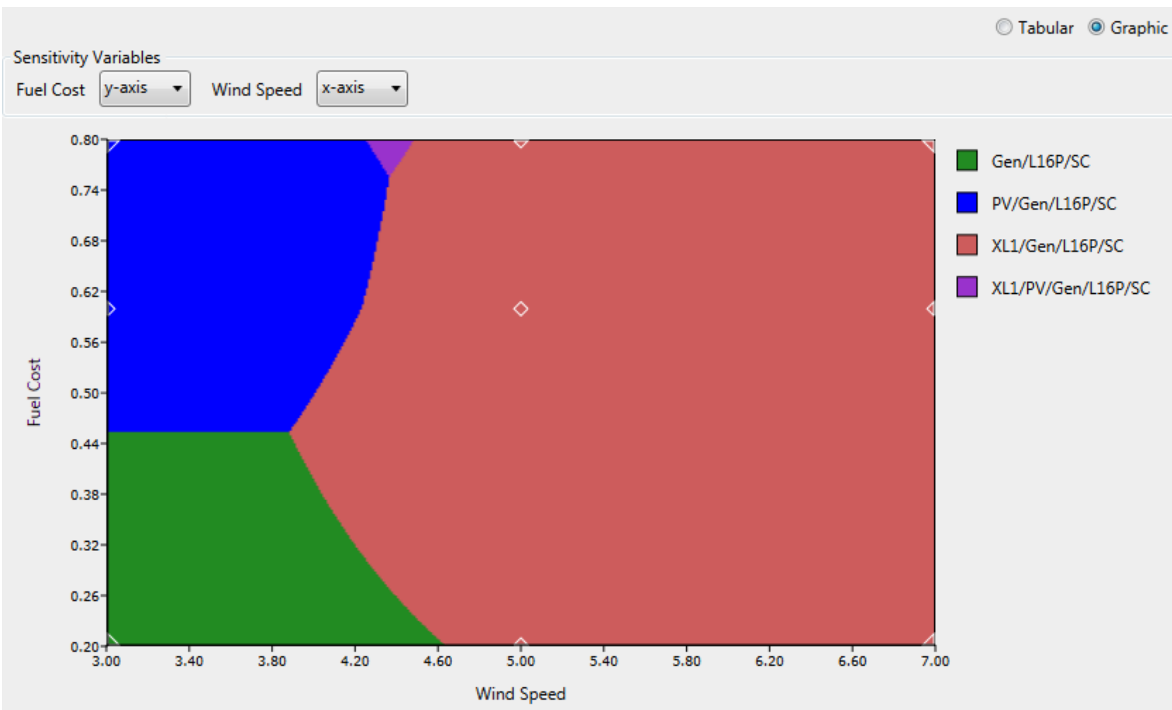
Categorized Overall

Architecture						Cost				System
PV	15/50	Gen100	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)
1.0	2	100	5	100	LF	$3.19	$211,635	$5,358	$163,000	17.5
1.0	2	100	4	100	LF	$3.24	$214,488	$6,003	$160,000	0
1.0	2	100	3	100	LF	$3.34	$221,364	$7,091	$157,000	0
1.0		100	5	100	LF	$3.43	$227,277	$9,285	$143,000	0

When the analysis involves more than one **sensitivity variable**, a graph often conveys the results in a more meaningful way than a table can. You can create three types of graphs: optimal system type charts, surface plots, and line graphs. These graphs are drawn right on the Sensitivity Results tab, but you can also create them in their own resizable windows by clicking the button labeled New Window. A right-click on any graph allows you to change its properties, copy it to the clipboard, or save it as an image file.

Sensitivity Graph

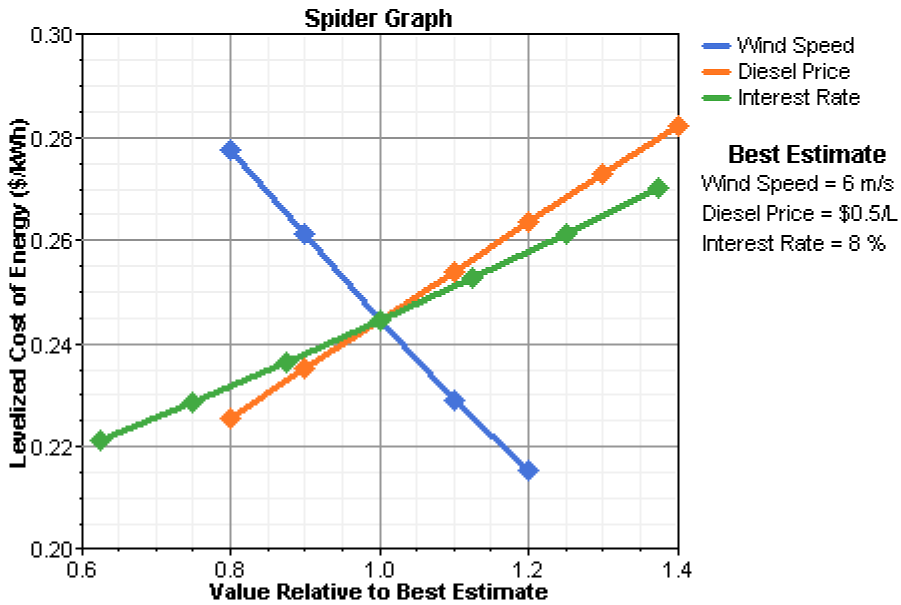
The optimal system type (OST) graph gives the highest-level view of the sensitivity results. It shows the least-cost type of system (diesel-storage is one type of system, wind-diesel-storage is another) versus two sensitivity variables. The example below shows the same information we just saw in the tabular display above. The graphic format makes it easier to see under which conditions the different types of systems are optimal. Diamonds indicate points where HOMER actually solved for the least-cost system. All other points are colored using interpolation.



3.3.1 Why Would I Do a Sensitivity Analysis?

There are good reasons why you might want to enter multiple values for a particular input variable. First, you might be uncertain as to what the exact value of some variable should be. By specifying a range of values, you can determine how important that variable is, and how the answers change depending on its value. In other words, you can determine the *sensitivity* of the outputs to changes in that variable.

For example, imagine that a modeler doing a preliminary analysis of a wind-diesel system was uncertain about three variables: the annual average wind speed, the average fuel price over the life of the project, and the interest rate. To determine the sensitivity of the system's cost of energy to those three variables, she did a sensitivity analysis using HOMER. Her best estimate for the wind speed was 6 m/s, for the fuel price was $0.50/L, and for the discount rate was 8%. But she entered multiple values for each variable, covering the range of uncertainty of each (by entering "0%" for the "expected inflation rate", the "nominal discount rate" input maps directly to the **real discount rate**). HOMER produced the spider graph shown below, showing that the cost of energy is most sensitive to the wind speed (the wind speed line is the steepest). As a result, the modeler chose to invest more time and money to obtain a more accurate estimate of the wind speed.



Another reason for performing a sensitivity analysis is to make a single analysis applicable to more than one installation. For example, imagine you are designing small renewable power systems for six telecom sites. If the sites are similar in most respects but there is some variation in wind speed from one site to another, you could specify several wind speeds spanning the appropriate range. Then a single analysis would be sufficient to design all six hybrid systems. The results of such an analysis might look like the example shown below, where HOMER has suggested a PV/storage/gen system for the site with the lowest wind speed, wind/PV/storage/gen systems for the sites with higher wind speeds, and a wind/storage/gen system for the highest wind speed.

Sensitivity		Architecture						Cost			
Gasoline Fuel Price ($/L)	Wind Scaled Average (m/s)	PV (kW)	XL1	Gen (kW)	L16P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)
0.40	3.00	2.0		3	12	1	CC	$0.62	$29,283	$850	$18,290
0.40	4.00	1.0	1	3	12	1	CC	$0.61	$28,921	$1,062	$15,190
0.40	5.00	1.0	1	3	12	1	CC	$0.54	$25,575	$803	$15,190
0.40	6.00	1.0	1	3	12	1	LF	$0.48	$22,882	$595	$15,190
0.40	7.00		1	3	12	2	CC	$0.42	$19,958	$852	$8,940

See also

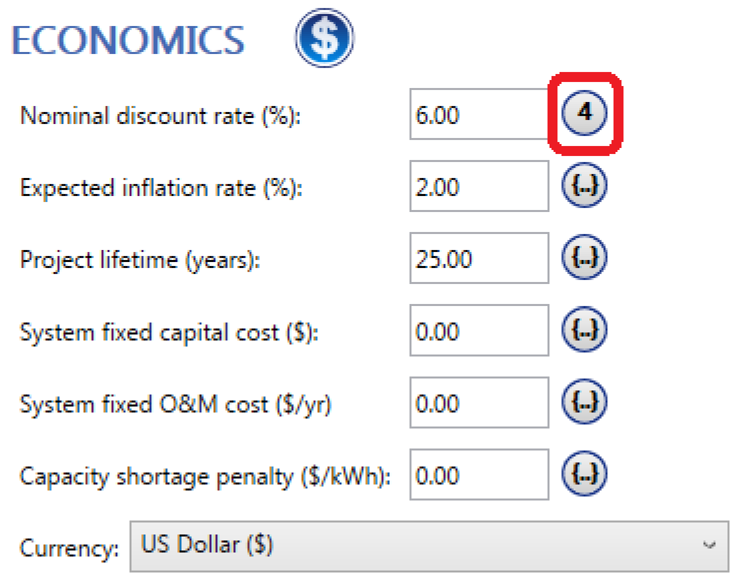
7.145 Sensitivity Analysis

7.91 Real Discount Rate

3.3.2 Adding Sensitivity Values

The Sensitivity Values dialog appears when you click on a sensitivity button. Use it to enter multiple values for a particular input variable in order to perform a **sensitivity analysis** on that variable. The values you enter in this table do not have to be evenly spaced, nor do they have to be in ascending or descending order. You can enter them in any order you want. You can link this variable to another by making a selection from the drop-down box labeled Link with:. For more information, see **Sensitivities Variable** .

In the following example, the user has entered several values for the **nominal discount rate**. The discount rate is therefore a **sensitivity variable** in this example.



See also

2.5.3 Sensitivity Inputs
3.3 Sensitivity Results
2.7.3.1 Why Would I Do a Sensitivity Analysis?
7.148 Sensitivity Variable
7.145 Sensitivity Analysis

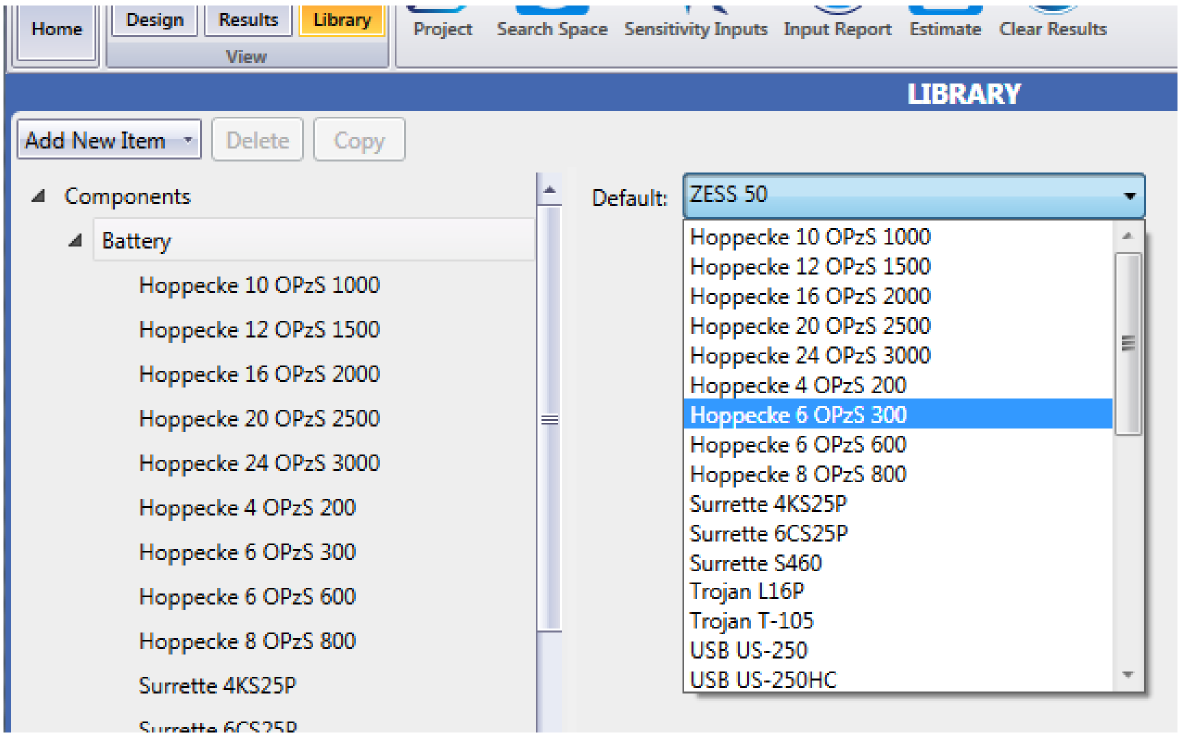
4. Library View

In the Library view, you can add, remove, or modify saved definitions for components, resources, and the grid. You can save simulation parameter sets, and load saved ones. You can also change the defaults for components, resources, and grid.

A Library tree will display on the left side of the screen listing **Components**, **Resources**, **Grid**, and **Simulation Parameters**. Different types of library entries are listed under each category. Entries in **bold** are in your user library. The non-bold entries are part of the HOMER built-in library and can't be modified. To change any of the built-in components, first select it and click the Copy button to make a copy of the entry in your user library. You can then edit the copy, which will appear in the list in bold.

You can change the default settings by selecting a library entry type (i.e. storage, wind turbine, fuels). We will use Storage, under the Components category, as an example. Click on the word Storage. In the space to the right of the tree, a drop-down menu will appear. You can use this menu to change the default Storage. You change the default for any of the entry types in the Library this way.

To view or edit any of the entries under the storage entry type, click on the triangle to the left of the word storage to expand the list, and then click on any of the entries.



4.1 Components Library

The components library contains saved component definitions, and allows you to specify new ones. You can create new battery models, and change advanced parameters.

See also

4.2.1 Create a New Fuel

4.1.1 Storage

Classification of the Storage Model

The new storage model has been created to be flexible and accommodate a breadth of storage systems. You can choose from any of the below types of storage models.

- **Idealized Storage Model**: Models a simple storage assuming a flat capacity curve. The Generic 1kWh Li-Ion battery is an example of the idealized model.
- **Kinetic Storage Model**: This model includes the available and bound storage tanks for reduction in available capacity at higher discharge rates. The Generic 1kWh Lead Acid battery is an example of the kinetic model.
- **Modified Kinetic Storage Model**: This model includes rate dependent losses, temperature dependence on capacity, cycle lifetime estimation using Rainflow Counting, and temperature effects on calendar life. The Generic 1kWh Lead Acid [ASM] and Generic 1kWh Li-Ion [ASM] batteries are included as examples of this model.
- **Idealized Power-Capacity Storage Model**: A storage system where the cell stack and electrolyte can be sized independently, and replaced individually. The Generic Vanadium battery is an example of this model.
- **Flywheel Storage Model**: This model only adds operating reserve in exchange for parasitic load to the system. The state of charge is not modeled in simulation. The Powerstore PS04 is an example of this model.

Choosing a type of Storage model

Once you decide which type of storage model best represents your storage system, find an example storage item in the library that uses the same model, and copy it to be able to make changes to it. You can customize all the parameters of a component in the library with the exception of changing the storage model.

Each storage model might have inputs common with other models and certain unique inputs that are characteristic of the system. Click on the above models to find out the unique inputs. Below is a list of common inputs that are common to across the storage models.

- **General Parameters**: Common to all storage models
- Storage inputs including the capacity curve: Unique to the Kinetic and Modified Kinetic storage model
- **Lifetime inputs**: Common to all storage models excluding flywheel. Modified Kinetic model has a unique set of lifetime inputs.
- Temperature sensitive information of the Storage System (Temperature versus Capacity and Temperature versus Lifetime): Unique to Modified Kinetic storage model
- **Default Cost Information**: Common to all storage models, although some of the inputs in this tab vary for different models.

The storage library listing is under the components category. Here you can view or specify the properties of a storage model. You can create a new storage model by copying an existing one. Use this menu to give the storage system a unique name and to set its properties. HOMER will add the new storage system to your **component library** . You will then see the new storage in the list of available storage types on the Storage menu. The following description is for the general, lifetime and defaults tab which is the common across most storage models.

General Parameters

Variable	Description
Name	A unique name used to identify this type of storage
Abbreviation	A short, distinctive name to identify this storage on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviations will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the storage
Website	An optional field to provide text for a web link for the storage
Url	The actual web address of the link defined in the "Website" input
Weight	An optional field used if the Modified Kinetic Battery Model is used or "Weight minimization" mode is selected.
Footprint	An optional field for reference
Notes	An optional field used to specify additional specifications, manufacturer contact information, or anything noteworthy

Storage type	Select a type from the dropdown menu. This changes the category of the storage component, as it is organized in the pop-up menus of the **Storage Set Up Window** in the Design View. This input has no effect on the technical modeling of the storage item.

Defaults

The Costs box includes the initial capital cost and replacement cost per storage, as well as annual operation and maintenance (O&M) costs per storage. When specifying the capital and replacement costs, remember to account for all costs associated with the storage, including installation. Note that the capital cost is the initial purchase price, the replacement cost is the cost of replacing the storage at the end of its lifetime, and the O&M cost is the annual cost of operating and maintaining the storage. For more details on this input, please refer the **storage component.**

See also

2.2.4 Storage
5.13 Kinetic Battery Model
7.37 Component Library

4.1.1.1 Creating an Idealized Storage Component

The Idealized Storage Model replicates a simple storage model that assumes a flat discharge curve since the supply voltage stays mostly constant during the discharge cycle. For this model, you need to enter only the nominal capacity in amp-hours. HOMER will use this as the actual capacity of the storage. Some high performance Lithium Ion batteries, for example are modeled well with an idealized storage model.

To create a new storage component that uses the idealized model, start by copying a component that uses it, such as the Generic 1kWh Li-Ion battery.

General

Variable	Description
Nominal Voltage	The rated voltage. It is called nominal because the actual voltage varies according to the storage's operating conditions and state of charge. This input is used to convert specifications in A or Ah to values in kW or kWh.
Nominal Capacity	The rated capacity in amp hours. It is the total capacity of the storage system.
Round Trip Efficiency	The round trip DC-to-storage-to-DC efficiency of the storage bank. HOMER assumes that the percentage loss on charge and on discharge are the same.
Minimum State of Charge	The **relative state of charge** below which the storage bank is never drawn.

Maximum Charge Rate	The maximum allowable charge rate of the storage component, measured in amps per amp-hour of unfilled capacity.
Maximum Charge Current	The absolute maximum charge current, in amps.
Maximum Discharge Current	The absolute maximum discharge current, in amps.

Lifetime

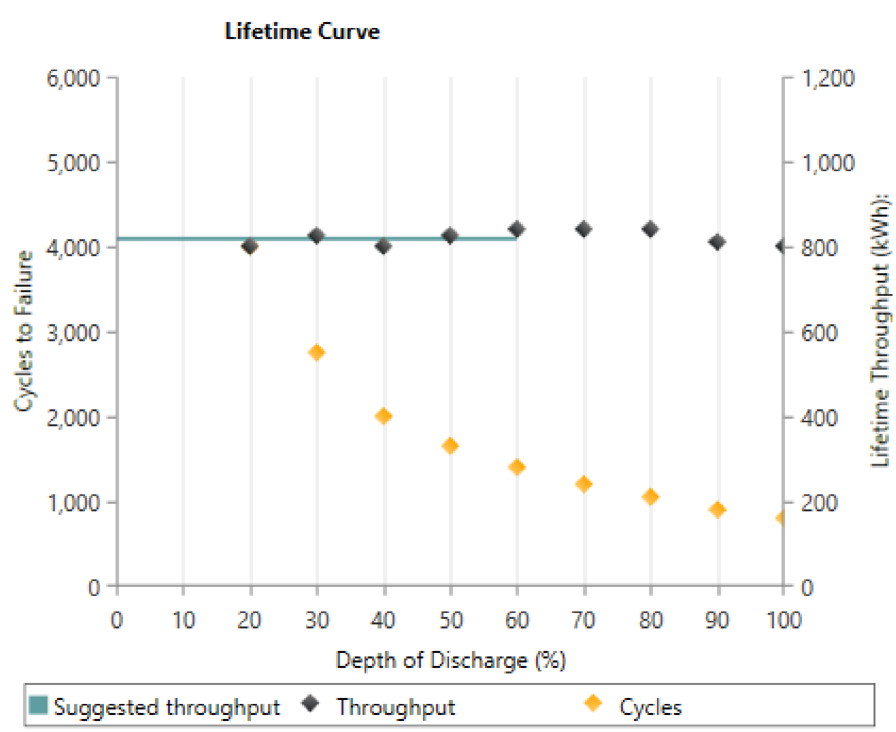
You can choose whether the storage will need replacement after a fixed length of time (float life, years), or after a fixed quantity of energy cycles through it (throughput, kWh), or whichever of those two happens first. If you choose to limit the storage life to a certain number of years, you will need to enter that number of years as the **float life**.

If you choose to limit the storage life to a certain quantity of energy throughput, you will need to enter that quantity as the **lifetime throughput**. You will also have the option of entering the storage lifetime curve to help calculate this lifetime throughput value.

In a lifetime test, the tester subjects the storage to repeated regular charge and discharge cycles. Each cycle, the storage is discharged down to a certain depth of discharge, then fully charged again. The lifetime test determines how many such cycles the storage can withstand before it needs replacement. Manufacturers perform a series of these tests at different depths of discharge to create the storage's lifetime curve.

A lifetime curve shows the number of cycles to failure versus the depth of the cycles. An example appears below. Such curves result from the lifetime tests that storage manufacturers typically perform to characterize the longevity of their products.

Depth of Discharge (%)	Cycles to Failure
20.00	4,000
30.00	2,750
40.00	2,000
50.00	1,650
60.00	1,400
70.00	1,200
80.00	1,050
90.00	900
100.00	800
Click here to add new item	



You specify the storage lifetime curve in HOMER as a table of cycles to failure versus depth of discharge. HOMER plots that series of points as yellow diamonds. As in the example that appears above, that plot typically shows a sharp decrease in the number of cycles to failure with increasing depth of discharge. But HOMER also plots the lifetime throughput, which it calculates for each point in the lifetime curve using the following equation:

$$Q_{lifetime,i} = f_i d_i \left(\frac{q_{max} V_{nom}}{1000 W/kW} \right)$$

where
:

$Q_{lifetime,i}$ = the lifetime throughput [kWh]

f_i = the number of cycles to failure

d_i = the depth of discharge [%]

q_{max} = the maximum capacity of the storage [Ah]

V_{nom} = the nominal voltage of the storage [V]

HOMER plots these values as black diamonds on the lifetime curve (using the right-hand *y*-axis). Their values typically show only a weak dependence on the depth of discharge. HOMER's simulation logic makes the simplifying assumption that the lifetime throughput does not depend on the depth of discharge. The horizontal black line in the lifetime curve shows the calculated value of lifetime throughput. The line is the average of the throughput values calculated for all the points you enter, and drawn only across the allowable range of depth of discharge.

The calculated lifetime throughput is for reference only; HOMER uses the input labeled "Lifetime throughput (kWh)" near the top of the menu in the simulation. If you want to use the calculated throughput value, be sure to copy it over to the "Lifetime throughput (kWh)" input.

4.1.1.2 Creating a Kinetic Storage Component

The Kinetic Battery Model (**Manwell and McGowan, 1993**) calculates the amount of energy that can be absorbed by or withdrawn from the storage bank in each time step. It models a storage as a two tank system, to separate the "available energy" that is available for electricity generation and the "bound energy" that cannot be used.

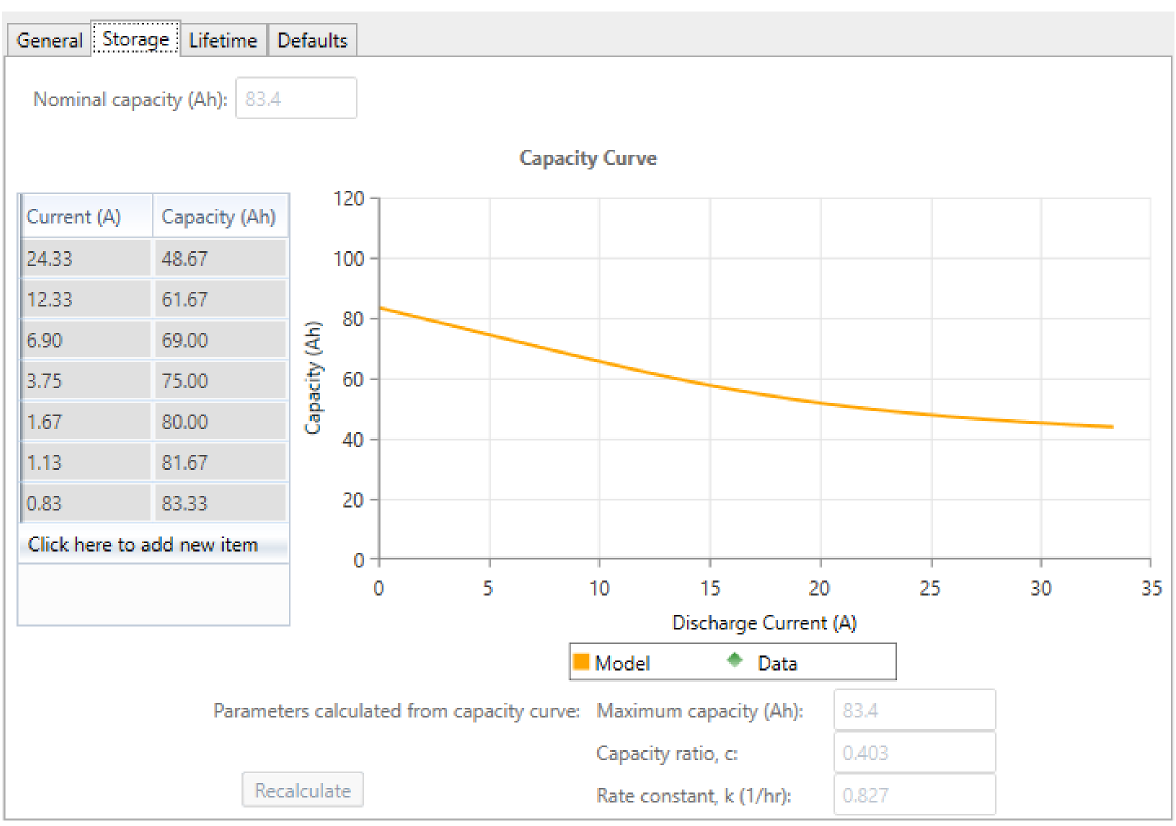
To create a new storage component with the Kinetic Battery Model, start by copying an existing component with that model, like the Generic 1kWh Lead Acid battery.

General

Variable	Description
Nominal Voltage	The rated voltage. It is called nominal because the actual voltage varies according to the storage's operating conditions and state of charge. This input is used to convert specifications in A or Ah to values

	in kW or kWh.
Round Trip Efficiency	The round trip DC-to-storage-to-DC efficiency of the storage bank
Minimum State of Charge	The **relative state of charge** below which the storage bank is never drawn
Maximum Charge Rate	The storage's maximum allowable charge rate, measured in amps per amp-hour of unfilled capacity
Maximum Charge Current	The absolute maximum charge current, in amps
Maximum Discharge Current	The absolute maximum discharge current, in amps

Storage



You can define a kinetic battery model by entering points into the capacity table pictured above. Click "Recalculate" to have HOMER calculate the parameters of a two-tank system that best fit the data given in the capacity curve. You can also enter the kinetic battery model parameters manually. For detailed information about these parameters and how they are used, please see the article on the **kinetic battery model**.

Variable	Description

Maximum Capacity	The combined size of the available and bound tanks
Capacity Ratio	The ratio of the size of the available tank to the combined size in both the tanks
Rate Constant	A measure of how quickly energy can move between the available and bound tanks

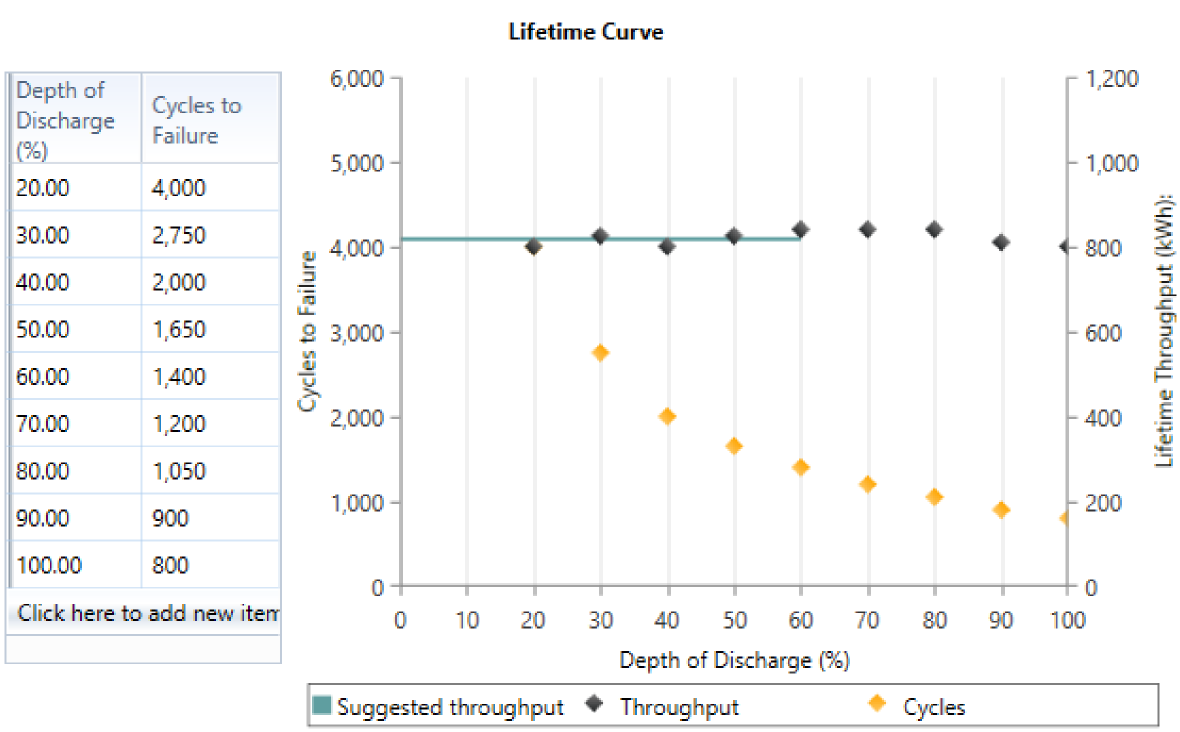
Lifetime

You can choose whether the storage will need replacement after a fixed length of time, or after a fixed quantity of energy cycles through it, or whichever of those two happens first. If you choose to limit the storage life to a certain number of years, you will need to enter that number of years as the **float life**.

If you choose to limit the storage life to a certain quantity of energy throughput, you will need to enter that quantity as the **lifetime throughput**. You will also have the option of entering the storage lifetime curve to help calculate this lifetime throughput value.

In a lifetime test, the tester subjects the storage to repeated regular charge and discharge cycles. Each cycle, the storage is discharged down to a certain depth of discharge, then fully charged again. The lifetime test determines how many such cycles the storage can withstand before it needs replacement. Manufacturers perform a series of these tests at different depths of discharge to create the storage's lifetime curve.

A lifetime curve shows the number of cycles to failure versus the depth of the cycles. An example appears below. Such curves result from the lifetime tests that storage manufacturers typically perform to characterize the longevity of their products.



You specify the storage lifetime curve in HOMER as a table of cycles to failure versus depth of discharge. HOMER plots that series of points as yellow diamonds. As in the example that appears above, that plot typically shows a sharp decrease in the number of cycles to failure with increasing depth of discharge. But HOMER also plots the lifetime throughput, which it calculates for each point in the lifetime curve using the following equation:

$$Q_{lifetime,i} = f_i d_i \left(\frac{q_{max} V_{nom}}{1000 W/kW} \right)$$

where
:

$Q_{lifetime,i}$ = the lifetime throughput [kWh]

f_i = the number of cycles to failure

d_i = the depth of discharge [%]

q_{max} = the maximum capacity of the storage [Ah]

V_{nom} = the nominal voltage of the storage [V]

HOMER plots these values as black diamonds on the lifetime curve (using the right-hand *y*-axis). Their values typically show only a weak dependence on the depth of discharge. HOMER's simulation logic makes the simplifying assumption that the lifetime throughput does not depend on the depth of discharge. The horizontal black line in the lifetime curve shows the calculated value of lifetime throughput. The line is the average of the throughput values calculated for all the points you enter, and drawn only across the allowable range of depth of discharge.

The calculated lifetime throughput is for reference only; HOMER uses the input labeled "Lifetime throughput (kWh)" near the top of the menu in the simulation. If you want to use the calculated throughput value, be sure to copy it over to the "Lifetime throughput (kWh)" input.

4.1.1.3 Creating a Modified Kinetic Storage Component

This feature requires the Advanced Storage Module. Click for more information.

To create a battery using the modified kinetic battery model, you'll need to copy one of the built-in batteries that use the modified kinetic model. You can identify the two built-in examples by the tag [Advanced] appended to the battery name. These are the Generic 1kWh Lead Acid [Advanced] and the Generic 1kWh Li-Ion [Advanced]. Although you can change all of the parameters of the battery and the modified kinetic model, you can't take a battery with one kind of model and change it to another model. See the Classification section of the **Storage** topic for the list and descriptions of these immutable classes of storage components.

The Modified Kinetic Battery Model is based on the regular Kinetic Battery Model, with the addition of rate dependent losses, temperature effects, and degradation of performance over the life time. The degradation effects are best modeled with HOMER in Multi-Year mode. For more technical details, see the **Modified Kinetic Battery Model** article.

General Inputs

The General tab contains a number of inputs that are common to all types of components, described in **Storage**. The General tab also includes several inputs that are specific to the Modified Kinetic Battery Model. These are defined in the following table.

Variable	Description
Max. charge rate	The maximum charging current allowed, defined as amps of charging current per Ah of the remaining headroom in the battery.
Max. charge current	The maximum allowable charging current, in amps.
Max. discharge current	The maximum allowable discharging current in amps.
Other round-trip losses	Additional losses in the battery system, such as wiring, or power electronics. These losses are not converted to heat in the thermal model.

Tip: Be sure to specify the weight when creating a component with the Modified Kinetic Battery Model. The model uses the weight to calculate heat transfer and thermal behavior.

Thermal

HOMER can keep the battery bank's internal temperature fixed to a specific temperature you specify, or it can run a simple lumped-capacity thermal model to estimate the battery internal temperature at each time step. The lumped thermal model tracks the battery internal temperature based on ambient temperature, losses converted to heat, conductance to ambient, and heat capacity. The lumped thermal model is used if "Consider temperature effects?" is checked in the design view, and requires a temperature resource.

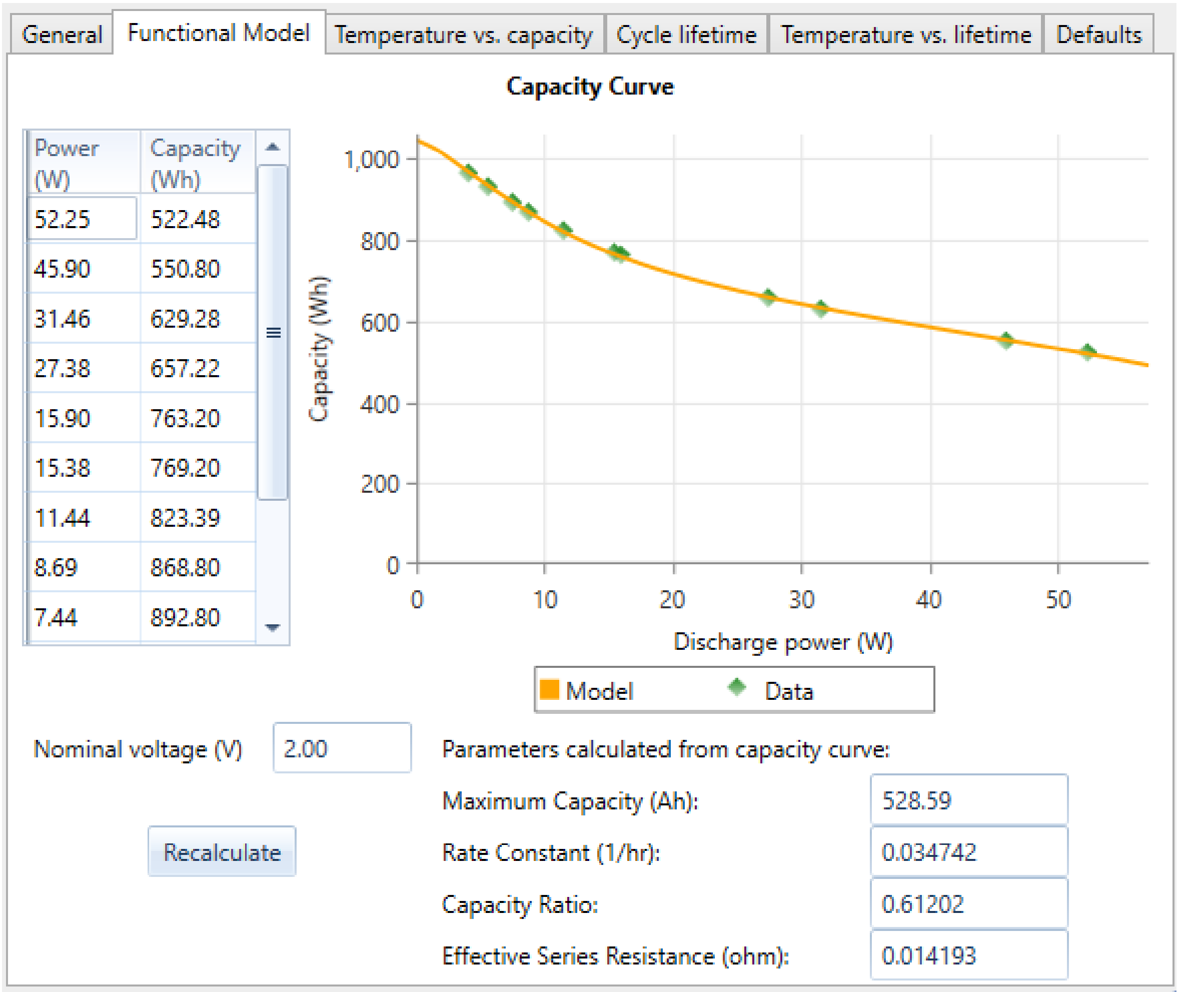
Variable	Description
Maximum operating temperature	Above this temperature, the battery will turn 'off', meaning that neither charging nor discharging is allowed.
Minimum operating temperature	Below this temperature, the battery will turn 'off', meaning that neither charging nor discharging is allowed.
Conductance to ambient (W/K)	The rate at which heat is exchanged between the component and ambient. This input is used when "Consider temperature effects?" is chosen. If this is set to a large value, the component will follow the

	ambient temperature (defined in the temperature resource) very closely.
Specific heat capacity (J/kgK)	The amount of heat energy the component absorbs, per kilogram of mass, before increasing in temperature by one degree Celsius. This input is used when "Consider temperature effects?" is chosen.
Fixed bulk temperature	Fixes the battery internal temperature to the value specified, when "Consider temperature effects?" is not selected. No temperature resource is needed with this option.

When the battery is added to a HOMER model, the user can select "Consider temperature effects?" or not. If "Consider temperature effects?" is selected, HOMER will use the Conductance to ambient and Specific heat capacity inputs. If you don't have data for specific heat capacity and conductance to ambient, you can set the specific heat capacity to zero, and the battery will track the ambient temperature exactly.

Functional Model

The functional model dictates how the battery behaves in simulation. These variables affect the amount of loss, the amount of available energy at any time, and the theoretical capacity of the battery. Simply enter the power-capacity discharge data in the table, and click the "Recalculate" button. HOMER will fit the Kinetic Battery Model parameters (k, c, Qmax) and the series resistance (R_0) for you. It can take a few minutes to fit the parameters to the data. Note that the units for this table are different than the capacity curve for the regular kinetic model. This is necessary for the computation of the resistor value. The units are power in watts, and capacity in watt-hours. Constant power discharge capacity data is available for many batteries.



Variable	Description
Nominal voltage	The no-load voltage of the battery model. You can generally set this to the manufacturer's nominal voltage of the battery.
Maximum Capacity*	The combined capacity of both tanks in the kinetic model, in amp-hours. See the article on the **Kinetic Battery Model** for details.
Rate constant*	The rate constant parameter specifies how quickly or slowly the two tanks of the kinetic model equalize, in units of 1/hr. See the article on the **Kinetic Battery Model** for details.
Capacity ratio*	The capacity ratio specifies the relative size of the two tanks of the kinetic battery model. See the article on the **Kinetic Battery Model** for details.
R_0*	The series resistance that is added to the kinetic model, in ohms. See the article **Modified Kinetic Battery Model** for technical details.

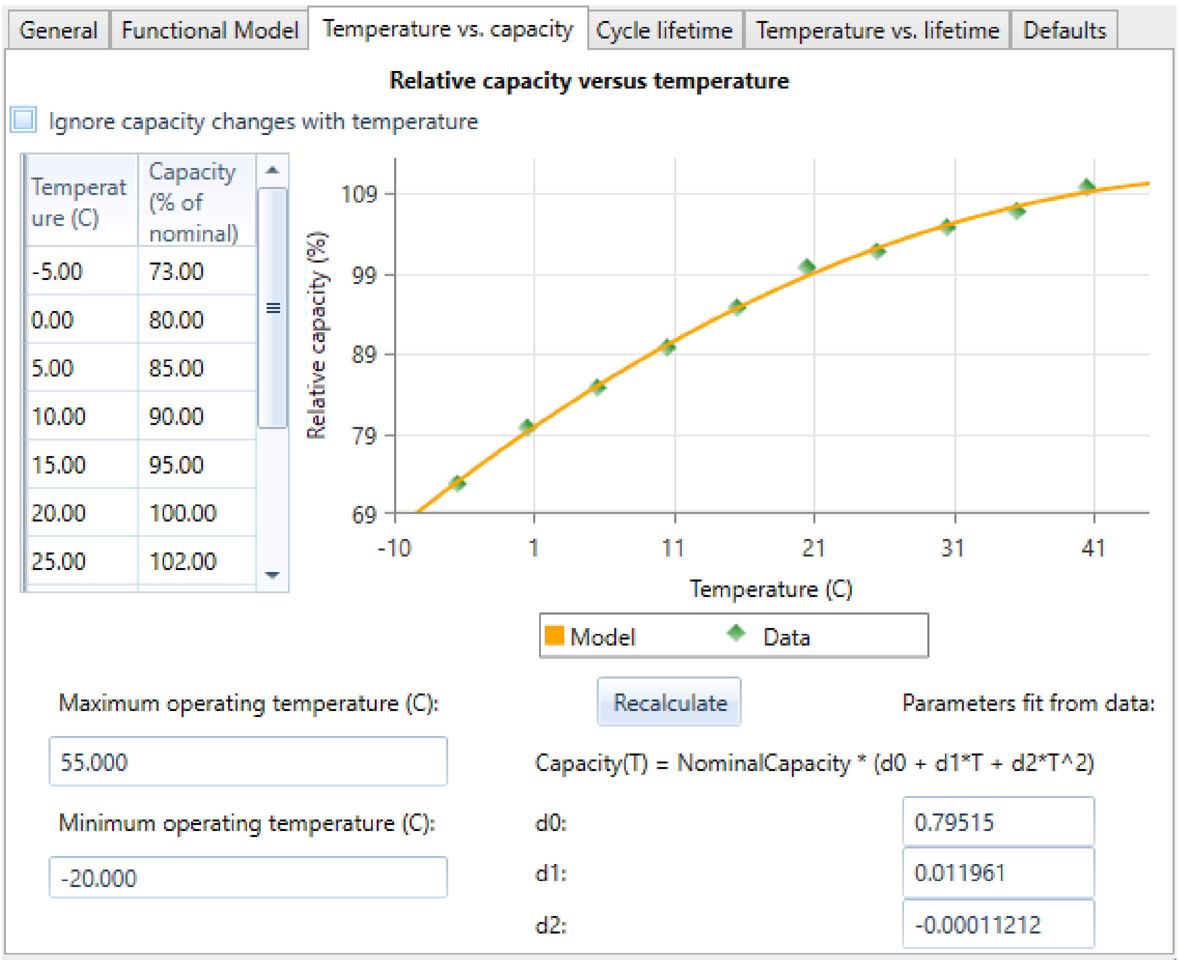
*Parameter is calculated from the data when you click Recalculate

Depending on your selections in the Temperature vs. capacity, Cycle lifetime, and Temperature vs. lifetime tabs, these parameters will be adjusted during the simulation to model degradation and variation of capacity with temperature.

Temperature versus Capacity Curve

Enter the relative capacity, in percent of the nominal capacity, versus temperature for the battery, into the table on the left side of the page.

Press the Recalculate button to calculate the three parameters for the quadratic fit. Also enter a maximum and minimum operating temperature. The battery will be shut down outside of this temperature range.

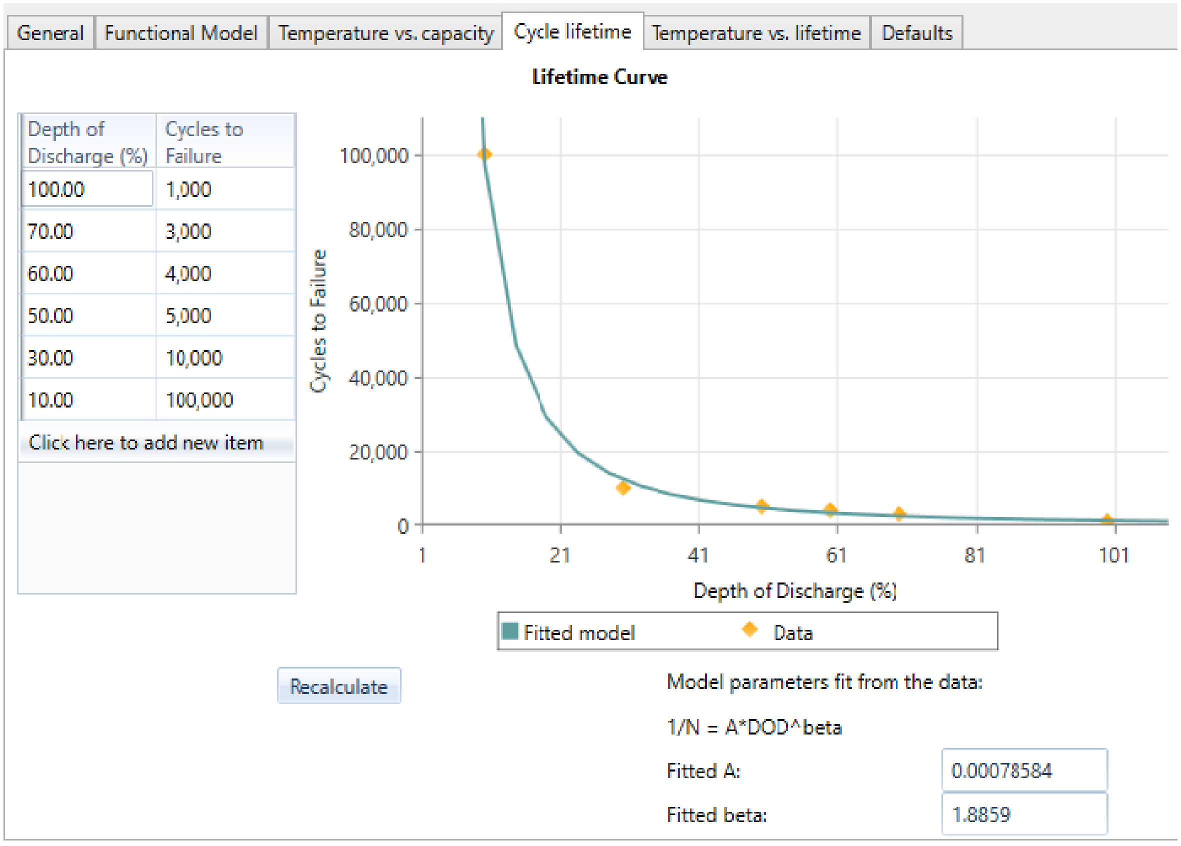


If you do not want to include temperature effects on capacity in the battery model, you can check the box in the top left corner of the page, "Ignore capacity changes with temperature". Checking this option will set the d0 term to 1.0, and d1 and d2 to zero, which makes the temperature 100% of nominal at all points.

Variable	Description
Maximum Operating Temperature	Maximum temperature of the battery bank. Above this temperature, charging and discharging are not allowed.
Minimum Operating Temperature	Minimum temperature of the battery bank. Below this temperature, charging and discharging are not allowed.
Fitted d0	Constant term in quadratic fit.
Fitted d1	Coefficient of temperature in quadratic fit.
Fitted d2	Coefficient of temperature squared in quadratic fit.

Cycle Lifetime

Enter data for cycles versus depth of discharge (DOD) into the table and click Recalculate. HOMER will calculate A and β (beta) automatically from your data. You can also manipulate A and β to create a specific behavior, such as a fixed kWh of throughput to failure.



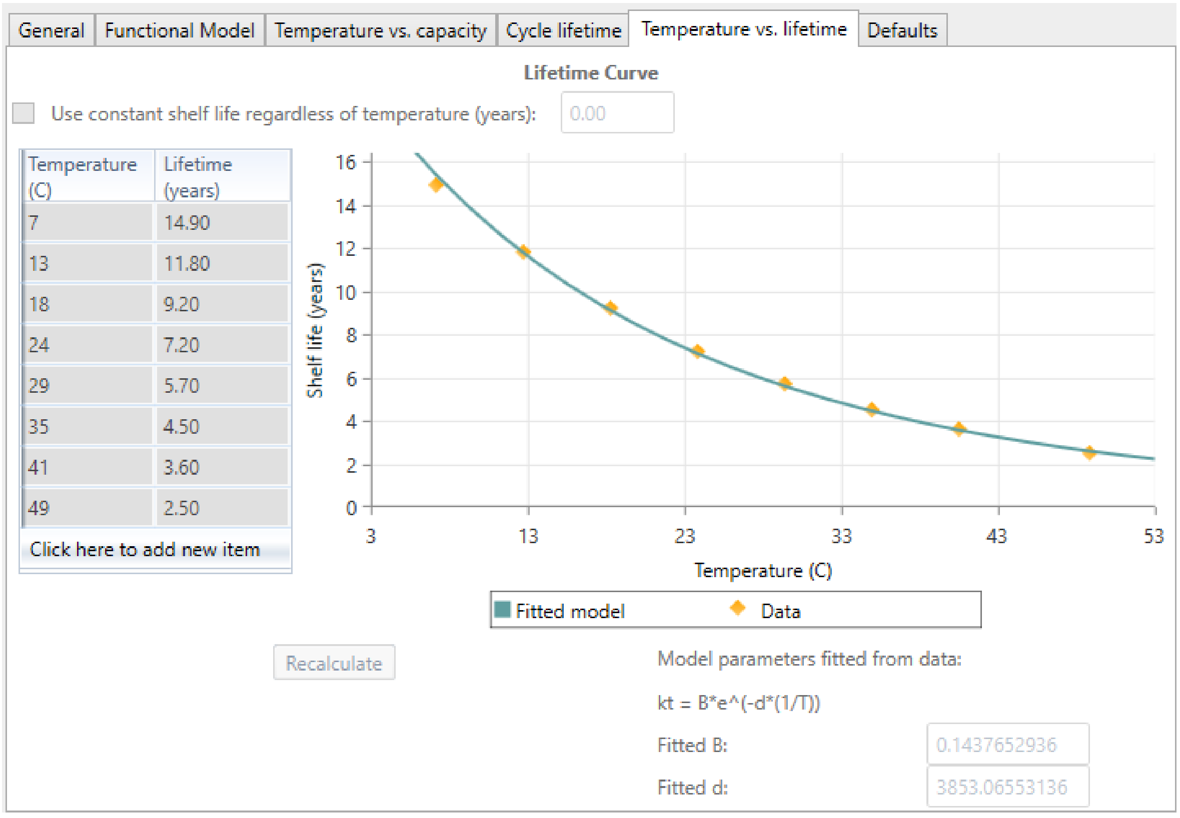
Variable	Description
Fitted A	Coefficient fit from data entered in the table. For physical significance, the inverse of A equals the nominal cycles to failure at 100% DOD times the Capacity degradation Limit as a fraction.
Fitted β	Exponent fit from data entered in the table. Set beta to 1 for a constant number of kWh throughput to end of life. Set beta to 0 for a set number of cycles to failure, with no dependence on DOD.

HOMER uses the Rainflow Counting Algorithm to calculate cycles and degradation from the state of charge time series in simulation. See the article **Modified Kinetic Battery Model** for more information.

Tip: The fit HOMER computes when you click Recalculate depends on the value of the Capacity degradation Limit input in the Default tab. If you change the value of the Capacity degradation Limit, you may want to Recalculate again.

Temperature versus Lifetime

Some datasheets or manufacturers can provide data for shelf life versus temperature. It is common for battery "shelf life" to be reduced at higher temperatures. Enter years versus temperature data into the table, and click Recalculate. HOMER will fit an Arrhenius type equation to the data.

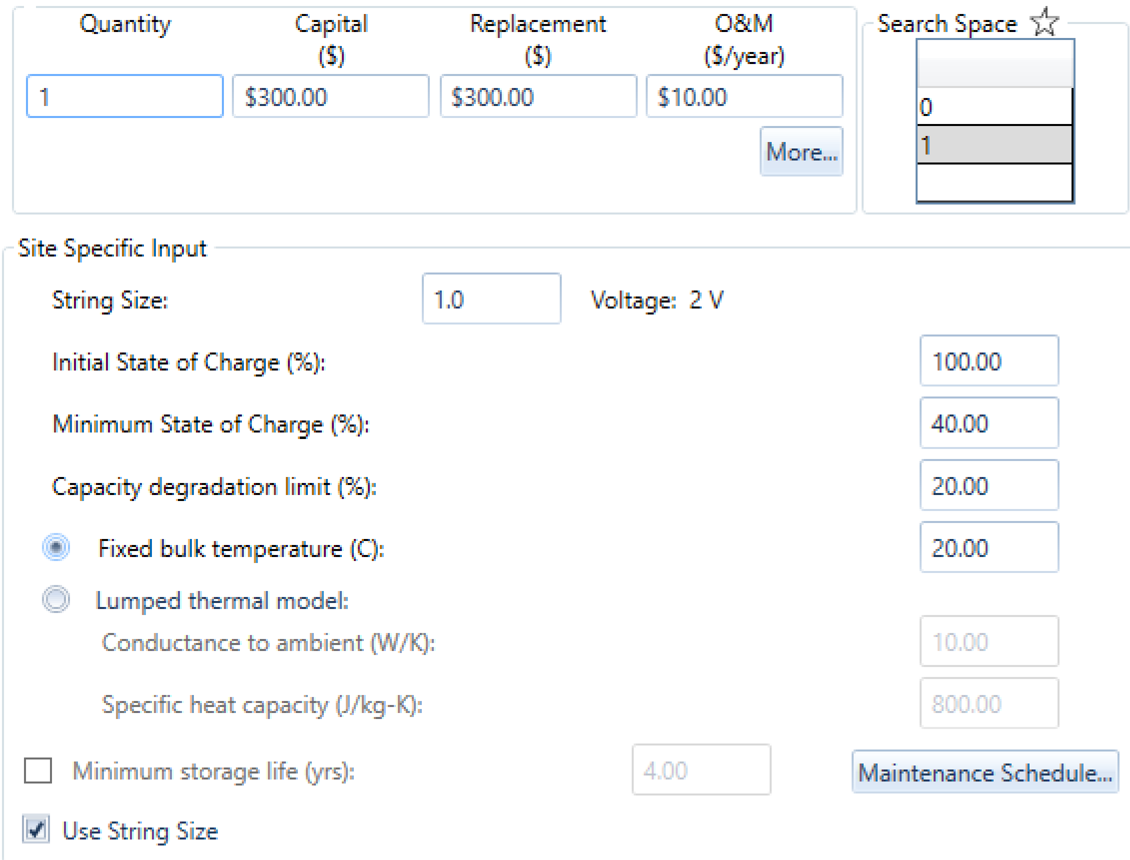


Variable	Description
Fitted B	Coefficient of the model. Conceptually, this is equal to the inverse of the shelf life (in hours) times the Capacity degradation Limit as a fraction.
Fitted d	Coefficient of the exponential term in the model. A large value of d indicates a stronger temperature dependence.

Tip: The fit HOMER computes when you click Recalculate depends on the value of the Capacity degradation Limit input in the Default tab. If you change the value of the Capacity degradation Limit, you may want to Recalculate again.

Defaults

In the defaults tab, you can set the default values for all of the inputs that are displayed in the Design View when a user adds the component to a HOMER model, including the cost table, search space, and site specific inputs. You can modify any of these values in the Design view after you have added the component to the model. You can't add sensitivity values for these inputs in the Library, but you can add sensitivity values to the input once you have added to the model in the design view.



The values that you enter here will be the default values displayed in the design view when you first add this component to a HOMER model. See the help topic **Modified Kinetic Battery** in the Design View help section for details on these inputs.

4.1.1.4 Creating a Idealized Power-Capacity Storage Component

4.1.1.4 Creating an Idealized Power-Capacity Storage Component

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The Idealized Power-Capacity storage model is intended to simulate certain kinds of storage systems that allow users to size energy and power independently. This option requires additional parameters, listed and described here. The nominal voltage, max charge rate, max charge current, max discharge current, min. state of charge, and conventional lifetime inputs are disabled for this storage type. The vanadium redox flow batteries are an example of storage systems that use the Idealized Power-Capacity model.

General

Variable	Description
Cell Stack Lifetime	The lifetime of the cell stack. The cell stack replacement cost occurs at the end of the cell stack lifetime.
Electrolyte Lifetime	The lifetime of the electrolyte. The electrolyte replacement cost occurs at the end of the electrolyte lifetime.

To create a storage component with this model, start by copying another storage component that uses it, such as the Generic Vanadium battery.

For more information

*The **HOMER Support Site** has a searchable knowledgebase and additional support options.*

***HOMER online** contains the latest information on model updates, as well as sample files, resource data, and contact information.*

4.1.1.5 Creating a Flywheel Storage Component

This window lets you view or specify the properties of library flywheels. You can create a new flywheel by copying an existing one. Change the properties as required and give the new component a unique name to distinguish it from others. HOMER will add this new flywheel to your component library when you click OK. The new flywheel will then appear in the list of available flywheel types on the Flywheel window.

Properties

Variable	Description
Description	A unique name used to identify this type of flywheel
Manufacturer	An optional field used to specify the manufacturer of the flywheel
Website	An optional field to hold the website of the manufacturer
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Charge/Discharge Capacity	The maximum amount of power the flywheel can absorb or provide. (HOMER assumes that the flywheel's capacity to absorb power is equal to its capacity to provide power.) This is the amount of **operating capacity** that the flywheel provides to the system.
Parasitic load	The amount of electricity necessary to operate the flywheel. HOMER models this as a constant electrical load, and considers a system **feasible** only if it can meet this load at all times during the simulation.

See also

2.2.4.5 Flywheel
7.37 Component Library

7.115 Operating Reserve

4.1.2 Generator

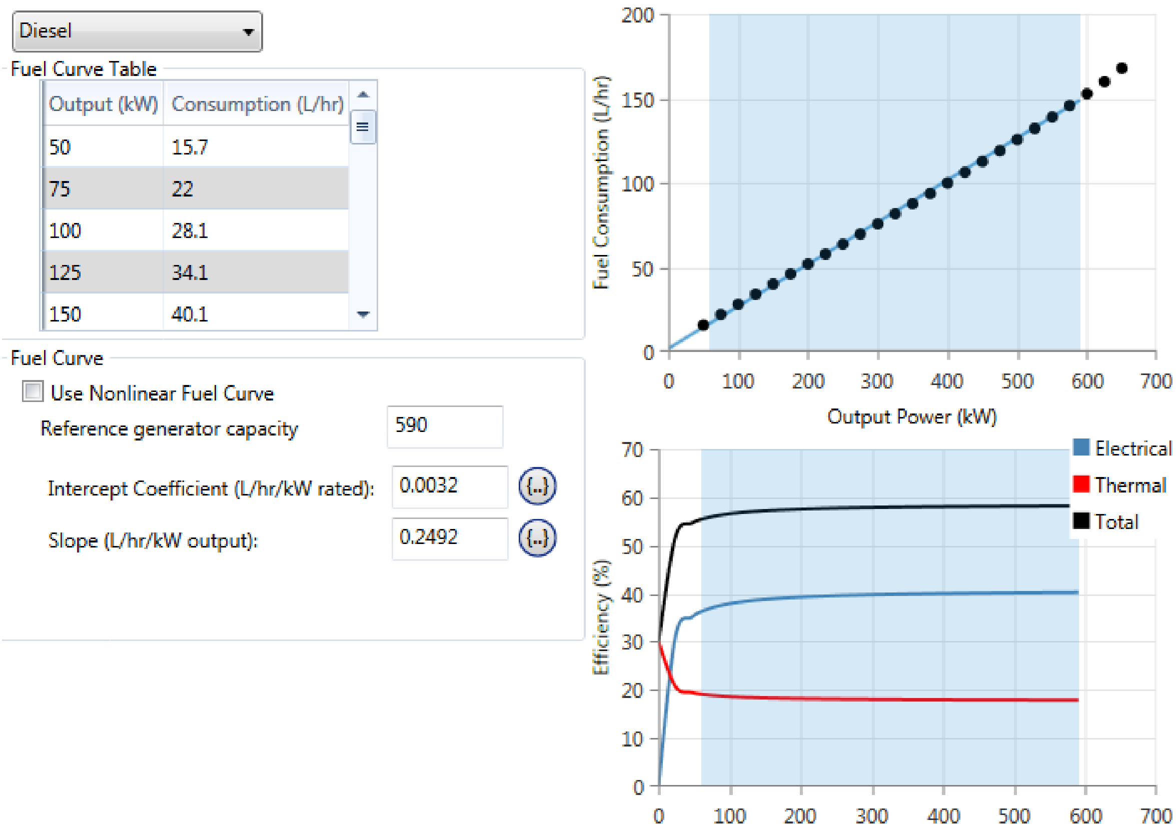
The generator library listing is under the components category. Here you can view or specify the properties of the library generator. You can create a new generator by copying an existing one.

General Parameters

Variable	Description
Name	A unique name used to identify this generator
Abbreviation	A short, distinctive name to identify this generator on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the generator
Website	An optional field to provide text for a web link for the generator
Url	The actual web address of the link defined in the "Website" input
Weight	Used if "Weight minimization" mode is selected.
Footprint	An optional field for reference
Notes	An optional field used to specify additional specifications, manufacturer contact information, or anything noteworthy
Electrical bus	The type of generator output current (alternating current or direct current)
Lifetime (Operating Hours)	The number of hours the generator can operate before needing replacement
Minimum Load Ratio	The minimum allowable load on the generator expressed as a percentage of its capacity
Heat Recovery Ratio	The percentage of waste heat that can be used to serve the thermal load. If you are not modeling a thermal load or you do not intend to recover waste heat from the generator, set this to zero. This input requires the Combined Heat and Power Module.
Minimum Run Time	Once the dispatch starts the generator, it will remain on for this duration or longer

Fuel

You can set the generator efficiency and calculate the fuel curve from specification data in the "Fuel" tab. Select the generator's fuel from the drop-down menu at the top of the page. You can enter data points of fuel consumption and output power in the fuel curve table, and HOMER will calculate a best-fit fuel curve from the data. HOMER will use the value in the "Reference generator capacity" when calculating the "Intercept coefficient". You can also input the fuel curve coefficients manually.



The fuel consumption versus power is plotted in the top chart. The efficiency versus power output is plotted in the lower chart. If you've specified a non-zero heat recovery ratio, the thermal efficiency and total (thermal + electrical) efficiency will also be plotted on the efficiency chart.

Operating Schedule

In the schedule tab, you can specify a default schedule for the generator. When adding the generator to your model, you can use a similar menu to modify the default operating schedule for the specific installation. The **Generator Schedule** subtopic describes how to define a generator operating schedule.

Maintenance Schedule

You can define the frequency, cost, and down-time of generator maintenance events in the generator maintenance schedule. The generator maintenance schedule tab allows you to define the default maintenance schedule for the generator component. When you add the generator to a model, you can modify the maintenance schedule from the default schedule you define here. The inputs are the same for the **generator maintenance schedule on the generator menu in the design view** and the generator maintenance schedule in the library discussed here. Refer to the **maintenance schedule** topic of the Generator menu in the design view for an instructions and details for defining a generator maintenance schedule.

Emissions

The Emissions tab in the **Generator** window gives you access to the following emissions factors input variables:

Variable	Description
Carbon Monoxide	The quantity of carbon monoxide emitted per unit of fuel consumed by the generator, in g/L*
Unburned Hydrocarbons	The quantity of unburned hydrocarbons emitted per unit of fuel consumed by the generator, in g/L*
Particulate Matter	The quantity of particulate matter emitted per unit of fuel consumed by the generator, in g/L*
Proportion of Fuel Sulfur Converted to PM	The fraction of the sulfur in the fuel that is emitted as particulate matter (the rest is emitted as sulfur dioxide), in %
Nitrogen Oxides	The quantity of nitrogen oxides emitted per unit of fuel consumed by the generator, in g/L*

*These units will be in g/m^3 for fuels that are measured in m^3 and g/kg for fuels measured in kg.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

4.1.3 Photovoltaic (PV)

The photovoltaic library listing is under the components category. Here you can view or specify the properties of the library photovoltaic panels. You can create a new panel by copying an existing one and then changing the specifications.

General Parameters

Variable	Description
Name	A unique name used to identify this type of PV
Abbreviation	A short, distinctive name to identify this PV on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the PV
Website	An optional field to provide text for a web link for the PV
Url	The actual web address of the link defined in the "Website" input
Weight	Used if "Weight minimization" mode is selected.
Footprint	An optional field for reference
Notes	An optional field used to specify additional specifications, manufacturer

	contact information, or anything noteworthy
Electrical bus	The type of PV output current (alternating current or direct current)
Concentrating PV	Check the box if this component is a **concentrating PV**
DNI rating condition	The irradiance at which concentrating PV panel will produce its rated output. This input applies to concentrating PV only. 850 W/m^2 (0.85 kW/m^2) is a typical value
Lifetime (yr)	The period of time, in years, before the PV must be replaced, and the replacement cost will be incurred
Derating factor	A scaling factor applied to the PV array power output to account for reduced output in real-world operating conditions compared to operating conditions at which the array was rated. A derating factor of 80% means that the panel produces 20% less power than the nominal specification

Converter

The Converter tab contains inputs to specify the dedicated **inverter** (for AC panels) or **maximum power point tracker** (for DC panels). The inputs are similar to those for the Inverter/MPPT for the **PV menu of the Design view**, and are described in that help article.

Temperature

You can input or download a **Temperature Resource** and HOMER will calculate the PV cell temperature. Using parameters you can specify in the Temperature tab of the PV, HOMER can take temperature effects on PV efficiency into account when calculating the PV array output. You can define the default values for a PV module temperature effects here, and can also change them once the panel is added to a HOMER model. See the help article on **temperature effects inputs for PV in the design view**.

Defaults

The defaults tab contains several inputs specific to the PV installation. You can set the default values here, and can modify them when you add the PV to a model. For an explanation of these inputs, refer to the **Advanced Inputs section of the PV design menu** help article.

Note: To the right of each numerical input is a sensitivity button ( )which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**

4.1.4 Wind Turbine

This menu lets you view or specify the properties of the library wind turbines. You can create a new wind turbine from scratch or by copying an existing one. Change the properties as required and give the new wind turbine a unique name to distinguish it from others. HOMER will add this new wind turbine to your **component library** when you click OK. The new wind turbine will then be included in the list of available wind turbine types on the **Wind Turbine** window.

General

Variable	Description
Name	A unique name used to identify this type of wind turbine
Abbreviation	A short, distinctive name to identify this wind turbine on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the wind turbine
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input
Weight	Used if "Weight minimization" mode is selected.
Footprint	An optional field for reference
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Electrical Bus	The type of electricity produced by the wind turbine, either direct current (DC) or alternating current (AC)
Rated power	The nominal power output (nameplate capacity) of the turbine. For reference only.

Power curve

The power curve is the most important property of the wind turbine. It describes the amount of power the turbine produces versus the wind speed at hub height.

Enter as many points on the power curve as you have available. HOMER uses linear interpolation to calculate the output of the wind turbine at intervening points. At wind speeds outside the range defined in the power curve, the turbine output is zero. It is assumed that the turbine shuts down for wind speeds slower than the minimum or faster than the maximum.

Losses

The Losses tab allows you to derate the turbine performance with several different factors. The "Overall loss factor" is calculated multiplicatively as in the following equation:

$$L_{overall} = \prod_{i=1}^{n} 1 + \frac{L_i}{100}$$

In this equation, each loss percentage is an L_i , from L_1 (availability losses) to L_7 (other losses). The turbine power output is then scaled down by the resulting factor.

Maintenance

In the Maintenance tab, check the box for "Consider maintenance schedule" to include a maintenance schedule with the wind turbine model. You can enter a procedure in a row of the maintenance table to represent a scheduled maintenance event. For more instructions and important details, see the **Maintenance subtopic of the Wind Turbine Menu in the Design View**.

4.1.5 Boiler

This window lets you view or specify the properties of boiler component models in the library. You can create a new boiler component by copying an existing one. Change the properties as required and give the new boiler a unique name to distinguish it from others. HOMER will add this new boiler to your component library when you click OK. The new boiler will then appear in the list of available boiler types on the Boiler menu in the Design view.

Properties

Variable	Description
Description	A unique name used to identify this type of boiler
Manufacturer	An optional field used to specify the manufacturer of the boiler
Website	An optional field to hold the website of the manufacturer
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Efficiency	The efficiency with which the boiler provides energy from the fuel. This is the percent of the lower heating value of the fuel burned which is captured and supplied to the thermal bus.
Emissions factors	The amount of each pollutant produced in kg per unit of fuel.

See also

2.2.6 Boiler
2.1.4 Thermal Load

4.1.6 Converter

This window lets you view or specify the properties of library flywheels. You can create a new flywheel from scratch or by copying an existing one. Change the properties as required and give the new wind turbine a unique name to distinguish it from others. HOMER will add this new flywheel to your component library when you click OK. The new flywheel will then appear in the list of available flywheel types on the Flywheel window.

Properties

Variable	Description
Description	A unique name used to identify this type of flywheel
Manufacturer	An optional field used to specify the manufacturer of the flywheel
Website	An optional field to hold the website of the manufacturer
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Charge/Discharge Capacity	The maximum amount of power the flywheel can absorb or provide. (HOMER assumes that the flywheel's capacity to absorb power is equal to its capacity to provide power.) This is the amount of **operating capacity** that the flywheel provides to the system.
Parasitic load	The amount of electricity necessary to operate the flywheel. HOMER models this as a constant electrical load, and considers a system **feasible** only if it can meet this load at all times during the simulation.

See also

2.2.4.5 Flywheel
7.37 Component Library
7.115 Operating Reserve

4.1.7 Hydroelectric

This window lets you view or specify the properties of library hydro components. You can create a new hydro component from scratch or by copying an existing one. Change the properties as required and give the new hydroelectric turbine a unique name to distinguish it from others. HOMER will add this new hydro component to your component library when you click OK. The new hydro component will then appear in the list of available hydro component types on the hydro component window.

General Properties

Variable	Description
Abbreviation	A short, distinctive name to identify this hydro component on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the hydro component

Name	A unique name used to identify this type of hydro component
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input

Other Properties

Variable	Description
Capacity	The maximum power input that the hydro component can convert to heat.
AC	The type of power produced by the hydro installation. Check the box for alternating current (AC). Otherwise the component will go on the direct current (DC) bus.
Available head	The default **available head** for this hydro component. When the component is added to a model, this value can be changed to match the specific installation.
Capital Cost	The initial cost incurred if the hydro component is included in the system.
Consider Systems without Turbine	If this box is checked, HOMER will simulate systems with and without the hydro component as optimization cases. Otherwise all simulations will include the hydro component.
Design flow rate	The flow rate for which this hydro turbine was designed. It is often the flow rate at which the turbine operates at maximum efficiency.
Efficiency	The efficiency with which the hydro system converts the energy in the water to electricity
Lifetime	The duration, in years, before the hydro component will be replaced. The replacement cost will be incurred at that time.
Maximum flow ratio	The maximum flow rate of the hydro turbine, as a percentage of its design flow rate. The turbine will generate power at the specified efficiency up to this flow. Additional flow above this level will not increase turbine power output.
Maximum capacity	This value is calculated from the other inputs.
Minimum flow ratio	The minimum flow rate of the hydro turbine, as a percentage of its design flow rate. Below this rate, the turbine will produce no power.
Nominal capacity	This value is calculated from the other inputs.
O & M Cost	The yearly cost of maintenance on the component, in currency units (derived from your settings in Windows) per year.

Pipe head loss	Pipe friction losses expressed as a percentage of the available head.
Replacement cost	The cost that will be incurred after the lifetime has elapsed.
Component requires one minute time steps	If you check this box, users of this component will have to set the simulation time step to one minute in order to run a calculation. Check this option if the component requires one-minute time steps to model the behavior accurately.

Costs

Do not use these inputs. Instead, use the cost inputs defined in the table above.

Physical Dimensions

These inputs specify the size and weight of the component. If "Weight minimization" mode is selected in the **System Control** menu, the weight parameter will be used in the calculation. Otherwise these values are for reference only.

Variable	Description
Footprint	The surface area occupied by the free-standing component, in m^2.
Volume	The volume in m^3.
Weight	The total weight of the component in kg. Optionally this can include all associated equipment for transportation and deployment of the component, for weight minimization mode.

See also

2.2.7 Hydro
7.37 Component Library

4.1.8 Thermal Load Controller

This window lets you view or specify the properties of library thermal load controllers. You can create a new thermal load controller from scratch or by copying an existing one. Change the properties as required and give the new thermal load controller a unique name to distinguish it from others. HOMER will add this new thermal load controller to your component library when you click OK. The new thermal load controller will then appear in the list of available thermal load controller types on the thermal load controller window.

General Properties

Variable	Description
Abbreviation	A short, distinctive name to identify this thermal load controller on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.

Manufacturer	An optional field used to specify the manufacturer of the thermal load controller
Name	A unique name used to identify this type of thermal load controller
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input

Other Properties

Variable	Description
Capacity	The maximum power input that the thermal load controller can convert to heat.
Do Not Optimize TLC	If you check this box, the thermal load controller will be modelled with unlimited capacity and zero cost. Many other inputs are ignored if this option is selected.
Electrical Bus	The bus or buses that the thermal load controller can draw electric power from.
Lifetime	The duration, in years, before the thermal load controller will be replaced. The replacement cost will be incurred at that time.
Component requires one minute time steps	If you check this box, users of this component will have to set the simulation time step to one minute in order to run a calculation. Check this option if the component requires one-minute time steps to model the behavior accurately.

Costs

These inputs define the default value for the cost of the component.

Variable	Description
Cost matrix	Click the down arrow on the right end of the row to use the cost matrix editor to input rows to the cost matrix.
Cost multipliers (capital, replacement, O&M)	Sets the default value for the cost multiplier sensitivity variables. In most cases these should all be left set to 1.

Physical Dimensions

These inputs specify the size and weight of the component. If "Weight minimization" mode is selected in the **System Control** menu, the weight parameter will be used in the calculation. Otherwise these values are for reference only.

Variable	Description

Footprint	The surface area occupied by the free-standing component, in m^2.
Volume	The volume in m^3.
Weight	The total weight of the component in kg. Optionally this can include all associated equipment for transportation and deployment of the component, for weight minimization mode.

See also

2.2.9 Thermal Load Controller
7.37 Component Library

4.1.9 Hydrokinetic

This menu lets you view or specify the properties of the library hydrokinetic components. You can create a new hydrokinetic component from scratch or by copying an existing one. Change the properties as required and give the new hydrokinetic component a unique name to distinguish it from others. HOMER will add this new hydrokinetic component to your **component library** when you click OK. The new hydrokinetic component will then be included in the list of available hydrokinetic component types on the **hydrokinetic component** window.

General

Variable	Description
Name	A unique name used to identify this type of hydrokinetic component
Abbreviation	A short, distinctive name to identify this hydrokinetic component on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the hydrokinetic component
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input
Weight	Used if "Weight minimization" mode is selected.
Footprint	An optional field for reference
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Electrical Bus	The type of electricity produced by the hydrokinetic component, either direct current (DC) or alternating current (AC)
Rated power	The nominal power output (nameplate capacity) of the turbine. For reference only.

Power curve

The power curve is the most important property of the hydrokinetic component. It describes the amount of power the turbine produces versus the water speed.

Enter as many points on the power curve as you have available. HOMER uses linear interpolation to calculate the output of the hydrokinetic component at intervening points. At water speeds outside the range defined in the power curve, the turbine output is zero. It is assumed that the turbine shuts down for water speeds slower than the minimum or faster than the maximum.

Defaults

You can set the default component lifetime, in years, in the Defaults tab. Once the hydrokinetic component is added to a model, the lifetime can be modified to reflect the actual installation.

4.1.10 Reformer

This window lets you view or specify the properties of library reformers. You can create a new reformer from scratch or by copying an existing one. Change the properties as required and give the new reformer a unique name to distinguish it from others. HOMER will add this new reformer to your component library when you click OK. The new reformer will then appear in the list of available reformer types on the reformer window.

General Properties

Variable	Description
Abbreviation	A short, distinctive name to identify this reformer on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the reformer
Name	A unique name used to identify this type of reformer
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input

Other Properties

Variable	Description
AC	The type of power produced by the reformer. Check the box for alternating current (AC). Otherwise the component will go on the direct current (DC) bus.

Capacity	The maximum rate at which the reformer can convert fuel into hydrogen, in kg/hr of hydrogen output.
Delivery cost	The cost of transporting the hydrogen produced by the reformer to the site of use, in $/kg/km.
Efficiency	The efficiency with which the reformer converts the fuel to hydrogen, in %.
Lifetime	The duration, in years, before the reformer will be replaced. The replacement cost will be incurred at that time.
Component requires one minute time steps	If you check this box, users of this component will have to set the simulation time step to one minute in order to run a calculation. Check this option if the component requires one-minute time steps to model the behavior accurately.

Costs

These inputs define the default value for the cost of the component.

Variable	Description
Cost matrix	Click the down arrow on the right end of the row to use the cost matrix editor to input rows to the cost matrix.
Cost multipliers (capital, replacement, O&M)	Sets the default value for the cost multiplier sensitivity variables. In most cases these should all be left set to 1.

Physical Dimensions

These inputs specify the size and weight of the component. If "Weight minimization" mode is selected in the **System Control** menu, the weight parameter will be used in the calculation. Otherwise these values are for reference only.

Variable	Description
Footprint	The surface area occupied by the free-standing component, in m^2.
Volume	The volume in m^3.
Weight	The total weight of the component in kg. Optionally this can include all associated equipment for transportation and deployment of the component, for weight minimization mode.

Fuel

You can select the default fuel resource used by this component. When the reformer is added to a model in the design view, you can change the fuel resource to reflect that of the actual installation.

See also

2.2.13 Reformer
7.37 Component Library

4.1.11 Electrolyzer

This window lets you view or specify the properties of library electrolyzers. You can create a new electrolyzer from scratch or by copying an existing one. Change the properties as required and give the new electrolyzer a unique name to distinguish it from others. HOMER will add this new electrolyzer to your component library when you click OK. The new electrolyzer will then appear in the list of available electrolyzer types on the electrolyzer window.

General Properties

Variable	Description
Abbreviation	A short, distinctive name to identify this electrolyzer on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the electrolyzer
Name	A unique name used to identify this type of electrolyzer
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input

Other Properties

Variable	Description
AC	The type of power produced by the electrolyzer. Check the box for alternating current (AC). Otherwise the component will go on the direct current (DC) bus.
Capacity	The maximum rate at which the electrolyzer can convert fuel into hydrogen, in kg/hr of hydrogen output.
Efficiency	The efficiency with which the electrolyzer converts the fuel to hydrogen, in %.
Schedule	This is the electrolyzer schedule, as can be defined in the schedule tab of the electrolyzer menu in the design view. Do not attempt to change it here.
Lifetime	The duration, in years, before the electrolyzer will be replaced. The replacement cost will be incurred at that time.
Minimum load ratio	The minimum output of the electrolyzer, as a percentage of the capacity. The electrolyzer can also turn off, and produce zero output.
Component requires one	If you check this box, users of this component will have to set the simulation time step to one minute in order to run a calculation.

minute time steps	Check this option if the component requires one-minute time steps to model the behavior accurately.

Costs

These inputs define the default value for the cost of the component.

Variable	Description
Cost matrix	Click the down arrow on the right end of the row to use the cost matrix editor to input rows to the cost matrix.
Cost multipliers (capital, replacement, O&M)	Sets the default value for the cost multiplier sensitivity variables. In most cases these should all be left set to 1.

Physical Dimensions

These inputs specify the size and weight of the component. If "Weight minimization" mode is selected in the **System Control** menu, the weight parameter will be used in the calculation. Otherwise these values are for reference only.

Variable	Description
Footprint	The surface area occupied by the free-standing component, in m^2.
Volume	The volume in m^3.
Weight	The total weight of the component in kg. Optionally this can include all associated equipment for transportation and deployment of the component, for weight minimization mode.

Fuel

You can select the default fuel resource used by this component. When the electrolyzer is added to a model in the design view, you can change the fuel resource to reflect that of the actual installation.

See also

2.2.12 Electrolyzer
7.37 Component Library

4.1.12 Hydrogen Tank

This window lets you view or specify the properties of library hydrogen tanks. You can create a new hydrogen tank from scratch or by copying an existing one. Change the properties as required and give the new hydrogen tank a unique name to distinguish it from others. HOMER will add this new hydrogen tank to your component library when you click OK. The new hydrogen tank will then appear in the list of available hydrogen tank types on the hydrogen tank window.

General Properties

Variable	Description

Abbreviation	A short, distinctive name to identify this hydrogen tank on the schematic and in the results. There isn't a specific limit on the abbreviation length, but long abbreviated names will not fit well on the schematic or results.
Manufacturer	An optional field used to specify the manufacturer of the hydrogen tank
Name	A unique name used to identify this type of hydrogen tank
Notes	An optional field used to specify manufacturer contact information, prices, or anything noteworthy
Website	An optional field to hold the website of the manufacturer
Url	The actual web address of the link defined in the "Website" input

Other Properties

Variable	Description
Absolute tank level (kg)	The initial tank level, if the initial tank level is specified as an absolute value in kg (see "Relative tank level" input below).
AC	Not used.
Capacity (kg)	The maximum amount of hydrogen that the tank can store, in kg.
Lifetime	The duration, in years, before the hydrogen tank will be replaced. The replacement cost will be incurred at that time.
Relative tank level (%)	The initial tank level, if the initial tank level is specified as a percent of capacity (see "Absolute tank level" input above).
Require year end tank level to equal or exceed initial tank level	If this input is checked, simulations with a lower tank level at the end of the year are infeasible.
Use absolute tank level	Selects absolute or relative tank level to specify the initial tank level. If this box is checked, the absolute tank level input will be used to set the initial tank level.
Component requires one minute time steps	If you check this box, users of this component will have to set the simulation time step to one minute in order to run a calculation. Check this option if the component requires one-minute time steps to model the behavior accurately.

Costs

These inputs define the default value for the cost of the component.

Variable	Description
Cost matrix	Click the down arrow on the right end of the row to use the cost matrix editor to input rows to the cost matrix.

Cost multipliers (capital, replacement, O&M)	Sets the default value for the cost multiplier sensitivity variables. In most cases these should all be left set to 1.

Physical Dimensions

These inputs specify the size and weight of the component. If "Weight minimization" mode is selected in the **System Control** menu, the weight parameter will be used in the calculation. Otherwise these values are for reference only.

Variable	Description
Footprint	The surface area occupied by the free-standing component, in m^2.
Volume	The volume in m^3.
Weight	The total weight of the component in kg. Optionally this can include all associated equipment for transportation and deployment of the component, for weight minimization mode.

See also

2.2.11 Hydrogen Tank

7.37 Component Library

4.2 Resources Library

The resources library contains saved resource definitions, and allows you to specify new resources. In this initial HOMER Pro release, only Fuels are implemented in the resource library. You can specify new fuels here, and access them from the Fuels dropdown menu in the Generator component. Solar, Wind, Temperature, Hydro and Biomass library resources are forthcoming.

4.2.1 Create a New Fuel

HOMER Pro users can create new fuels with specific properties. The properties are initially copied from the fuel that was selected when you clicked the New button. Change the properties as required and give the new fuel a unique name to distinguish it from others. HOMER will add this new fuel to your **component library** when you click OK. The new fuel will then be included in the list of available fuel types on the **Generator** and **Boiler** windows.

Variable	Description
Name	A unique name for the fuel
Lower Heating Value	The energy released per kg of fuel consumed
Density	Density in kg/m3 (the density of water is 1000 kg/m3)

Carbon Content	The mass-based carbon content of the fuel, in %
Sulfur Content	The mass-based sulfur content of the fuel, in %
Units	The preferred units for amount and price of the fuel
Bio Fuel Source	If this box is checked, this fuel can only be produced by the Biomass Resource.
Stored Hydrogen	If this box is checked, the fuel can only be used be components that can connect to the hydrogen bus.
External fuel	Read only. This value is TRUE unless "Bio Fuel Source" or "Stored Hydrogen" is selected.
Limit Quantity	Components using this fuel will not operate once the total system consumption exceeds the value set in "Quantity Available". This input is ignored if "Bio Fuel" or "Stored Hydrogen" is selected.
Quantity available	The maximum quantity of fuel the system can use per year. This input is only used if "Limit quantity" is selected. This input is ignored if the fuel is not an "External Fuel".
Fuel Price	Default price for this fuel. Once the fuel is added to a model, the fuel price or sensitivity values can be chosen for the scenario in the model.

4.3 Grid Library

The grid library contains saved definitions of custom grid configurations. Here you can view existing grid definitions, modify advanced grid parameters, and save new grid definitions that you can quickly add to any model.

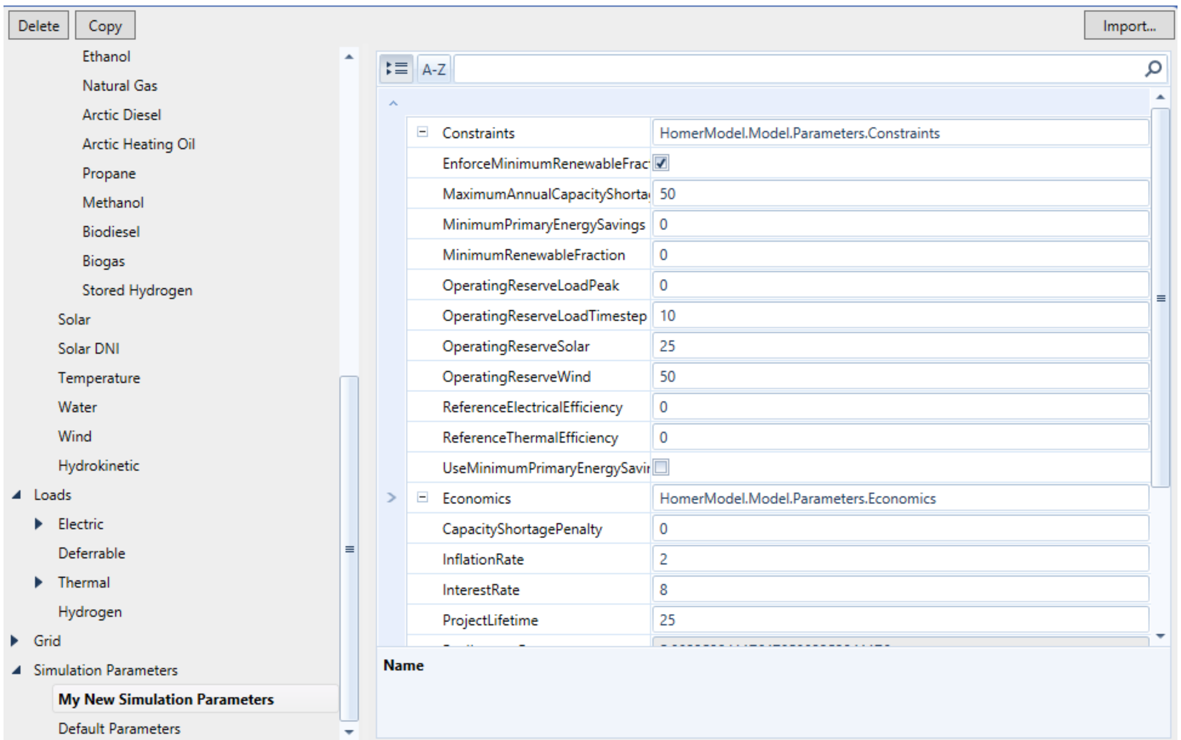
See also

2.2.10.1 Simple Rates

4.4 Simulation Parameters Library

The simulation parameters library contains preset saved configurations for simulations. Here you can view existing simulation parameter sets, modify existing ones, and save new definitions that you can quickly set on any model.

You can use this library to create your own default settings. First copy an existing simulation parameters entry or create a new on from scratch. Adjust the settings as desired. Then, as described for Batteries in the main **library help page**, click on "Simulation Parameters" and change the entry in the drop down menu to the right of the library tree.



The parameters here correspond to those in the **Project Set Up**.

See also

2.4 Project Tab

5. HOMER's Calculations

5.1 How HOMER Calculates the PV Array Power Output

HOMER uses the following equation to calculate the output of the PV array:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right]$$

where
:

Y_{PV}	is the rated capacity of the PV array, meaning its power output under **standard test conditions** [kW]
f_{PV}	is the **PV derating factor** [%]
$\overline{G}_T$	is the **solar radiation incident on the PV array** in the current time step [kW/m^2]
$\overline{G}_{T,STC}$	is the incident radiation at **standard test conditions** [1 kW/m^2]
$?_P$	is the **temperature coefficient of power** [%/°C]
T_c	is the **PV cell temperature** in the current time step [°C]

$T_{c,STC}$ is the PV cell temperature under **standard test conditions** [25 °C]

If, on the PV window, you choose not to model the effect of temperature on the PV array, HOMER assumes that the temperature coefficient of power is zero, so that the above equation simplifies to:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right)$$

See also

2.2.2 Photovoltaic Panels (PV)
5.8 How HOMER Calculates the PV Cell Temperature
5.9 How HOMER Calculates the Radiation Incident on the PV Array
7.124 PV Derating Factor
7.128 PV Temperature Coefficient of Power
7.156 Standard Test Conditions

5.2 Beacon Power Smart Energy 25 Flywheel

The Smart Energy 25 is a 25 kWh, 100 kW carbon fiber flywheel. It is an AC device, but HOMER will connect it to the DC bus because it cannot model AC electrical storage. To model this flywheel in HOMER, you should add a converter, but make it free, 100% efficient, and larger than the aggregate capacity of the largest number of flywheels that you are considering.

HOMER requires you to use 1-minute time steps (set in the **System Control** menu) to properly model the fast behavior of the Beacon Flywheel. If your system also includes PV, we recommend modeling the PV as an AC device with the inverter costs and losses included with the PV module.

In a hybrid power application, energy storage provides a buffer so that diesel generators can be turned off and remain off during short lulls in the wind or passing clouds. To maximize this benefit HOMER may use the full range of the energy storage device's state of charge before turning on another generator and recharging the device close to 100% state of charge.

5.3 How HOMER Calculates Emissions

HOMER calculates the emissions of the following six pollutants:

Pollutant	Description
Carbon Dioxide (CO_2)	Nontoxic greenhouse gas.
Carbon Monoxide (CO)	Poisonous gas produced by incomplete burning of carbon in fuels. Prevents delivery of oxygen to the body's organs and tissues, causing headaches, dizziness, and impairment of visual perception, manual

	dexterity, and learning ability.
Unburned Hydrocarbons (UHC)	Products of incomplete combustion of hydrocarbon fuel, including formaldehyde and alkenes. Lead to atmospheric reactions causing photochemical smog.
Particulate Matter (PM)	A mixture of smoke, soot, and liquid droplets that can cause respiratory problems and form atmospheric haze.
Sulfur Dioxide (SO_2)	A corrosive gas released by the burning of fuels containing sulfur (like coal, oil and diesel fuel). Cause respiratory problems, acid rain, and atmospheric haze.
Nitrogen Oxides (NO_x)	Various nitrogen compounds like nitrogen dioxide (NO_2) and nitric oxide (NO) formed when any fuel is burned at high temperature. These compounds lead to respiratory problems, smog, and acid rain.

Emissions of these pollutants result from:

- the production of electricity by the generator(s)
- the production of thermal energy by the boiler
- the consumption of grid electricity

HOMER models the emissions of the generators and the boiler in a similar way, since both consume fuel of known properties. It models the grid slightly differently. This article will first cover how HOMER calculates the emissions of the generators and boiler, then how it calculates the emissions from the grid.

Generators, Boiler, and Reformer

Before simulating the power system, HOMER determines the emissions factor (kg of pollutant emitted per unit of fuel consumed) for each pollutant. After the simulation, it calculates the annual emissions of that pollutant by multiplying the emissions factor by the total annual fuel consumption.

You directly specify the emissions factors for four of the six pollutants: carbon monoxide, unburned hydrocarbons, particulate matter, and nitrogen oxides. Using these values and the carbon and sulfur content of the fuel, HOMER does some calculations to find the emissions factors for the two remaining pollutants: carbon dioxide and sulfur dioxide. In doing so, HOMER uses three principal assumptions:

1. Any carbon in the fuel that does not get emitted as carbon monoxide or unburned hydrocarbons gets emitted as carbon dioxide.
2. The carbon fraction of the unburned hydrocarbon emissions is the same as that of the fuel.
3. Any sulfur in the *burned* fuel that does not get emitted as particulate matter gets emitted as sulfur dioxide.

Grid

In simulating a grid-connected system, HOMER calculates the net grid purchases, equal to the total grid purchases minus the total grid sales. To calculate the emissions of each pollutant associated with these net grid purchases, HOMER multiplies the net grid purchases (in kWh) by the emission factor (in g/kWh) for each pollutant. If the system sells more power to the grid than it buys from the grid over the year, the net grid purchases will be negative and so will the grid-related emissions of each pollutant.

5.4 How HOMER Calculates the Hydro Power Output

In each time step, HOMER calculates the electrical power output of the hydro turbine using the following equation:

$$P_{hyd} = \frac{\eta_{hyd} \cdot \rho_{water} \cdot g \cdot h_{net} \cdot \dot{Q}_{turbine}}{1000\ W/kW}$$

where
:

P_{hyd} = power output of the hydro turbine [kW]

η_{hyd} = **hydro turbine efficiency** [%]

ρ_{water} = density of water [1000 kg/m^3]

g = acceleration due to gravity [9.81 m/s^2]

h_{net} = **effective head** [m]

$\dot{Q}_{turbine}$ = **hydro turbine flow rate** [m^3/s]

See also

7.107 Nominal Hydro Power

5.5 How HOMER Calculates Clearness Index

On the Solar Resource window, for each month of the year you can enter the average radiation for the month. Based on the value of the average radiation, the month of the year, and the latitude, HOMER calculates the clearness index. This article describes the relationship between the two variables, and how HOMER calculates clearness index from the global horizontal radiation (GHI).

The **clearness index** is a dimensionless number between 0 and 1 indicating the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface. The following equation defines the monthly average clearness index:

$$K_T = \frac{H_{ave}}{H_{o,ave}}$$

where
:

H_{ave} is the monthly average radiation on the horizontal surface of the earth [kWh/m^2/day]

$H_{o,ave}$ is the *extraterrestrial horizontal radiation*, meaning the radiation on a horizontal surface at the top of the earth's atmosphere [kWh/m^2/day]

For a given latitude, we can calculate $H_{o,ave}$ for any month of the year. So if we know either H_{ave} or K_T , we can calculate the other using the above equation. HOMER does exactly that every time you enter a value into the monthly data table on the Solar Resource Inputs window. If you enter an average radiation value, HOMER will calculate the corresponding clearness index.

The rest of this article describes how HOMER calculates $H_{o,ave}$, the monthly average extraterrestrial radiation.

As described in more detail in the article on calculating the radiation incident on the PV array, HOMER uses the following equation to calculate the intensity of solar radiation at the top of the Earth?s atmosphere:

$$G_{on} = G_{sc}\left(1 + 0.033 \cdot \cos\frac{360n}{365}\right)$$

where
:

G_{sc} is the solar constant [1.367 kW/m^2]

n is the day of the year [a number between 1 and 365]

The equation above gives the extraterrestrial radiation on a surface normal to the sun's rays. To calculate the extraterrestrial radiation on the *horizontal* surface, HOMER uses the following equation:

$$G_o = G_{on}\cos\theta_Z$$

where
:

θ_Z is the zenith angle [?]

HOMER calculates the zenith angle using the following equation:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$$

where
:

ϕ is the latitude [?]

δ is the solar declination [?]

ω is the hour angle [?]

HOMER calculates the solar declination according to the following equation:

$$\delta = 23.45^\circ \sin\left(360^\circ \frac{284+n}{365}\right)$$

where
:

n is the day of the year [a number between 1 and 365]

We can find the total daily extraterrestrial radiation per square meter by integrating the equation for G_o from sunrise to sunset. This integration gives the following equation:

$$H_o = \frac{24}{\pi} G_{on} \left[\cos\phi \cos\delta \sin\omega_s + \frac{\pi\omega_s}{180^\circ} \sin\phi \sin\delta \right]$$

where
:

H_o is the average extraterrestrial horizontal radiation for the day [kWh/m²/day]

ω_s is the sunset hour angle [?]

HOMER calculates the sunset hour angle using the following equation:

$$\cos\omega_s = -\tan\phi \tan\delta$$

HOMER calculates H_o for each day of the month, and finds the average for the month as follows:

$$H_{o,ave} = \frac{\sum_{n=1}^{N} H_o}{N}$$

where
:

$H_{o,ave}$ is the average extraterrestrial horizontal radiation for the month [kWh/m²/day]

N is the number of days in the month

If you enter the monthly average global solar radiation, HOMER divides it by $H_{o,ave}$ to find the monthly average clearness index.

See also

2.2.2 Photovoltaic Panels (PV)
5.9 How HOMER Calculates the Radiation Incident on the PV Array
7.33 Clearness Index

5.6 How HOMER Calculates the Maximum Battery Charge Power

In each time step, HOMER calculates the maximum amount of power that the storage bank can absorb. It uses this "maximum charge power" when making decisions such as whether the storage can absorb all available surplus renewable power, or how much surplus power a cycle charging generator should produce. The maximum charge power varies from one time step to the next according to its state of charge and its recent charge and discharge history.

HOMER imposes three separate limitations on the storage bank's maximum charge power. The first limitation comes from the kinetic storage model. As described in the article on the **kinetic storage model**, the maximum amount of power that can be absorbed by the two-tank system is given by the following equation:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)}$$

where

Q_1 is the available energy [kWh] in the storage at the beginning of the time step,

Q is the total amount of energy [kWh] in the storage at the beginning of the time step,

c is the storage capacity ratio [unitless],

k is the storage rate constant [h^{-1}], and

Δt is the length of the time step [h].

The second limitation relates to the **maximum charge rate** of the storage, which is the A/Ah value visible on the **storage details window**. The storage charge power corresponding to this maximum charge rate is given by the following equation:

$$P_{batt,cmax,mcr} = \frac{\left(1 - e^{-\alpha_c \Delta t}\right)\left(Q_{\max} - Q\right)}{\Delta t}$$

where

α_c is the storage's maximum charge rate [A/Ah], and

Q_{max} is the total capacity of the storage bank [kWh].

The third limitation relates to the storage's maximum charge current, which also appears on the storage details window. The maximum storage bank charge power corresponding to this maximum charge current is given by the following equation:

$$P_{batt,cmax,mcc} = \frac{N_{batt} I_{max} V_{nom}}{1000}$$

where

N_{batt} is the number of batteries in the storage bank,

I_{max} is the storage's maximum charge current [A], and

V_{nom} is the storage's nominal voltage [V].

HOMER sets the maximum storage charge power equal to the least of these three values, assuming each applies after charging losses, hence:

$$P_{batt,cmax} = \frac{\mathrm{MIN}\left(P_{batt,cmax,kbm}, P_{batt,cmax,mcr}, P_{batt,cmax,mcc}\right)}{\eta_{batt,c}}$$

where $\eta_{batt,c}$ is the **storage charge efficiency**.

See also

5.7 How HOMER Calculates the Maximum Battery Discharge Power

5.13 Kinetic Battery Model

5.7 How HOMER Calculates the Maximum Battery Discharge Power

In each time step, HOMER calculates the maximum amount of power that the storage bank can discharge. It uses this "maximum discharge power" when making decisions such as whether the storage can serve the load on its own. The maximum discharge power varies from one time step to the next according to its state of charge and its recent charge and discharge history, as determined by the kinetic storage model.

As described in the article on the **kinetic storage model**, the maximum amount of power that the storage bank can discharge over a specific length of time is given by the following equation:

$$P_{batt,dmax,kbm} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)}$$

where

Q_1 is the available energy [kWh] in the storage at the beginning of the time step,

Q is the total amount of energy [kWh] in the storage at the beginning of the time step,

Q_{max} is the total capacity [kWh] of the storage bank,

c is the storage capacity ratio [unitless],

k is the storage rate constant [h^{-1}], and

Δt is the length of the time step [h].

HOMER assumes that the discharging losses occur after the energy leaves the two-tank system, hence the storage bank's maximum discharge power is given by the following equation:

$$P_{batt,dmax} = \eta_{batt,d} \, P_{batt,dmax,kbm}$$

where $\eta_{batt,d}$ is the **storage discharge efficiency**.

Modified Kinetic Model

In the **Modified Kinetic Battery Model**, the losses are modeled with a series resistor. The output power for a given current, I, is defined by the following relation:

$$P_{out} = V_0 I - R_0 I^2$$

In the above equation, P_{out} is the output power, V_0 is the nominal voltage, and R_0 is the series resistance. Intuitively we can judge that the term $R_0 I^2$ is the loss in the resistor. The circuit behavior also leads to a maximum possible output power. At higher currents, the I^2 term begins to dominate, and the output power actually decreases with increasing current. We can find the current at this point by setting the derivative dP_{out}/dI to zero:

$$I_{Pout,max} = V_0 / (2 R_0)$$

For the modified kinetic battery model, this limit applies at all times, in addition to the kinetic battery model limit described in the previous section.

See also

5.6 How HOMER Calculates the Maximum Battery Charge Power
5.13 Kinetic Battery Model

5.8 How HOMER Calculates the PV Cell Temperature

The PV cell temperature is the temperature of the surface of the PV array. During the night it is the same as the ambient temperature, but in full sun the cell temperature can exceed the ambient temperature by 30?C or more.

If in the PV Array inputs window you choose to consider the effect of temperature on the PV array, then HOMER will calculate the cell temperature in each time step, and use that in calculating the power output of the PV array. This article describes how HOMER calculates the cell temperature from the ambient temperature and the radiation striking the array.

We start by defining an energy balance for the PV array, using the following equation from **Duffie and Beckman (1991)**:

$$\tau\alpha G_T = \eta_c G_T + U_L (T_c - T_a)$$

where
:

τ is the **solar transmittance** of any cover over the PV array [%]

α is the **solar absorptance** of the PV array [%]

G_T is the solar radiation striking the PV array [kW/m^2]

η_c is the electrical conversion efficiency of the PV array [%]

U_L is the coefficient of heat transfer to the surroundings [kW/m^2?C]

T_c is the PV cell temperature [?C]

T_a is the ambient temperature [?C]

The above equation states that a balance exists between, on one hand, the solar energy absorbed by the PV array, and on the other hand, the electrical output plus the heat transfer to the surroundings. We can solve that equation for cell temperature to yield:

$$T_c = T_a + G_T \left(\frac{\tau\alpha}{U_L} \right) \left(1 - \frac{\eta_c}{\tau\alpha} \right)$$

It is difficult to measure the value of (*??* / U_L) directly, so instead manufacturers report the nominal operating cell temperature (NOCT), which is defined as the cell temperature that results at an incident radiation of 0.8 kW/m^2, an ambient temperature of 20?C, and no load operation (meaning η_c = 0). We can substitute these values into the above equation and solve it for *??*/U_L to yield the following equation:

$$\frac{\tau\alpha}{U_L} = \frac{T_{c,NOCT} - T_{a,NOCT}}{G_{T,NOCT}}$$

where
:

$T_{c,NOCT}$ is the **nominal operating cell temperature** [?C]

$T_{a,NOCT}$ is the ambient temperature at which the NOCT is defined [20?C]

$G_{T,NOCT}$ is the solar radiation at which the NOCT is defined [0.8 kW/m^2]

If we assume that $\tau\alpha/U_L$ is constant, we can substitute this equation into the cell temperature equation to yield:

$$T_c = T_a + G_T \left(\frac{T_{c,NOCT} - T_{a,NOCT}}{G_{T,NOCT}} \right) \left(1 - \frac{\eta_c}{\tau\alpha} \right)$$

HOMER assumes a value of 0.9 for $\tau\alpha$ in the above equation, as **Duffie and Beckman (1991)** suggest. Since the term $\eta_c / \tau\alpha$ is small compared to unity, this assumption does not introduce significant error.

HOMER assumes that the PV array always operates at its maximum power point, as it would if it were controlled by a maximum power point tracker. That means HOMER assumes the cell efficiency is always equal to the maximum power point efficiency:

$$\eta_c = \eta_{mp}$$

where
:

η_{mp} is the efficiency of the PV array at its maximum power point [%]

So in the equation for cell temperature we can replace η_c with η_{mp} to yield:

$$T_c = T_a + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left(1 - \frac{\eta_{mp}}{\tau\alpha}\right)$$

But η_{mp} depends on the cell temperature T_c. HOMER assumes that the efficiency varies linearly with temperature according to the following equation:

$$\eta_{mp} = \eta_{mp,STC}\left[1 + \alpha_P\left(T_c - T_{c,STC}\right)\right]$$

where
:

$\eta_{mp,STC}$ is the **maximum power point efficiency under standard test conditions** [%]

α_P is the **temperature coefficient of power** [%/?C]

$T_{c,STC}$ is the cell temperature under **standard test conditions** [25?C]

The temperature coefficient of power is normally negative, meaning that the efficiency of the PV array decreases with increasing cell temperature.

We can substitute this efficiency equation into the preceding cell temperature equation and solve for cell temperature to yield:

$$T_c = \frac{T_a + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left[1 - \frac{\eta_{mp,STC}\left(1 - \alpha_P T_{c,STC}\right)}{\tau\alpha}\right]}{1 + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_P \eta_{mp,STC}}{\tau\alpha}\right)}$$

The temperatures in the above equation must be in Kelvin. HOMER uses this equation to calculate the cell temperature in each time step.

See also

2.2.2 Photovoltaic Panels (PV)
5.1 How HOMER Calculates the PV Array Power Output
5.9 How HOMER Calculates the Radiation Incident on the PV Array
7.126 PV Nominal Operating Cell Temperature
7.156 Standard Test Conditions

5.9 How HOMER Calculates the Radiation Incident on the PV Array

The Solar GHI resource window allows you to specify the *global horizontal radiation* (GHI) for each time step in the HOMER simulation. The GHI is the total amount of solar radiation striking the horizontal surface on the earth. But the power output of the PV array depends on the amount of radiation striking the surface of the PV array, which in general is not horizontal. So in each time step, HOMER must calculate the global solar radiation incident on the surface of the PV array. This article describes that process, which is based on the methods in the first two chapters of **Duffie and Beckman (1991)**

We can describe the orientation of the PV array using two parameters: a slope, and an azimuth. The slope is the angle formed between the surface of the panel and the horizontal, so a slope of zero indicates a horizontal orientation, whereas a 90° slope indicates a vertical orientation. The azimuth is the direction towards which the surface faces. HOMER uses the convention whereby zero azimuth corresponds to due south, and positive values refer to west-facing orientations. So an azimuth of -45° corresponds to a southeast-facing orientation, and an azimuth of 90° corresponds to a west-facing orientation.

The other factors relevant to the geometry of the situation are the latitude, the time of year, and the time of day. The time of year affects the solar declination, which is the latitude at which the sun's rays are perpendicular to the earth's surface at solar noon. HOMER uses the following equation to calculate the solar declination:

$$\delta = 23.45^\circ \sin\left(360^\circ \frac{284+n}{365}\right)$$

where
:

n is the day of the year [a number 1 through 365]

The time of day affects the location of the sun in the sky, which we can describe by an hour angle. HOMER uses the convention whereby the hour angle is zero at solar noon (the time of day at which the sun is at its highest point in the sky), negative before solar noon, and positive after solar noon. HOMER uses the following equation to calculate the hour angle:

$$\omega = (t_s - 12\text{hr}) \cdot 15°/\text{hr}$$

where
:

t_s is the solar time [hr]

The value of t_s is 12hr at solar noon, and 13.5hr ninety minutes later. The above equation follows from the fact that the sun moves across the sky at 15 degrees per hour.

HOMER assumes that all time-dependent data, such as solar radiation data and electric load data, are specified not in solar time, but in *civil time* (also called local standard time). HOMER calculates solar time from civil time using the following equation:

$$t_s = t_c + \frac{\lambda}{15°/\text{hr}} - Z_c + E$$

where
:

t_c is the civil time in hours corresponding to the midpoint of the time step [hr]

λ is the longitude [°]

Z_c is the time zone in hours east of GMT [hr]

E is the equation of time [hr]

Note that west longitudes are negative, and time zones west of GMT are negative as well.

The equation of time accounts for the effects of obliquity (the tilt of the earth's axis of rotation relative to the plane of the ecliptic) and the eccentricity of the earth's orbit. HOMER calculates the equation of time as follows:

$$E = 3.82\begin{pmatrix} 0.000075 + 0.001868 \cdot \cos B - 0.032077 \cdot \sin B \\ - 0.014615 \cdot \cos 2B - 0.04089 \cdot \sin 2B \end{pmatrix}$$

where B is given by:

$$B = 360° \frac{(n-1)}{365}$$

where n is the day of the year, starting with 1 for January 1st.

Now, for a surface with any orientation, we can define the angle of incidence, meaning the angle between the sun's beam radiation and the normal to the surface, using the following equation:

$$\cos\theta = \sin\delta\sin\phi\cos\beta$$
$$-\sin\delta\cos\phi\sin\beta\cos\gamma$$
$$+\cos\delta\cos\phi\cos\beta\cos\omega$$
$$+\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega$$
$$+\cos\delta\sin\beta\sin\gamma\sin\omega$$

where
:

ϑ is the angle of incidence [°]

β is the slope of the surface [°]

γ is the azimuth of the surface [°]

ϕ is the latitude [°]

δ is the solar declination [°]

ω is the hour angle [°]

An incidence angle of particular importance, which we will need shortly, is the *zenith angle*, meaning the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead, and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find a equation for the zenith angle by setting ? = 0° in the above equation, which yields:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$$

where
:

ϑ_z is the zenith angle [°]

Now we turn to the issue of the amount of solar radiation arriving at the top of the atmosphere over a particular point on the earth's surface. HOMER assumes the output of the sun is constant in time. But the amount of sunlight striking the top of the earth's atmosphere varies over the year because the distance between the sun and the earth varies over the year due to the eccentricity of earth's orbit. To calculate the *extraterrestrial normal radiation*, defined as the amount of solar radiation striking a surface normal (perpendicular) to the sun's rays at the top of the earth's atmosphere, HOMER uses the following equation:

$$G_{on} = G_{sc}\left(1 + 0.033 \cdot \cos\frac{360n}{365}\right)$$

where
:

G_{on} is the extraterrestrial normal radiation [kW/m^2]

G_{sc} *is the solar constant [1.367 kW/m²]*

n *is the day of the year [a number between 1 and 365]*

To calculate the *extraterrestrial horizontal radiation*, defined as the amount of solar radiation striking a horizontal surface at the top of the atmosphere, HOMER uses the following equation:

$$G_o = G_{on} \cos\theta_Z$$

where
:

G_o *is the extraterrestrial horizontal radiation [kW/m²]*

G_{on} *is the extraterrestrial normal radiation [kW/m²]*

θ_z *is the zenith angle [°]*

Since HOMER simulates on a time step by time step basis, we integrate the above equation over one time step to find the average extraterrestrial horizontal radiation over the time step:

$$\overline{G_o} = \frac{12}{\pi} G_{on} \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1 \right) + \frac{\pi(\omega_2 - \omega_1)}{180°} \sin\phi \sin\delta \right]$$

where
:

$\overline{G_o}$ *is the extraterrestrial horizontal radiation averaged over the time step [kW/m²]*

G_{on} *is the extraterrestrial normal radiation [kW/m²]*

ω_1 *is the hour angle at the beginning of the time step [°]*

ω_2 *is the hour angle at the end of the time step [°]*

The above equation gives the average amount of solar radiation striking a horizontal surface at the top of the atmosphere in any time step. The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. The ratio of the surface radiation to the extraterrestrial radiation is called the **clearness index**. The following equation defines the clearness index:

$$k_T = \frac{\overline{G}}{\overline{G_o}}$$

where
:

$\overline{G}$ *is the global horizontal radiation on the earth's surface averaged over the time step [kW/m²]*

$\overline{G_o}$ *is the extraterrestrial horizontal radiation averaged over the time step [kW/m²]*

Now let us look more closely at the solar radiation on the earth's surface. Some of that radiation is *beam radiation*, defined as solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere. Beam radiation (sometimes called direct radiation) casts a shadow. The rest of the radiation is *diffuse radiation*, defined as solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast a shadow. The sum of beam and diffuse radiation is called global solar radiation, a relation expressed by the following equation:

$$\overline{G} = \overline{G}_b + \overline{G}_d$$

where

:

$\overline{G}_b$ *is the beam radiation [kW/m²]*

$\overline{G}_d$ *is the diffuse radiation [kW/m²]*

The distinction between beam and diffuse radiation is important when calculating the amount of radiation incident on an inclined surface. The orientation of the surface has a stronger effect on the beam radiation, which comes from only one part of the sky, than it does on the diffuse radiation, which comes from all parts of the sky.

However, in most cases we measure only the global horizontal radiation, not its beam and diffuse components. For that reason, HOMER expects you to enter global horizontal radiation in HOMER's Solar Resource Inputs window. That means that in every time step, HOMER must resolve the global horizontal radiation into its beam and diffuse components to find the radiation incident on the PV array. For this purpose HOMER uses correlation of **Erbs et al. (1982)**, which gives the *diffuse fraction* as a function of the clearness index as follows:

$$\frac{\overline{G}_d}{\overline{G}} = \begin{cases} 1.0 - 0.09 \cdot k_T & \text{for } k_T \le 0.22 \\ 0.9511 - 0.1604 \cdot k_T + 4.388 \cdot k_T^2 - 16.638 \cdot k_T^3 + 12.336 \cdot k_T^4 & \text{for } 0.22 < k_T \le 0.80 \\ 0.165 & \text{for } k_T > 0.80 \end{cases}$$

For each time step, HOMER uses the average global horizontal radiation to calculate the clearness index, then the diffuse radiation. It then calculates the beam radiation by subtracting the diffuse radiation from the global horizontal radiation.

We are now almost ready to calculate the global radiation striking the tilted surface of the PV array. For this purpose HOMER uses the HDKR model, which assumes that there are three components to the diffuse solar radiation: an isotropic component which comes all parts of the sky equally, a circumsolar component which emanates from the direction of the sun, and a horizon brightening component which emanates from the horizon. Before applying that model we must first define three more factors.

The following equation defines R_b, the ratio of beam radiation on the tilted surface to beam radiation on the horizontal surface:

$$R_b = \frac{\cos\theta}{\cos\theta_z}$$

The anisotropy index, with symbol A_i, is a measure of the atmospheric transmittance of beam radiation. This factor is used to estimate the amount of circumsolar diffuse radiation, also called forward scattered radiation. The anisotropy index is given by the following equation:

$$A_i = \frac{\overline{G}_b}{\overline{G}_o}$$

The final factor we need to define is a factor used to account for 'horizon brightening', or the fact that more diffuse radiation comes from the horizon than from the rest of the sky. This term is related to the cloudiness and is given by the following equation:

$$f = \sqrt{\frac{\overline{G}_b}{\overline{G}}}$$

The HDKR model calculates the global radiation incident on the PV array according to the following equation:

$$\overline{G}_T = \left(\overline{G}_b + \overline{G}_d A_i\right) R_b + \overline{G}_d \left(1 - A_i\right)\left(\frac{1+\cos\beta}{2}\right)\left[1 + f\sin^3\left(\frac{\beta}{2}\right)\right] + \overline{G}\rho_g\left(\frac{1-\cos\beta}{2}\right)$$

where

:

β *is the slope of the surface [°]*

ρ_g *is the ground reflectance, which is also called the albedo [%]*

HOMER uses this quantity to calculate the cell temperature and the power output of the PV array.

See also

2.3.1 Solar GHI Resource
5.1 How HOMER Calculates the PV Array Power Output
5.8 How HOMER Calculates the PV Cell Temperature
7.33 Clearness Index

5.10 How HOMER Calculates Wind Turbine Power Output

HOMER calculates the power output of the wind turbine in each time step. This entails a three-step process to first calculate the wind speed at the hub height of the wind turbine, then to calculate how much power the wind turbine would produce at that wind speed at standard air density, then to adjust that power output value for the actual air density.

Calculating Hub Height Wind Speed

In each time step, HOMER calculates the wind speed at the hub height of the wind turbine using the inputs you specify in the Wind Resource window and the Wind Shear window.

If you choose to apply the logarithmic law, HOMER calculates the hub height wind speed using the following equation:

$$U_{hub} = U_{anem} \cdot \frac{\ln(z_{hub} / z_0)}{\ln(z_{anem} / z_0)}$$

where
:

U_{hub} = the wind speed at the hub height of the wind turbine [m/s]

U_{anem} = the wind speed at anemometer height [m/s]

z_{hub} = the hub height of the wind turbine [m]

z_{anem} = the **anemometer height** [m]

z_0 = the surface roughness length [m]

ln(..) = the natural logarithm

If you choose to apply the power law, HOMER calculates the hub height wind speed using the following equation:

$$U_{hub} = U_{anem} \cdot \left(\frac{z_{hub}}{z_{anem}} \right)^{\alpha}$$

where
:

U_{hub} = the wind speed at the hub height of the wind turbine [m/s]

U_{anem} = the wind speed at anemometer height [m/s]

z_{hub} = the hub height of the wind turbine [m]

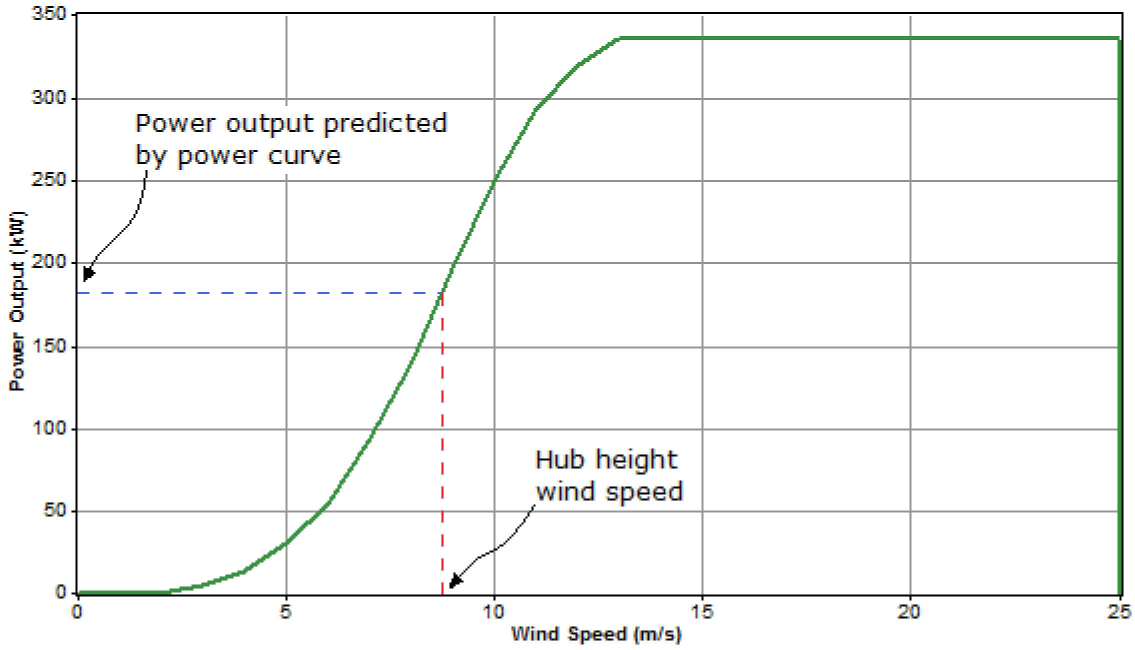
z_{anem} = the **anemometer height** [m]

α = the power law exponent

Calculating Turbine Power Output At Standard Air Density

Once HOMER has determined the hub height wind speed, it refers to the wind turbine's power curve to calculate the power output one would expect from that wind turbine at that wind speed under standard conditions of temperature and pressure. In the diagram below, the red dotted line indicates the hub height wind speed, and the blue dotted line indicates the wind turbine power output that the power curve predicts for that wind speed.

If the wind speed at the turbine hub height is not within the range defined in the power curve, the turbine will produce no power. This follows the assumption that wind turbines produce no power at wind speeds below the minimum cutoff or above the maximum cut-out wind speeds.



Applying Density Correction

Power curves typically specify wind turbine performance under conditions of standard temperature and pressure (STP). To adjust to actual conditions, HOMER multiplies the power value predicted by the power curve by the air density ratio, according to following equation:

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) \cdot P_{WTG,STP}$$

where
:

P_{WTG}	= the wind turbine power output [kW]
$P_{WTG,STP}$	= the wind turbine power output at standard temperature and pressure [kW]
ρ	= the actual air density [kg/m3]
ρ_0	= the air density at standard temperature and pressure (1.225 kg/m3)

See also

2.3.4 Wind Resource
2.3.4.2 Wind Resource Variation with Height
7.4 Altitude

5.11 Operation of a Co-fired Generator

A co-fired generator operates on a mixture of fossil fuel and **biogas**. In each time step, HOMER calculates the required output of the generator and the corresponding mass flow rates of fossil fuel and biogas. This calculation is based on several key assumptions:

Assumptions:

1. The biogas **substitution ratio** (z_{gas}) is a constant, independent of engine output power or fuel mixture.
2. The system will at all times attempt to maximize the use of biogas and minimize the use of fossil fuel.
3. The **fossil fraction** cannot go below a certain minimum.
4. Even if the derating factor associated with operating in dual-fuel mode is less than 100%, the generator can produce up to 100% of its rated power provided the fossil fraction is high enough.

The fuel curve of a co-fired generator defines the fuel consumption of the generator in pure fossil mode. So, the fossil fuel consumption in pure fossil mode is given by the following equation: (please see table of nomenclature below for a definition of all symbols)

$$\dot{m}_0 = \rho_{fossil}\left(F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}\right) \qquad (1)$$

And from assumption 1,

$$\dot{m}_0 = \dot{m}_{fossil} + \frac{\dot{m}_{gas}}{z_{gas}}$$

$$\therefore \qquad \dot{m}_{gas} = z_{gas}\left(\dot{m}_0 - \dot{m}_{fossil}\right) \qquad (2)$$

Where z_{gas} is the biogas **substitution ratio**. Now from the definition of the **fossil fraction**,

$$x_{fossil} \equiv \frac{\dot{m}_{fossil}}{\dot{m}_0} \qquad (3)$$

Using equations 2 and 3,

$$\dot{m}_{gas} = z_{gas}\left(\dot{m}_0 - x_{fossil}\dot{m}_0\right)$$

$$\therefore \qquad \dot{m}_{gas} = z_{gas}\dot{m}_0\left(1 - x_{fossil}\right) \qquad (4)$$

But for a given value of P_{bio}, the value of x_{fossil} is unknown so the above equation is not enough on its own to solve for the biogas flow rate. From assumption 2, we want to maximize $\dot{m}_{gas}$, which means we want to minimize x_{fossil}. But from assumption 3,

$$x^*_{fossil} \le x_{fossil} \le 1$$

where x^*_{fossil} is the **minimum fossil fraction** required for ignition. So the target value for $\dot{m}_{gas}$ corresponds to . Using equation 4,

$$\dot{m}^t_{gas} = z_{gas}\dot{m}_0\left(1 - x^*_{fossil}\right) \quad (5)$$

But there are two independent upper limits on the actual value of $\dot{m}_{gas}$. At the minimum fossil fraction, the output of the generator is limited to Y^*_{gen}, defined as follows:

$$Y^*_{gen} = \tau \cdot Y_{gen}$$

where τ, the **derating factor**, is less than or equal to 1. This limitation can be implemented by imposing an upper limit on $\dot{m}_{gas}$ corresponding to and . Using equations 1 and 4, this maximum value can be defined as:

$$\dot{m}^*_{gas} = z_{gas}\rho_{fossil}\left(F_0 \cdot Y_{gen} + F_1 \cdot Y^*_{gen}\right)\cdot\left(1 - x^*_{fossil}\right) \quad (6)$$

This upper limit can be thought of as a physical limitation -- the maximum rate at which biogas can be ingested in the engine. The available biomass resource, a_{gas}, constitutes the other upper limit on $\dot{m}_{gas}$. So the actual value of $\dot{m}_{gas}$ is the minimum of , $\dot{m}^*_{gas}$, and a_{gas}:

$$\dot{m}_{gas} = \text{MIN}\left(\dot{m}^t_{gas}, \dot{m}^*_{gas}, a_{gas}\right) \quad (7)$$

Knowing the value of $\dot{m}_{gas}$, we can determine x_{fossil}. Solving equation 4 for x_{fossil},

$$x_{fossil} = 1 - \frac{\dot{m}_{gas}}{z_{gas}\dot{m}_0} \quad (8)$$

And from equation 3,

$$\dot{m}_{fossil} = x_{fossil} \cdot \dot{m}_0 \quad (9)$$

So at any time step, given particular values of P_{bio} and a_{gas}, the biogas flow rate and the fossil fuel flow rate can be calculated from equations 7 and 9, respectively.

Table of Nomenclature

Symbol	Units	Description
ρ_{fossil}	kg/L	density of fossil fuel
τ	%	**generator derating factor**
a_{gas}	kg/hr	available biogas flow rate

$\dot{m}_0$	kg/hr	fossil fuel flow rate (in pure fossil mode)
$\dot{m}_{fossil}$	kg/hr	fossil fuel flow rate (in dual-fuel mode)
$\dot{m}_{gas}$	kg/hr	biogas flow rate (in dual-fuel mode)
$\dot{m}^{*}_{gas}$	kg/hr	maximum value of biogas flow rate
$\dot{m}^{t}_{gas}$	kg/hr	target value of biogas flow rate
x_{fossil}	%	**fossil fraction**
x^{*}_{fossil}	%	**minimum fossil fraction**
z_{gas}	none	biogas **substitution ratio**
F_0	L/hr/kW	**generator fuel curve intercept coefficient**
F_1	L/hr/kW	**generator fuel curve slope**
P_{gen}	kW	power output of the generator
Y^{*}_{gen}	kW	maximum output of generator at minimum fossil fraction
Y_{gen}	kW	rated capacity of the generator

5.12 How HOMER Creates the Generator Efficiency Curve

On the Generator Inputs window, when you enter the fuel curve inputs HOMER draws the corresponding efficiency curve. This article explains how HOMER creates that graph from the fuel curve inputs.

Fuel units

You may have noticed that the units of the fuel curve inputs sometimes change when you select a different fuel from the drop-down box. That's because in HOMER, fuels can be denominated in units of kg, L, or m^3. When you create a new fuel, you choose which units you want to use for that fuel. For example, you may choose to denominate liquid fuels (e.g. diesel, gasoline, ethanol) in L, and gaseous fuels (e.g. natural gas, hydrogen) in m^3. Once you have created a fuel, all the inputs that relate to that fuel will use the specified units. For example, if diesel fuel is denominated in L, then the price of diesel fuel will be in $/L and the fuel curve inputs for a diesel generator will be in L/hr/kW. Similarly, if natural gas is denominated in m^3 then its price will be in $\$/m^3$ and the fuel curve inputs for a natural gas engine will be in m^3/hr/kW. This article uses the term "units" to mean the units specified for the particular fuel, whether kg, L, or m^3. For example, "units/hr" means L/hr for a fuel denominated in L, and kg/hr for a fuel denominated in kg.

Fuel curve

The fuel curve describes the amount of fuel the generator consumes to produce electricity. HOMER assumes that the fuel curve is a straight line. The following equation gives the generator's fuel consumption in units/hr as a function of its electrical output:

$$F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}$$

where F_0 is the fuel curve intercept coefficient in units/hr/kW, F_1 is the fuel curve slope in units/hr/kW, Y_{gen} is the rated capacity of the generator in kW, and P_{gen} is the electrical output of the generator in kW.

Efficiency curve

In HOMER, we define the generator's electrical efficiency as the electrical energy coming out divided by the chemical energy of the fuel going in. The following equation gives this relationship:

$$\eta_{gen} = \frac{3.6 \cdot P_{gen}}{\dot{m}_{fuel} \cdot \mathrm{LHV}_{fuel}}$$

where P_{gen} is the electrical output in kW, m_{fuel} is the mass flow rate of the fuel in kg/hr and LHV_{fuel} is the lower heating value (a measure of energy content) of the fuel in MJ/kg. The factor of 3.6 arises because 1 kWh = 3.6 MJ.

The mass flow rate of the fuel is related to F, the generator's fuel consumption, but the exact relationship depends on the units of the fuel. If the fuel units are kg, then m_{fuel} and F are equal, so the equation for m_{fuel} is as follows:

$$\dot{m}_{fuel} = F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}$$

If the fuel units are L, the relationship between m_{fuel} and F involves the density. The equation for m_{fuel} is as follows:

$$\dot{m}_{fuel} = \rho_{fuel}\left(\frac{F}{1000}\right) = \frac{\rho_{fuel}\left(F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}\right)}{1000}$$

where ρ_{fuel} is the fuel density in kg/m^3. If the fuel units are m^3 the factor of 1000 is unnecessary, and the equation for m_{fuel} is as follows:

$$\dot{m}_{fuel} = \rho_{fuel} F = \rho_{fuel}\left(F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}\right)$$

Let us further develop the efficiency equation for the case where the fuel units are L. In this case, the efficiency equation becomes:

$$\eta_{gen} = \frac{3600 \cdot P_{gen}}{\rho_{fuel}\left(F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}\right) \cdot \mathrm{LHV}_{fuel}}$$

If we divide numerator and denominator by Y_{gen}, the capacity of the generator, and define a new symbol p_{gen} for the relative output of the generator ($p_{gen} = P_{gen}/Y_{gen}$) then the efficiency equation becomes:

$$\eta_{gen} = \frac{3600 \cdot p_{gen}}{\rho_{fuel}\left(F_0 + F_1 \cdot p_{gen}\right) \cdot \mathrm{LHV}_{fuel}}$$

That equation gives the efficiency of the generator as a function of its relative output. It is this relation that HOMER plots in the efficiency curve on the Generator Inputs window when the fuel units are L.

If the fuel units are m3, the efficiency equation becomes:

$$\eta_{gen} = \frac{3.6 \cdot p_{gen}}{\rho_{fuel}\left(F_0 + F_1 \cdot p_{gen}\right) \cdot \mathrm{LHV}_{fuel}}$$

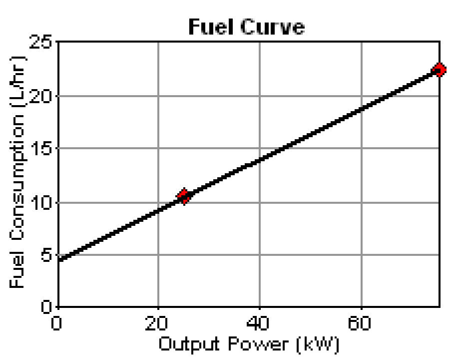
Finally, if the fuel units are kg, the efficiency equation becomes:

$$\eta_{gen} = \frac{3.6 \cdot p_{gen}}{\left(F_0 + F_1 \cdot p_{gen}\right) \cdot \mathrm{LHV}_{fuel}}$$

Example

For an example, let's analyze a 75 kW generator that burns diesel. Assume diesel has a density of 820 kg/m^3 and a lower heating value of 43.2 MJ/kg. If the generator consumes 22.5 L/hr at full load and 10.5 L/hr at 25 kW, what does its efficiency curve look like?

First we need to calculate the fuel curve slope and intercept coefficient. We assume (as we must in HOMER) that the fuel curve is a straight line passing through the two given points, as shown in the graph below.



Note that if we were given more than two points on this curve, we could calculate the line of best fit, using a linear regression technique for example. But, since we are given only two points, we can directly calculate the slope and intercept of the line that passes through those points.

We can find the slope and intercept of that line as follows:

$$\text{slope} = \frac{22.5\ \text{L/hr} - 10.5\ \text{L/hr}}{75\ \text{kW} - 25\ \text{kW}} = 0.24\ \text{L/hr/kW}$$

$$\text{intercept} = 10.5 \text{ L/hr} - (25 \text{ kW})(0.24 \text{ L/hr/kW}) = 4.5 \text{ L/hr}$$

Note that HOMER's first fuel curve input is not the intercept itself, but rather the intercept coefficient, defined as the intercept divided by the rated capacity of the generator. (This is so that HOMER can apply the fuel curve inputs to each generator size that you specify in the Sizes to consider table.) So the two fuel curve inputs are:

$$F_0 = \frac{\text{intercept}}{\text{rated output}} = \frac{4.5 \text{ L/hr}}{75 \text{ kW}} = 0.06 \text{ L/hr/kW}$$

$$F_1 = \text{slope} = 0.24 \text{ L/hr/kW}$$

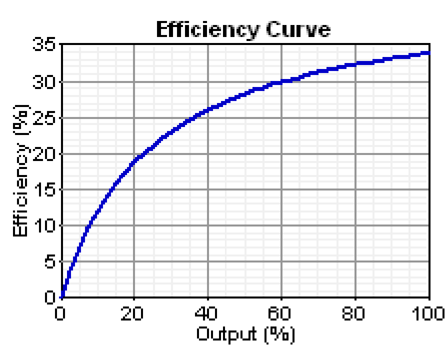
Since this is a liquid fuel denominated in L, the appropriate efficiency equation is:

$$\eta_{gen} = \frac{3600 \cdot p_{gen}}{\rho_{fuel}\left(F_0 + F_1 \cdot p_{gen}\right) \cdot \text{LHV}_{fuel}}$$

So we can substitute our values of density, lower heating value, and fuel curve as follows:

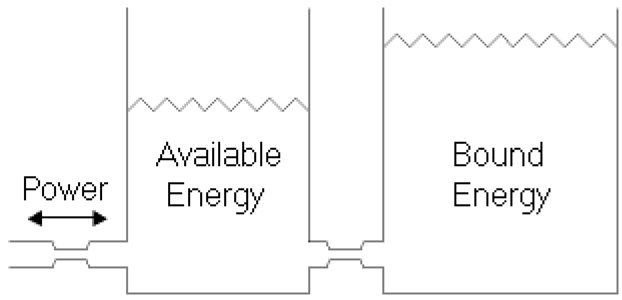
$$\eta_{gen} = \frac{3600 \cdot p_{gen}}{820\left(0.06 + 0.24 \cdot p_{gen}\right) \cdot 43.2}$$

Therefore the efficiency is 33.9% at full load (p_{gen}= 1), 28.2% at 50% load, 18.8% at 20% load, and 7.0% at 5% load. The efficiency curve is shown below:



5.13 Kinetic Battery Model

HOMER uses the Kinetic Battery Model (**Manwell and McGowan, 1993**) to determine the amount of energy that can be absorbed by or withdrawn from the storage bank each time step. The Kinetic Battery model, so named because it is based on the concepts of electrochemical kinetics, models a storage as a two tank system. The first tank contains "available energy", or energy that is readily available for conversion to DC electricity. The second tank contains "bound energy", or energy that is chemically bound and therefore not immediately available for withdrawal. The following diagram illustrates the concept:



Three parameters are used to describe this two tank system. The maximum (or theoretical) storage capacity (Q_{max}) is the total amount of energy the two tanks can contain. The capacity ratio (c) is the ratio of the size of the available energy tank to the combined size of both tanks. The rate constant (k) relates to the conductance between the two tanks, and is therefore a measure of how quickly the storage can convert bound energy to available energy or vice-versa. HOMER determines these three parameters from the storage's capacity curve, which you specify in the **Storage library** view.

The total amount of energy stored in the storage at any time is the sum of the available and bound energy, hence:

$$Q = Q_1 + Q_2$$

where Q_1 is the available energy and Q_2 is the bound energy.

Using differential equations, one can show that the maximum amount of power that the storage can discharge over a specific length of time Δt is given by the following equation:

$$P_{batt,dmax,kbm} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)}$$

Similarly, the maximum amount of power that the storage can absorb over a specific length of time is given by the following equation:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)}$$

The preceding two equations give the allowable range for the power into or out of the storage bank in any one time step. (HOMER imposes two additional limitations on the charge power. For more information please see the article on **calculating the maximum charge power**. Once HOMER calculates the actual charge or discharge power, it calculates the resulting amount of available and bound energy at the end of the time step using the following two equations:

$$Q_{1,end} = Q_1 e^{-k\Delta t} + \frac{(Qkc - P)\left(1 - e^{-k\Delta t}\right)}{k} + \frac{Pc\left(k\Delta t - 1 + e^{-k\Delta t}\right)}{k}$$

$$Q_{2,end} = Q_2 e^{-k\Delta t} + Q(1-c)(1-e^{-k\Delta t}) + \frac{P(1-c)(k\Delta t - 1 + e^{-k\Delta t})}{k}$$

where

Q_1 is the available energy [kWh] at the beginning of the time step,

Q_2 is the bound energy [kWh] at the beginning of the time step,

$Q_{1,end}$ is the available energy [kWh] at the end of the time step,

$Q_{2,end}$ is the bound energy [kWh] at the end of the time step,

P is the power [kW] into (positive) or out of (negative) the storage bank, and

Δt is the length of the time step [h].

See also

5.6 How HOMER Calculates the Maximum Battery Charge Power

5.7 How HOMER Calculates the Maximum Battery Discharge Power

5.14 Modified Kinetic Battery Model

The Modified Kinetic Model is based on the Kinetic Battery Model (**Manwell and McGowan, 1993**). The Modified Kinetic Model adds a series resistance, temperature effects on capacity, temperature effects on degradation rate, and cycle-by-cycle degradation based on depth of discharge (DOD). The model is designed to use commonly available data (some battery datasheets, for example, provide all the necessary information to define the complete model), and is designed so that parts of the model can be left out if data is not available, if the model is not representative of the real behavior, or if the behavior does not apply for the conditions being modeled.

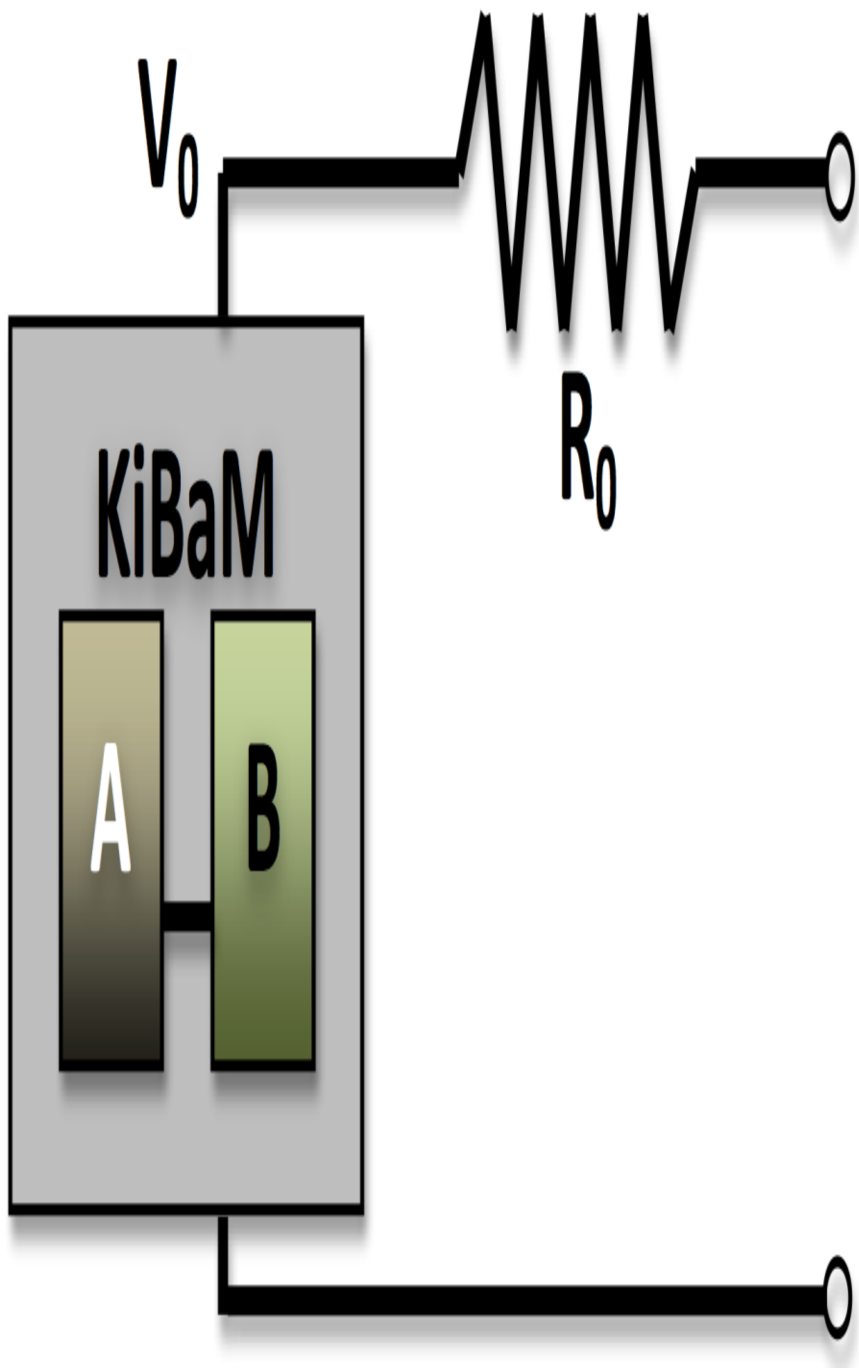
Tip: Be sure to specify the weight when creating a component with the Modified Kinetic Battery Model. The model uses the weight to calculate heat transfer and thermal behavior.

The different aspects of the model combine linearly, and are easy to isolate, so that the data entered to generate the model can be reproduced in simulation. For example, you can enter a lifetime versus temperature curve that includes a point at 40 C and 5 years. You can create a model with temperature fixed at 40 C and the battery is not used (so cycle life is not a factor). You can check that the battery will be replaced every 5 years. Essentially, the model was kept as simple as possible while still including all of the desired phenomena.

See the topic **Kinetic Battery Model** for a review of the Kinetic Battery Model (KiBaM) and the parameters maximum capacity, capacity ratio, and rate constant. This article explains the details and function of the Modified Kinetic Model. For information about defining a Modified Kinetic Battery in the library, see the topic **Modified Kinetic Battery Model**.

Functional Model

The time step to time step behavior of the battery in simulation is governed by the functional model.



For a given power output, the current, I, is defined as:

$$P_{out} = IV_{output} = V_0 I - R_0 I^2 \qquad (1)$$

This quadratic equation is solved for the current, I. This current is then applied to the Kinetic Battery Model to determine the state for the following time step. The equations used for this are described in the help topic **Kinetic Battery Model**.

The maximum discharge power and maximum charge power are calculated similarly to the regular Kinetic Battery Model. In addition, there is a maximum discharge power limit imposed by the circuit model, which is found by simply finding the current that gives the maximum value of P_{out} for the quadratic function in (1):

$$I_{Pout,max} = V_0 / (2 R_0) \qquad (2)$$

Thermal Model

The storage component temperature is modeled as a lumped thermal capacity. You specify the thermal conductance to ambient (watts per kelvin), the mass of the component (pounds; multiply kilograms by 2.20 to convert to pounds), and the specific heat capacity (joules per kilogram-kelvin). If you specify a specific heat capacity of zero, the battery internal temperature will follow the temperature resource exactly.

> **Tip:** By not selecting "Consider temperature effects?" in the site specific inputs of the battery menu, the battery internal temperature will simply stay constant at the temperature specified in the library. In this case, the thermal model is not used.

In each time step of the simulation, any energy dissipated by the effective series resistance is converted to heat and increases the bulk temperature of the storage bank. Additionally, heat dissipates to or is absorbed from the surroundings according to the convection equation: $q = h\Delta T$. You can specify the ambient temperature for simulation in the temperature resource. Losses specified by the "Other round-trip losses" input are not converted to heat in the thermal model.

The temperature of the storage component can be plotted in the time series results viewer. This is the temperature used to calculate temperature effects on capacity and temperature effects on degradation rate.

Temperature Effect on Capacity

Some batteries exhibit variation in capacity with temperature, for example, a decrease in the available energy at cold temperatures. You can enter relative capacity (percent of nominal) versus temperature (Celsius) into the table in the Temperature vs. Capacity tab of the Modified Kinetic Battery menu in the Library view. The modified kinetic model fits a quadratic function to the capacity versus temperature data you enter in the table.

In simulation, HOMER effectively adjusts the minimum state of charge up or down based on the current temperature of the battery pack. For example, consider a case where the minimum state of charge specified in the site specific inputs is 20%. At the point in the temperature/capacity curve where the capacity is 100% (often about 20 or 25 C), the minimum state of charge will be zero. If, at cold temperatures, the battery capacity is 80% of the nominal value, the minimum state of charge will be effectively set to 40%.

It is possible to have a case where the battery is at the minimum state of charge, and then the minimum state of charge increases due to a temperature change. If the battery is not charged, the state of charge will remain constant, below the minimum state of charge. Of course, the battery is not allowed to discharge any energy until the state of charge is increased to above the minimum state of charge. Likewise, it is possible to exhaust the battery completely, and if the battery is warmed and the minimum state of charge decreases accordingly (in the case of typical capacity versus temperature behavior), HOMER could then take more energy out of the previously exhausted battery.

The user must also specify a maximum and minimum operating temperature. If the battery temperature is outside of these bounds, the battery will not operate.

Degradation

The Modified Kinetic Model tracks degradation using two variables that increase as the pack degrades over its life. One tracks time and temperature over the pack's lifetime, and the other tracks the wear from cycles, adjusted for depth of discharge. Each of these two quantities represents a fractional degradation, from 0 when the pack is new, to 0.2 at the end of life (for the default case of a 20% capacity degradation limit).

Functional degradation is modeled as a gradual decrease in storage capacity and increase in series resistance. The capacity degradation follows the maximum of the two values; whichever variable is higher defines the fractional degradation in capacity. The series resistance is scaled larger by the sum of the two degradation variables. See **Neubauer 2014** and **Smith and Earleywine 2012** for a discussion of this approach.

> **Note:** In some cases, the **Multi-Year Module** is necessary to model degradation effects accurately. You can still model degradation effects without the Multi-Year module, but only the first year will be simulated. This may be adequate for cases where the battery is degraded and replaced after just one year.

Degradation with Time and Temperature

The first degradation variable increases with each time step regardless of whether the storage component is being used or is idle. The rate of increase of this variable depends only on temperature, as described in the following relationship:

$$kt = B*e^{-d/T}$$

In the above equation, kt is the rate of increase of the time-and-temperature degradation variable. B and d are constants fit to data, and T is the temperature in kelvins. The constant B is scaled such that the degradation variable goes from zero to 0.2 (or the value of the capacity degradation limit when you clicked 'Recalculate') over the course of one lifetime. With this fit, the input data can theoretically be reproduced in simulation. If the battery is held at constant temperature in a simulation, the time and temperature degradation variable will reach 0.2 (or the capacity degradation limit you set) after the time specified for that temperature. You can enter data in the form of years of shelf life versus temperature into the table in the Temperature vs. Lifetime tab of the Modified Kinetic Battery menu in the Library view.

Cycle degradation

The second degradation variable tracks the cycle fatigue on the battery. The relationship between cycles to failure and depth of discharge (DOD) is described by the following equation:

$$1/N = AD^{\beta}$$

In the above equation, N is the number of cycles, D is the depth of discharge (a fractional number between 0 and 1), and A and β are fitted constants. These constants are fitted to the data you enter in the cycles versus depth of discharge table. The constant A is scaled so that the degradation variable goes from zero to 0.2 (or whatever capacity degradation limit you had set when you clicked 'Recalculate') over the course of a lifetime of cycles. Similar to the lifetime and temperature fit described above, the input data will be reproduced in simulation; if you run a model where the battery charges and discharges cyclically at a specific DOD, the battery will reach its end of life at the number of cycles specified for the DOD.

In simulation, the Rainflow Counting algorithm is used to convert the battery state of charge time series into discrete cycles, each with a DOD. Using the above equation, the fraction of lifetime degradation for each cycle is calculated and summed to calculate the total degradation as follows:

$$D = \sum_{i=0}^{N} AD_i^{\beta}$$

Each cycle has a depth of discharge D_i. The summation is performed over all the cycles calculated using the rainflow counting method to calculate the cumulative amount of degradation of the of the cycle-life degradation variable. See **ASTM E1049-85(2011)e1** and **Manwell, McGowan et. al. 2005** for implementation and justification of the rainflow counting algorithm.

> **Note:** Since the **temperature effects on battery capacity** modifies the minimum state of charge of the battery to change the battery capacity, the number of charge/discharge cycles before the battery end of life can differ slightly from the specified value. For example, consider a battery with a minimum state of charge of 20%, 1,000 cycles to failure at 80% DOD, and capacity that decreases at low temperatures. In simulation, the minimum state of charge might rise to 25% to model the reduced capacity at lower temperature. In that case, the battery might last more than 1,000 full cycles.

End of Life

The battery is considered dead and is instantly replaced when either the time-and-temperature degradation variable or the cycle degradation variable reaches the fraction specified by the Capacity Degradation Limit input. The Capacity degradation Limit sets the percent of degradation at which the battery is replaced. There are two contexts in which you can set the Capacity degradation Limit: in the Library, when you are creating a new battery with the Modified Kinetic Battery Model, and in the design view site-specific inputs when you are creating a HOMER model.

When you enter data and calculate parameters in the Temperature vs. lifetime and Cycle Lifetime tabs, HOMER takes into account the Capacity degradation limit you have set in the defaults tab when calculating the fitted constants. This has the result of replicating the data you input in a simulation when the default Capacity Degradation Limit is used. If you change the Capacity degradation limit in the Defaults tab, you may wish to go back to the Cycle Lifetime and Lifetime vs. Temperature tabs and Recalculate.

If you change the Capacity degradation Limit in the design view, the effect is as you would expect. Increasing the Capacity degradation Limit will increase the time between battery replacements. You can set a sensitivity on this variable to compare the trade-offs between replacing the storage component sooner versus keeping it longer with degraded performance.

See also

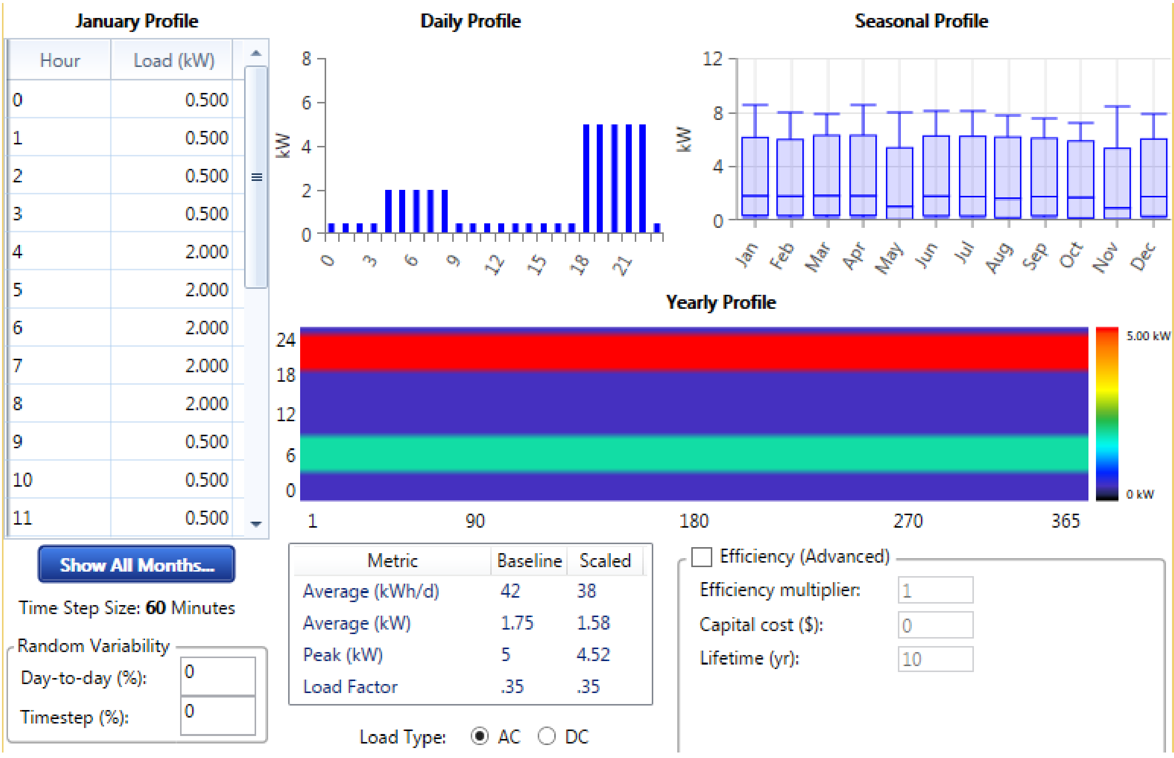
5.6 How HOMER Calculates the Maximum Battery Charge Power
5.7 How HOMER Calculates the Maximum Battery Discharge Power

5.15 Generating Synthetic Load Data

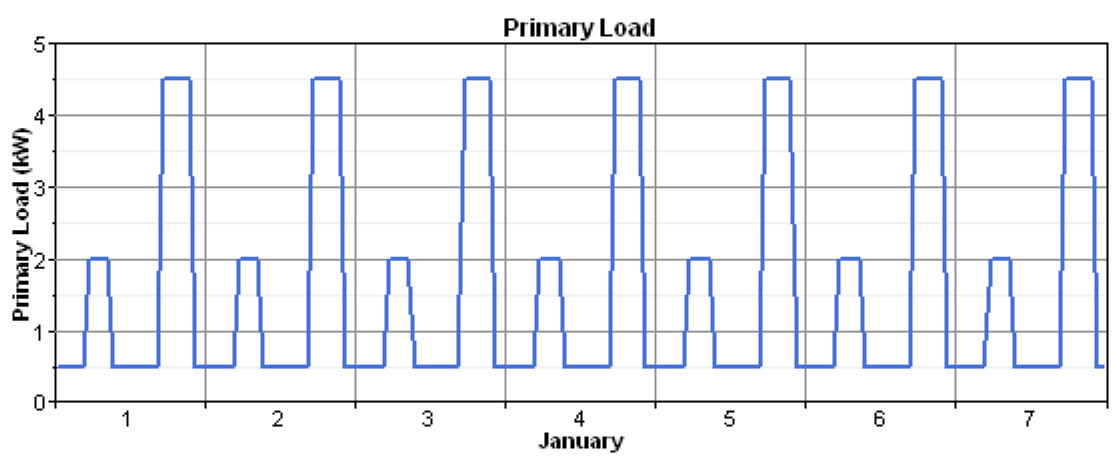
Random variability

Random variability is defined with two values, "Day-to-day" and "Timestep". If you have imported time-series load data, these values will be listed for reference and will not be editable. If you are generating synthetic load with HOMER, you can change these values.

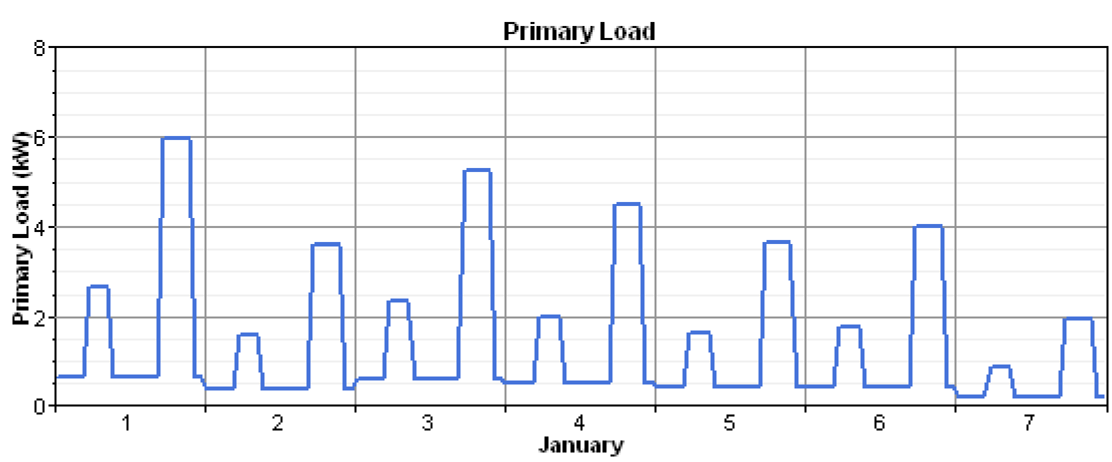
The random variability inputs allow you to add randomness to the load data to make it more realistic. To see the effect that each type of variability has on the load data, let's consider the following average load profile:



First let's look at the load data without any added variability. A plot of the first week of the year shows that the load profile repeats precisely day after day:

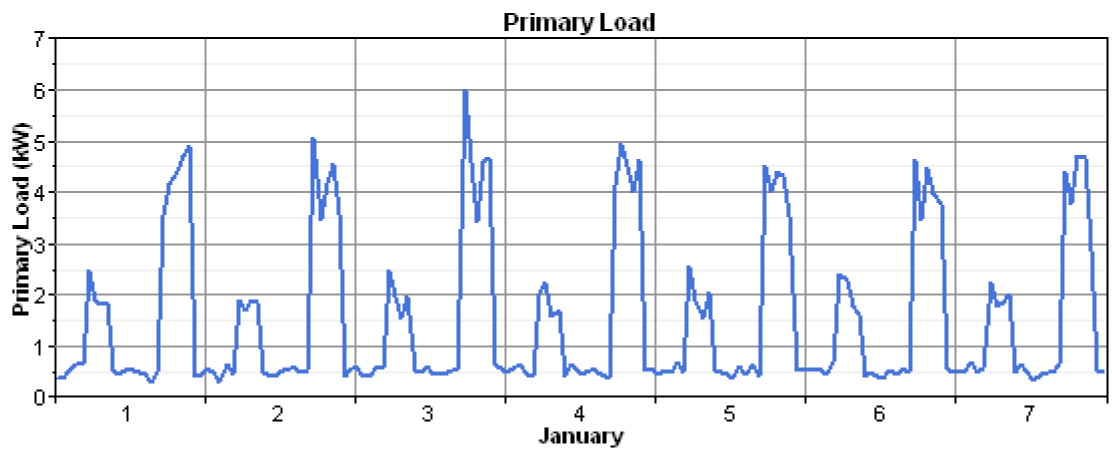


In reality though, the size and shape of the load profile will vary from day to day. So adding variability can make the load data more realistic. First, let's add 20% day-to-day variability. That causes HOMER to perturb each day's load profile by a random amount, so that the load retains the same shape for each day, but is scaled upwards or downwards. Now a plot of the first week of the year looks like this:



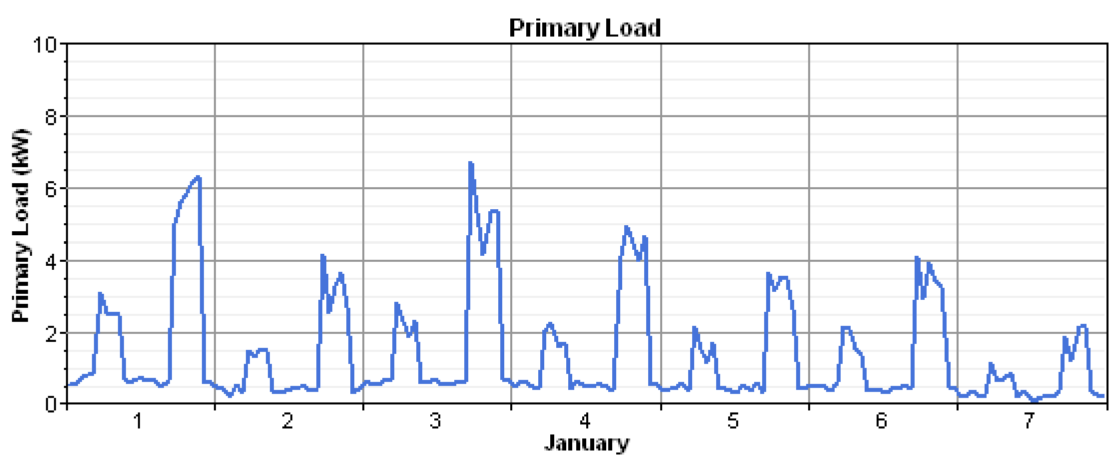
So day-to-day variability causes the *size* of the load profile to vary randomly from day to day, although the *shape* stays the same.

To see the effect of time-step-to-time-step variability, let's reset the day-to-day variability to zero and add 15% time-step-to-time-step variability. Now a plot of the first week of the year looks like this:



So the time-step-to-time-step variability disturbs the *shape* of the load profile without affecting its *size*.

By combining day-to-day and time-step-to-time-step variability, we can create realistic-looking load data. With 20% day-to-day variability and 15% time-step-to-time-step variability, a plot of the first week of the year looks like this:



The mechanism for adding day-to-day and time-step-to-time-step variability is simple. First HOMER assembles the year-long array of load data from the daily profiles you specify. Then, it steps through that time series, and in each time step it multiplies the value in that time step by a perturbation factor α:

$$\alpha = 1 + \delta_d + \delta_{ts}$$

where
:

δ_d = daily perturbation value

δ_{ts} = time step perturbation value

HOMER randomly draws the daily perturbation value *once per day* from a normal distribution with a mean of zero and a standard deviation equal to the "daily variability" input value. It randomly draws the time step perturbation value every time step from a normal distribution with a mean of zero and a standard deviation equal to the "time-step-to-time-step variability" input value.

See also

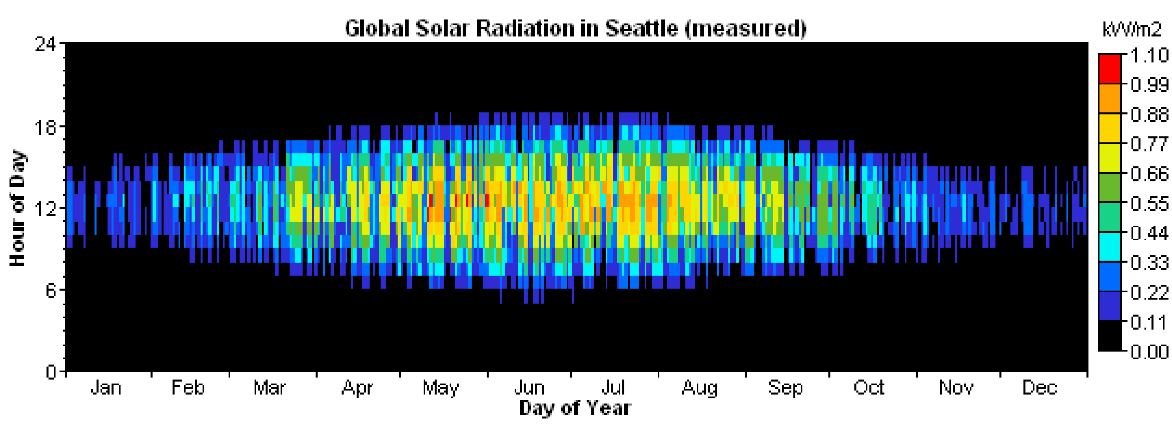
2.2.13 Reformer

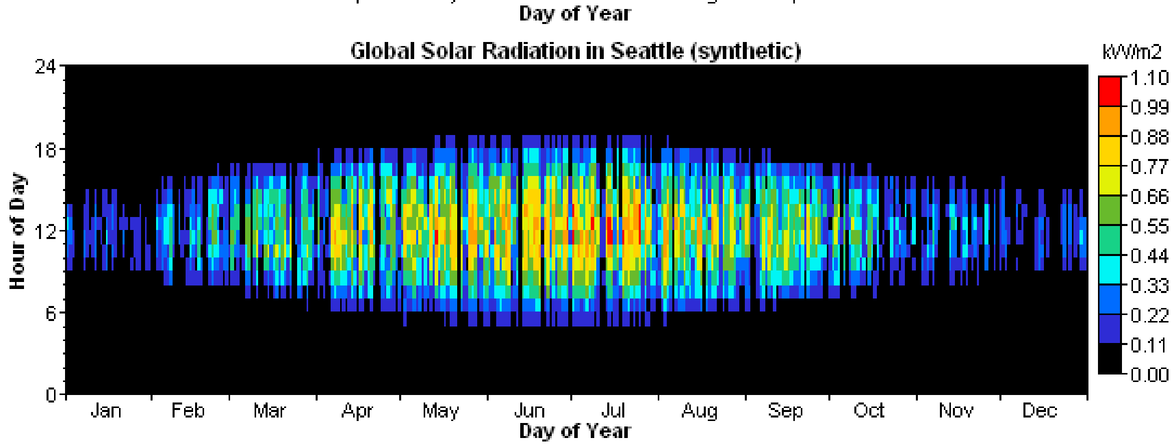
7.37 Component Library

5.16 Generating Synthetic Solar Data

When you do not have access to measured solar radiation data, you can use HOMER's capability to generate synthetic hourly solar data from monthly average data. HOMER synthesizes hourly solar radiation data using an algorithm based on the work of **V.A. Graham**. We have found this algorithm to produce realistic hourly data, and it is easy to use because it requires only the latitude and the twelve monthly average values.

The realistic nature of synthetic data created by this algorithm is demonstrated in the two **DMaps** below. The first shows the measured TMY2 solar data for Seattle, WA. The second shows the synthetic data created by specifying Seattle's latitude and monthly average radiation values. The synthetic data display realistic day-to-day and hour-to-hour patterns. If one hour is cloudy, there is a relatively high likelihood that the next hour will also be cloudy. Similarly, one cloudy day is likely to be followed by another cloudy day.





The algorithm creates synthetic solar data with certain statistical properties that reflect global averages. So data generated for a particular location will not perfectly replicate the characteristics of the real solar resource. But our tests show that synthetic solar data produce virtually the same simulation results as real data. Differences in key performance output variables like annual PV array production, fuel consumption, generator run time, and **storage throughput** are typically less than 5%. Differences in key economic output variables like **total net present cost** and **levelized cost of energy** are typically less than 2%.

To generate synthetic solar data, go to the Solar Resource window. For each month enter either the average **clearness index** or the average daily radiation. If you enter the clearness index, HOMER will calculate the average daily radiation, and vice versa, using the latitude. For details, see the **article on how HOMER calculates clearness index**.

For assistance in finding monthly solar data, see **Finding data to run HOMER**

See also

5.5 How HOMER Calculates Clearness Index

5.17 Generating Synthetic Wind Data

When you have no access to measured wind speed data, you can create time series wind speed data using HOMER's synthetic wind speed data synthesis algorithm. This algorithm requires you to enter a few parameters, from which it generates artificial but statistically reasonable time series data. The algorithm produces data that mimic the characteristics of real wind speed data, including strong and sustained gusts, long lulls between windy periods, and seasonal and diurnal patterns.

Tip: When you import measured wind speed data, it can have any time step down to one minute. Similarly, when you generate synthetic wind data, it can have any time step down to one minute.

Parameters

To generate synthetic wind speed data, go to the Wind Resources window and choose `Enter monthly averages`. You can enter the twelve monthly average wind speeds, or select the project location on the **Home Page** and click the button labeled "Download from Internet..." in the **wind resource menu**. HOMER uses the monthly average wind speeds, plus the four parameters in the following table, to synthesize wind data for simulation.

Parameter	Description	Default
Weibull *k*	Reflects the breadth of the distribution of wind speeds over the year.	2.0
1-hour autocorrelation factor	Reflects how strongly the wind speed in one time step tends to depend on the wind speed in the previous time step.	0.85
Diurnal pattern	Reflects how strongly the wind speed depends on	0.25

strength	the time of day.	
Hour of peak wind speed	The hour of day that tends to be windiest on average.	15

The HOMER resource database has data for some regions that includes specific values for these four parameters for each location. If you have downloaded a resource that includes values for these inputs, the resource values will be filled automatically. If the wind resource does not change these values from their defaults, you can estimate the value of each of these parameters without detailed knowledge of the wind data in a particular location. The articles on each of the parameters give guidance for doing so. The help topic: **Wind Data Histograms** also discusses typical values and the distributions of these parameters.

Algorithm

HOMER follows a five-step process to synthesize one year of time series wind speed data:

Step 1

In the first step of the algorithm, HOMER generates a sequence of autocorrelated numbers, one for each time step of the year, using the first-order autoregressive model:

$$z_i = a \cdot z_{i-1} + f(t)$$

where
:

z_t = the value in time step i

z_{t-1} = the value in time step i-1

a = the autoregressive parameter

$f(t)$ = a 'white noise' function that returns a random number drawn from a normal distribution with mean of zero and a standard deviation of 1

HOMER sets the autoregressive parameter equal to the one-time-step autocorrelation coefficient:

$$a = r_1$$

But on the Wind Resource window you enter the *one-hour autocorrelation coefficient*, which is different from the one-time-step autocorrelation coefficient if the time step is not 60 minutes.

To calculate the one-time-step autocorrelation coefficient from the one-hour autocorrelation factor, HOMER assumes logarithmic decay in the autocorrelation function, in which case the following equation gives the autocorrelation parameter for a lag of k time steps:

$$r_k = r_1^k$$

Solving that for r_1 gives:

$$r_1 = \exp\left[\frac{\ln(r_k)}{k}\right]$$

The one-hour autocorrelation factor is r_k where k is the number of time steps that fit in one hour, meaning:

$$k = \frac{60}{t}$$

Where t is the time step in minutes.

This first step of the algorithm produces a series of numbers that conform to a normal distribution with a mean of zero and a standard deviation of 1.

Step 2

In the second step of the algorithm, HOMER creates a full year of data by piecing together the desired average diurnal wind speed profile, repeated every day. Because the average wind speed varies by month, the average diurnal wind speed profile scales to a different value each month, but within each month the diurnal pattern simply repeats over and over.

Step 3

In the third step, HOMER performs a probability transformation on the sequence of numbers generated in Step 2 so that it conforms to the same normal distribution as the sequence generated in Step 1.

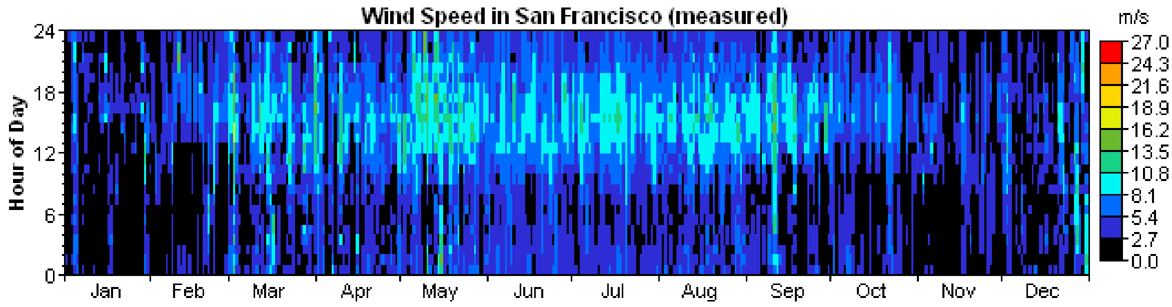
Step 4

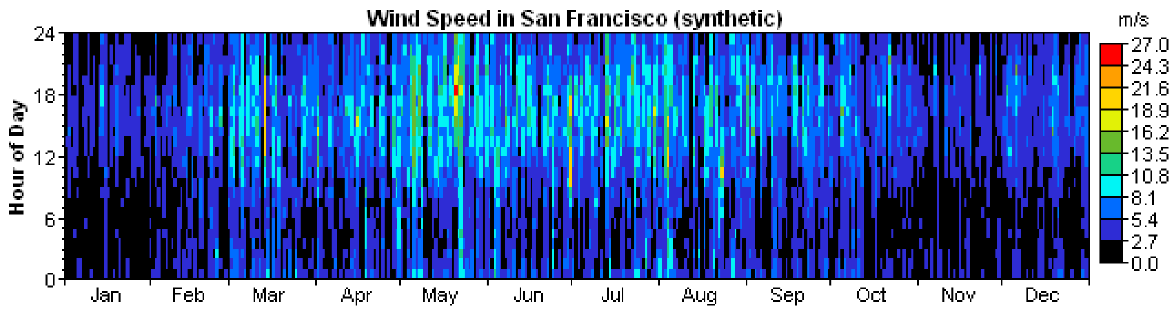
In the fourth step, HOMER adds the sequence generated in Step 3 to the sequence generated in Step 1. The resulting sequence conforms to a normal distribution, but exhibits the desired degree of autocorrelation.

Step 5

In the fifth and final step, HOMER performs a probability transformation on the sequence generated in Step 4 to make it conform to the desired Weibull distribution.

The two **DMaps** below demonstrate the results of the synthetic wind data generation algorithm. The first shows the measured wind speed data for San Francisco, California from the TMY2 data set. The second shows the synthetic wind speed data that HOMER generated from the monthly average wind speeds and the four wind data parameters measured from the real data:





For assistance in finding wind data, see **Finding data to run HOMER**

See also

2.1.1 Adding a Load to the Model
5.16 Generating Synthetic Solar Data
6. Finding Data to Run HOMER
7.121 Probability Transformation
6.3 Wind Data Histograms

6.3 Wind Data Histograms

5.18 Unit Conversions

If we are missing a factor you need, please let us know by writing to support@homerenergy.com. A good online unit conversion website is **www.onlineconversion.com**.

Energy

- 1 kWh = 3,600,000 J
- 1 kWh = 3.6 MJ
- 1 kWh = 3,412.14 Btu
- 1 kWh = 0.0341296 therm [US]

Length

- 1 m = 1000 mm
- 1 m = 3.28084 ft
- 1 ft = 0.3048 m

Speed

- 1 m/s = 3.6 km/hr
- 1 m/s = 2.23694 mph
- 1 m/s = 1.94385 knot
- 1 mph = 0.44704 m/s
- 1 knot = 0.514444 m/s

Volume

- 1 m^3 = 1000 L
- 1 ft^3 = 0.0283168 m^3

- 1 gallon [US, liquid] = 3.78541 L
- 1 barrel [US, petroleum] = 158.987 L

Flow Rate

- 1 m^3/s = 1000 L/s
- 1 ft^3/min [or cfm] = 0.4719475 L/s
- 1 ft^3/s [or cfs] = 28.316847 L/s
- 1 gallon/min [US] = 0.0630902 L/s

Weight/Mass

- 1 kg = 1000 g
- 1 t [tonne] = 1,000 kg
- 1 kg = 2.20462 lb
- 1 lb = 0.453592 kg
- 1 ton [short] = 907.185 kg
- 1 ton [long] = 1,016.05 kg

6. Finding Data to Run HOMER

One of the biggest challenges in using a model like HOMER is finding the numbers to put into it. This page is meant to help you find the information you need. If you know of any other helpful sources, **please let us know** so we can add them. Note that NREL cannot guarantee the accuracy of any data from external sources, and does not endorse any manufacturer or retailer.

Electric Load Data

The only source of hourly load data that we're aware of is the DG Marketplace, which you can visit at **www.dgmarketplace.com**. This website sells typical residential, commercial, and industrial load data for locations across the US.

Geography

To find your latitude and longitude, check **maps.google.com**. For help with Google Maps, see this Google Support article about latitude and longitude: **Latitude and longitude coordinates**).

To find your time zone, check **www.worldtimezone.com**.

Solar Radiation Data

HOMER will accept solar radiation data as monthly averages or as a time series. Time series solar radiation data is most commonly available with an hourly time step, but HOMER can accept any time step down to one minute. One of the best sources of solar radiation data is the TMY2 and TMY3 data sets provided for free by the US National Renewable Energy Laboratory. You can import TMY2 and TMY3 files directly into HOMER's Solar Resource Inputs window.

- NREL provides TMY2 data at: **http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/tmy2/**).

- And TMY3 data at: **http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/**).
- NASA's Surface Solar Energy Data Set provides monthly average solar radiation data for everywhere on earth at **http://eosweb.larc.nasa.gov/sse/**.
- This help file contains a **table of monthly solar data** for selected worldwide locations.
- The US Renewable Resource Data Center provides US data and maps at **www.nrel.gov/rredc/solar_resource.html**.
- The World Radiation Data Center provides worldwide solar data at **http://wrdc-mgo.nrel.gov**. Note that data from this website need a lot of processing to be useful in HOMER.
- GeoModel Solar has many solar data sets available at various resolutions: **http://solargis.info**.

Wind Speed Data

It can be difficult to obtain measured wind speed data. Proper measurement of wind speed is expensive and time consuming, and average wind speeds can vary markedly over short distances because of terrain effects. For these reasons, it is often necessary to **synthesize** wind data from estimated monthly average wind speeds.

Many countries have published wind atlases:

- Wind maps for many US states are available at **apps2.eere.energy.gov/wind/windexchange/windmaps/**.
- The Canadian Wind Atlas is available at **www.windatlas.ca**.
- The Brazilian Wind Atlas is available at **www.cresesb.cepel.br/publicacoes/index.php?task=livro&cid=1**.

A number of other websites provide wind speed data:

- The US Renewable Resource Data Center provides information on wind data at **http://www.nrel.gov/rredc/wind_resource.html**.
- The website **www.weatherbase.com** provides monthly average wind speed data for many cities around the world.
- The **Windustry** website maintains a list of US wind data resources at **www.windustry.com/resources/windmaps.htm**.
- The US National Climatic Data Center provides monthly average wind speed data for many US cities at **http://www1.ncdc.noaa.gov/pub/data/ccd-data/wndspd12.txt**. To convert from mph to m/s, divide by 2.23694.
- The Technical University of Denmark maintains a database of wind characteristics at **www.winddata.com**.

Renewable Power System Components

Several retailers sell components for renewable power systems . The website **www.ecobusinesslinks.com** maintains a list of renewable power retailers around the world. A few have very helpful websites providing cost and performance data for PV panels, wind turbines, hydro turbines, batteries, converters, and other system components. Check out:

- The Alternative Energy Store at **www.altenergystore.com**
- SolarEnergy.com at **www.solarenergy.com**

- The Solar Biz at **www.thesolarbiz.com**
- The Energy Development Co-operative at **www.unlimited-power.co.uk**

Other sources of cost and performance data for renewable power system components include:

- The Renewable Energy Technology Characterizations, a detailed report on the performance and costs of solar, wind, and biomass power systems, available at **http://www1.eere.energy.gov/ba/pba/pdfs/entire_document.pdf**. This report includes predictions of future performance and costs out to the year 2030.
- SolarBuzz, which provides price data for PV modules, inverters, batteries, and charge controllers at **www.solarbuzz.com**.
- The EPA provides a prices and references for renewable technologies at **http://www.epa.gov/cleanenergy/energy-resources/renewabledatabase.html**.

Generators

- A very useful document covering the technology, emissions, and costs of natural gas-fired reciprocating generators, microturbines, fuel cells, and Stirling engines is the Gas-Fired Distributed Energy Resource Technology Characterizations, available at **http://www.nrel.gov/docs/fy04osti/34783.pdf**.

PV

- PV WATTS v.1 is a simple and useful tool for estimating a PV derating factor. **http://rredc.nrel.gov/solar/calculators/pvwatts/version1/derate.cgi**.

Emissions

- This help file contains a **table of US grid emissions factors**.

The US Environmental Protection Agency provides emissions coefficients for CO_2, SO_2, and NO_x for US locations at their Power Profiler website at **http://oaspub.epa.gov/powpro/ept_pack.charts**.

The EPA's **eGRID** website contains even more emissions data, including state-by-state average emissions factors for all the pollutants that HOMER models.

- Additional data is available The EPA document Emissions Factors, Global Warming Potentials, Unit Conversions, Emissions, and Related Facts, November 1999, at **www.epa.gov/appdstar/pdf/brochure.pdf**.

Policies and Incentives

- For information on current net metering policies across the Unites States, see the US Department of Energy web page on the topic at **www.eere.energy.gov/greenpower/markets/netmetering.shtml**
- For a list of renewable energy incentives across the United States, see the Database of State Incentives for Renewable Energy at **www.dsireusa.org**.

6.1 US Grid Emissions Factors

The following table contains the *average* emissions factors for the year 2010 for each US state. Source: **eGRID**.

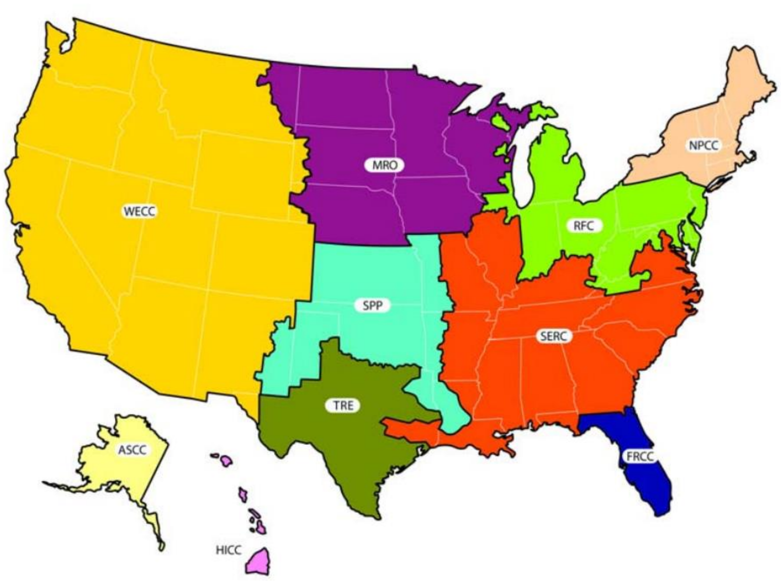
State	Average grid emissions factors		
	CO_2	SO_2	NO_x
	g/kWh	g/kWh	g/kWh
Alaska	493	0.18	1.47
Alabama	511	1.25	0.40
Arkansas	538	1.05	0.59
Arizona	496	0.30	0.50
California	232	0.06	0.08
Colorado	825	0.87	1.07
Connecticut	279	0.15	0.17
District of Columbia	1028	4.04	1.73
Delaware	698	2.44	0.73
Florida	557	0.69	0.37
Georgia	583	1.56	0.42
Hawaii	700	1.79	1.51
Iowa	737	1.80	0.74
Idaho	60	0.10	0.06
Illinois	487	1.05	0.37
Indiana	908	3.04	0.90
Kansas	754	0.86	0.94
Kentucky	940	2.51	0.85
Louisiana	508	0.98	0.71
Massachusetts	482	0.91	0.34
Maryland	612	0.72	0.45
Maine	219	0.26	0.25
Michigan	637	2.06	0.69

Minnesota	591	0.79	0.64
Missouri	832	2.44	0.61
Mississippi	510	0.94	0.51
Montana	678	0.79	0.70
North Carolina	536	0.86	0.38
North Dakota	887	3.28	1.45
Nebraska	660	1.61	0.94
New Hampshire	253	1.57	0.24
New Jersey	280	0.24	0.15
New Mexico	821	0.41	1.52
Nevada	478	0.21	0.35
New York	287	0.36	0.20
Ohio	800	3.76	0.70
Oklahoma	671	1.13	0.96
Oregon	183	0.26	0.18
Pennsylvania	532	1.66	0.54
Rhode Island	454	0.09	0.24
South Carolina	413	0.00	0.08
South Dakota	352	1.16	1.16
Tennessee	518	1.35	0.36
Texas	577	1.02	0.35
Utah	830	0.56	1.36
Virginia	471	1.20	0.50
Vermont	1	0.00	0.04
Washington	136	0.04	0.13
Wisconsin	707	1.66	0.51
West Virginia	893	1.24	0.60
Wyoming	948	1.28	1.20
US average	**570**	**1.19**	**0.64**

The following table contains the average *marginal* CO_2 emissions factors for grid electricity in the US in the year 2010.

	EPA region name	Marginal CO_2 emissions factor
		g/kWh
Region 1	Alaska Systems Coordinating Council	634
Region 2	Florida Reliability Coordinating Council	580
Region 3	Hawaiian Islands Coordinating Council	735
Region 4	Midwest Reliability Organization	915
Region 5	Northeast Power Coordinating Council	536
Region 6	Reliability First Corporation	836
Region 7	SERC Reliability Corporation	732
Region 8	Southwest Power Pool	704
Region 9	Texas Regional Entity	536
Region 10	Western Electricity Coordinating Council	553
US average		**676**

Figure B-2. eGRID NERC Region Representational Map



6.2 Published Solar Data

The following tables show the monthly average **clearness index** for various locations around the world. The data for U.S. sites were calculated from the TMY2 data set. Data for all other locations were taken from **Duffie & Beckmann**.

Africa

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Luanda, Angola	S8.8	0.52	0.53	0.52	0.53	0.55	0.49	0.42	0.38	0.43	0.47	0.52	0.50

Cairo, Egypt	N30.0	0.56	0.60	0.61	0.63	0.66	0.68	0.67	0.66	0.66	0.65	0.59	0.56
Addis Ababa, Ethiopia	N9.0	0.59	0.60	0.57	0.54	0.52	0.45	0.37	0.38	0.46	0.61	0.68	0.64
Nairobi, Kenya	S1.3	0.63	0.62	0.59	0.52	0.49	0.46	0.39	0.40	0.51	0.54	0.52	0.61
Casablanca, Morocco	N33.6	0.51	0.54	0.56	0.58	0.58	0.59	0.61	0.61	0.61	0.56	0.54	0.48
Benin City, Nigeria	N6.1	0.46	0.47	0.46	0.46	0.47	0.43	0.36	0.34	0.37	0.44	0.51	0.48
Dakar, Senegal	N14.7	0.62	0.67	0.68	0.67	0.65	0.60	0.53	0.50	0.52	0.60	0.60	0.59
Pretoria, South Africa	S25.8	0.55	0.56	0.57	0.57	0.65	0.67	0.69	0.67	0.63	0.57	0.57	0.57
El Fasher, Sudan	N13.6	0.68	0.70	0.70	0.68	0.67	0.64	0.61	0.61	0.64	0.67	0.70	0.70
Sidi-Dou-Said, Tunisia	N6.9	0.51	0.51	0.55	0.55	0.60	0.63	0.66	0.64	0.61	0.59	0.58	0.53
Entebbe, Uganda	N0.1	0.50	0.48	0.48	0.47	0.47	0.48	0.46	0.46	0.48	0.48	0.48	0.49

Asia

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madras, India	N13.0	0.60	0.66	0.66	0.65	0.59	0.53	0.52	0.53	0.54	0.49	0.50	0.48
New Delhi, India	N28.6	0.51	0.52	0.50	0.54	0.53	0.46	0.45	0.44	0.53	0.55	0.54	0.51
Akita, Japan	N39.7	0.30	0.35	0.41	0.42	0.43	0.41	0.43	0.44	0.43	0.44	0.33	0.27
Kagoshima, Japan	N31.6	0.42	0.40	0.41	0.39	0.38	0.36	0.42	0.47	0.42	0.46	0.44	0.43
Shimizu, Japan	N32.7	0.48	0.45	0.46	0.41	0.41	0.38	0.47	0.49	0.44	0.46	0.48	0.49
Kuala Lumpur, Malaysia	N3.1	0.51	0.52	0.52	0.50	0.50	0.48	0.49	0.48	0.46	0.50	0.44	0.49
Karachi, Pakistan	N24.8	0.67	0.66	0.63	0.61	0.60	0.58	0.50	0.49	0.60	0.66	0.68	0.67
Lahore, Pakistan	N31.5	0.49	0.55	0.58	0.56	0.57	0.54	0.49	0.50	0.56	0.58	0.57	0.53
Singapore, Singapore	N1.0	0.47	0.47	0.47	0.45	0.44	0.45	0.45	0.44	0.44	0.42	0.39	0.41

Colombo, Sri Lanka	N6.9	0.35	0.49	0.53	0.52	0.49	0.47	0.44	0.43	0.43	0.45	0.35	0.52
Bangkok, Thailand	N13.7	0.55	0.52	0.54	0.51	0.47	0.45	0.42	0.42	0.42	0.48	0.56	0.56

Canada

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beaverlodge, AB	N55.2	0.48	0.55	0.62	0.59	0.53	0.54	0.54	0.53	0.49	0.48	0.47	0.44
Edmonton, AB	N53.6	0.54	0.57	0.61	0.58	0.55	0.54	0.59	0.55	0.55	0.54	0.51	0.49
Suffield, AB	N50.3	0.55	0.59	0.62	0.57	0.56	0.57	0.62	0.60	0.57	0.56	0.35	0.49
Cape St. James, BC	N51.9	0.34	0.39	0.44	0.47	0.51	0.49	0.48	0.50	0.49	0.42	0.36	0.31
Fort Nelson, BC	N58.8	0.43	0.50	0.56	0.58	0.52	0.50	0.50	0.50	0.48	0.46	0.39	0.38
Nanaimo, BC	N49.2	0.31	0.39	0.46	0.50	0.54	0.53	0.59	0.57	0.52	0.45	0.34	0.28
Port Hardy, BC	N50.7	0.33	0.38	0.40	0.43	0.46	0.46	0.48	0.45	0.43	0.38	0.31	0.28
Prince George, BC	N53.9	0.40	0.43	0.50	0.53	0.48	0.52	0.53	0.52	0.47	0.42	0.38	0.32
Sandspit, BC	N53.3	0.33	0.39	0.45	0.46	0.48	0.44	0.43	0.46	0.44	0.39	0.35	0.30
Summerland, BC	N49.6	0.37	0.44	0.51	0.53	0.54	0.54	0.59	0.57	0.56	0.49	0.36	0.31
Vancouver, BC	N49.3	0.31	0.37	0.44	0.48	0.52	0.52	0.57	0.54	0.51	0.43	0.33	0.28
Churchill, MB	N58.8	0.56	0.63	0.70	0.67	0.54	0.53	0.52	0.49	0.41	0.36	0.45	0.51
The Pas, MB	N54.0	0.51	0.58	0.62	0.61	0.55	0.52	0.52	0.50	0.46	0.42	0.41	0.45
Winnipeg, MB	N49.9	0.57	0.62	0.62	0.56	0.54	0.55	0.57	0.55	0.52	0.48	0.44	0.49
Fredericton, NB	N45.9	0.47	0.52	0.50	0.47	0.46	0.48	0.49	0.49	0.48	0.44	0.39	0.41
St. John's West, NF	N47.5	0.39	0.44	0.44	0.42	0.43	0.47	0.50	0.45	0.45	0.37	0.35	0.33
Halifax Citadel, NS	N44.7	0.41	0.46	0.48	0.44	0.44	0.48	0.47	0.35	0.35	0.45	0.39	0.35
Kentville, NS	N45.1	0.41	0.48	0.50	0.46	0.48	0.51	0.51	0.52	0.51	0.46	0.38	0.35

Sable Island, NS	N43.9	0.33	0.38	0.45	0.46	0.49	0.49	0.51	0.50	0.50	0.43	0.35	0.31
Inuvik, NT	N68.3	0.70	0.55	0.63	0.65	0.58	0.53	0.49	0.43	0.40	0.41	0.56	0.00
Mould Bay, NT	N76.2	0.00	0.00	0.58	0.66	0.63	0.52	0.43	0.37	0.43	0.52	0.00	0.00
Norman Wells, NT	N65.3	0.43	0.52	0.61	0.61	0.56	0.56	0.53	0.35	0.46	0.37	0.44	0.60
Sachs Harbour, NT	N72.0	0.00	0.64	0.68	0.67	0.61	0.53	0.51	0.43	0.40	0.45	0.00	0.00
Alert, NU	N82.5	0.00	0.00	0.60	0.61	0.61	0.55	0.46	0.41	0.48	0.00	0.00	0.00
Baker Lake, NU	N64.3	0.53	0.58	0.72	0.69	0.62	0.53	0.51	0.47	0.42	0.43	0.53	0.56
Cambridge Bay, NU	N69.1	0.00	0.58	0.66	0.68	0.62	0.55	0.48	0.43	0.40	0.53	0.73	0.00
Coral Harbour, NU	N64.2	0.51	0.61	0.68	0.70	0.65	0.56	0.47	0.47	0.44	0.48	0.52	0.60
Eureka, NU	N80.0	0.00	0.00	0.59	0.61	0.63	0.56	0.46	0.40	0.46	0.00	0.00	0.00
Hall Beach, NU	N68.8	0.00	0.60	0.66	0.69	0.62	0.57	0.49	0.47	0.39	0.48	0.69	0.00
Iqaluit, NU	N63.8	0.50	0.58	0.63	0.68	0.59	0.48	0.43	0.43	0.40	0.39	0.44	0.53
Isachen, NU	N78.8	0.00	0.00	0.59	0.61	0.61	0.53	0.42	0.35	0.43	0.59	0.00	0.00
Resolute, NU	N74.7	0.00	0.79	0.66	0.70	0.64	0.58	0.47	0.42	0.43	0.54	0.00	0.00
Big Trout Lake, ON	N53.8	0.57	0.63	0.64	0.63	0.53	0.47	0.51	0.46	0.41	0.39	0.41	0.50
Guelph, ON	N43.5	0.46	0.55	0.52	0.49	0.51	0.54	0.54	0.53	0.49	0.45	0.34	0.39
Kapuskasing, ON	N49.4	0.48	0.57	0.61	0.54	0.51	0.56	0.52	0.47	0.46	0.40	0.38	0.45
Moosonee, ON	N51.3	0.50	0.59	0.58	0.54	0.47	0.48	0.47	0.45	0.42	0.37	0.35	0.44
Ottawa, ON	N45.5	0.48	0.54	0.55	0.51	0.51	0.51	0.53	0.51	0.48	0.44	0.36	0.41
Toronto, ON	N43.7	0.40	0.45	0.47	0.48	0.35	0.53	0.54	0.52	0.49	0.45	0.34	0.34
Charlottetown, PE	N46.3	0.47	0.53	0.52	0.48	0.48	0.35	0.35	0.35	0.47	0.41	0.39	0.38
Fort Chimo, PQ	N58.1	0.52	0.58	0.67	0.65	0.48	0.45	0.42	0.43	0.42	0.37	0.41	0.44

Inoucdjouac, PQ	N58.5	0.57	0.64	0.73	0.70	0.55	0.51	0.46	0.44	0.45	0.36	0.33	0.45
Montreal, PQ	N45.5	0.45	0.51	0.35	0.48	0.49	0.49	0.52	0.49	0.49	0.41	0.35	0.38
Nitchequon, PQ	N53.2	0.52	0.62	0.63	0.62	0.52	0.46	0.43	0.43	0.39	0.35	0.39	0.46
Normandin, PQ	N48.8	0.52	0.60	0.62	0.56	0.49	0.49	0.48	0.49	0.44	0.38	0.39	0.47
Sept-Iles, PQ	N50.2	0.48	0.56	0.53	0.47	0.48	0.50	0.46	0.50	0.46	0.43	0.40	0.42
Bad Lake, SK	N51.3	0.60	0.62	0.64	0.58	0.57	0.57	0.59	0.57	0.56	0.56	0.52	0.51
Swift Current, SK	N50.3	0.57	0.60	0.63	0.57	0.56	0.56	0.61	0.59	0.56	0.56	0.52	0.51
Whitehorse, YT	N60.7	0.42	0.35	0.56	0.58	0.54	0.51	0.48	0.49	0.45	0.42	0.39	0.37

Europe

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Brussels, Belgium	N35.8	0.27	0.32	0.36	0.40	0.43	0..43	0.42	0.43	0.43	0.38	0.30	0.24
Copenhagen, Denmark	N55.8	0.25	0.34	0.44	0.48	0.48	0.53	0.48	0.49	0.45	0.39	0.32	0.28
Nice, France	N43.7	0.48	0.48	0.55	0.57	0.56	0.58	0.63	0.59	0.58	0.57	0.35	0.51
Stuttgart, Germany	N48.8	0.35	0.39	0.42	0.46	0.46	0.47	0.49	0.47	0.35	0.45	0.35	0.32
London, Great Britian	N51.5	0.24	0.29	0.34	0.35	0.39	0.43	0.40	0.39	0.39	0.35	0.31	0.25
Athens, Greece	N38.0	0.40	0.43	0.48	0.51	0.57	0.59	0.61	0.60	0.57	0.52	0.46	0.40
Rome, Italy	N41.9	0.43	0.47	0.51	0.53	0.55	0.57	0.61	0.61	0.58	0.55	0.48	0.43
Vlissigen, Netherlands	N51.5	0.30	0.36	0.41	0.44	0.46	0.48	0.45	0.46	0.45	0.41	0.33	0.29
Lisbon, Portugal	N38.7	0.45	0.35	0.55	0.57	0.60	0.62	0.67	0.68	0.62	0.57	0.52	0.53
Warsaw, Poland	N52.3	0.25	0.26	0.39	0.39	0.43	0.47	0.46	0.49	0.42	0.33	0.24	0.21
Cluj, Romania	N46.8	0.43	0.45	0.35	0.48	0.52	0.53	0.55	0.54	0.52	0.48	0.38	0.33
Moscow, Russia	N55.8	0.39	0.44	0.46	0.44	0.48	0.35	0.46	0.46	0.41	0.32	0.26	0.26

St. Petersburg, Russia	N60.0	0.34	0.40	0.44	0.44	0.51	0.51	0.49	0.46	0.41	0.33	0.26	0.26
Almeria, Spain	N36.8	0.57	0.56	0.53	0.56	0.60	0.62	0.66	0.64	0.61	0.60	0.57	0.58
Zurich, Switzerland	N47.5	0.28	0.36	0.41	0.44	0.47	0.47	0.52	0.47	0.48	0.39	0.30	0.26
Kiev, Ukraine	N35.4	0.38	0.41	0.42	0.45	0.49	0.53	0.35	0.35	0.35	0.42	0.29	0.28
Odessa, Ukraine	N46.5	0.31	0.32	0.38	0.44	0.35	0.53	0.53	0.54	0.52	0.45	0.30	0.27

Latin America

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
San Juan, Puerto Rico	N18.4	0.54	0.56	0.58	0.57	0.53	0.53	0.55	0.55	0.53	0.53	0.54	0.53
Ciudad Univ., Mexico	N19.4	0.60	0.59	0.61	0.58	0.51	0.35	0.47	0.46	0.44	0.51	0.56	0.60
Buenos Aires, Argentina	S34.6	0.58	0.59	0.57	0.54	0.51	0.46	0.48	0.52	0.51	0.52	0.57	0.56
Valparaiso, Chile	S33.0	0.51	0.46	0.44	0.38	0.33	0.31	0.34	0.40	0.41	0.42	0.46	0.48
Izobamba, Ecuador	S0.4	0.42	0.39	0.39	0.37	0.43	0.44	0.45	0.45	0.43	0.40	0.41	0.42
Huancayo, Peru	S12.1	0.66	0.61	0.63	0.69	0.74	0.80	0.78	0.76	0.72	0.70	0.70	0.65
Caracas, Venezuela	N10.5	0.46	0.47	0.46	0.43	0.42	0.43	0.45	0.45	0.45	0.43	0.44	0.44
Maracaibo, Venezuela	N10.6	0.49	0.35	0.48	0.43	0.41	0.45	0.47	0.46	0.45	0.43	0.43	0.47

Middle East

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bet Dagan, Israel	N32.0	0.53	0.57	0.58	0.62	0.66	0.69	0.69	0.69	0.67	0.63	0.58	0.51

Pacific

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aspendale, Australia	S38.0	0.57	0.57	0.54	0.48	0.45	0.46	0.47	0.46	0.48	0.35	0.53	0.55

Darwin, Australia	S12.4	0.44	0.47	0.49	0.61	0.64	0.71	0.73	0.70	0.66	0.60	0.62	0.49
Perth, Australia	S31.9	0.58	0.61	0.58	0.53	0.52	0.35	0.55	0.57	0.59	0.58	0.56	0.59
Nandi, Fiji	S17.8	0.47	0.48	0.47	0.49	0.51	0.52	0.52	0.53	0.52	0.51	0.51	0.51
Wellington, New Zealand	S41.3	0.52	0.52	0.48	0.46	0.42	0.42	0.41	0.42	0.46	0.49	0.51	0.35
Quezon City, Phillipines	N14.6	0.47	0.35	0.52	0.54	0.49	0.46	0.41	0.37	0.42	0.42	0.45	0.45
Koror Island	N7.3	0.48	0.35	0.35	0.51	0.48	0.46	0.45	0.45	0.47	0.48	0.49	0.47
Kwajalein Island	N8.7	0.55	0.57	0.55	0.52	0.35	0.35	0.35	0.51	0.49	0.49	0.35	0.52
Wake Island	N19.3	0.56	0.58	0.59	0.58	0.59	0.59	0.56	0.56	0.55	0.56	0.58	0.57

United States

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anchorage, AK	N61.2	0.38	0.47	0.49	0.46	0.47	0.45	0.44	0.41	0.43	0.37	0.42	0.36
Annette, AK	N55.0	0.39	0.38	0.41	0.44	0.46	0.45	0.43	0.49	0.45	0.38	0.36	0.35
Barrow, AK	N71.3	0.51	0.41	0.58	0.57	0.48	0.42	0.41	0.36	0.32	0.40	0.60	0.00
Bethel, AK	N60.8	0.44	0.51	0.57	0.52	0.43	0.43	0.38	0.38	0.43	0.37	0.44	0.42
Bettles, AK	N66.9	0.48	0.51	0.57	0.61	0.55	0.48	0.47	0.47	0.42	0.44	0.47	1.41
Big Delta, AK	N64.0	0.45	0.49	0.55	0.55	0.51	0.48	0.48	0.47	0.49	0.46	0.48	0.48
Cold Bay, AK	N55.2	0.37	0.40	0.41	0.38	0.33	0.34	0.33	0.33	0.32	0.36	0.36	0.34
Fairbanks, AK	N64.8	0.43	0.52	0.58	0.60	0.50	0.49	0.48	0.47	0.45	0.47	0.50	0.43
Gulkana, AK	N62.1	0.44	0.53	0.58	0.57	0.49	0.49	0.50	0.47	0.47	0.45	0.47	0.43
King Salmon, AK	N58.7	0.40	0.46	0.48	0.47	0.44	0.41	0.40	0.38	0.41	0.43	0.41	0.38
Kodiak, AK	N57.8	0.42	0.46	0.44	0.46	0.44	0.40	0.41	0.42	0.42	0.44	0.43	0.36
Kotzebue,	N66.9	0.4	0.5	0.5	0.6	0.5	0.4	0.4	0.3	0.4	0.4	0.5	1.0

AK		6	0	8	1	3	7	5	9	4	6	3	1
Mcgrath, AK	N63.0	0.45	0.52	0.61	0.59	0.49	0.45	0.44	0.42	0.41	0.43	0.44	0.46
Nome, AK	N64.5	0.43	0.52	0.59	0.63	0.51	0.47	0.42	0.42	0.44	0.46	0.42	0.50
St Paul Is., AK	N57.1	0.34	0.39	0.43	0.45	0.39	0.35	0.34	0.33	0.36	0.38	0.35	0.34
Talkeetna, AK	N62.3	0.42	0.50	0.54	0.58	0.49	0.44	0.43	0.43	0.43	0.39	0.45	0.48
Yakutat, AK	N59.5	0.42	0.47	0.50	0.47	0.41	0.39	0.37	0.41	0.38	0.42	0.40	0.39
Birmingham, AL	N33.6	0.48	0.50	0.54	0.56	0.53	0.54	0.53	0.55	0.55	0.56	0.51	0.47
Huntsville, AL	N34.6	0.45	0.51	0.50	0.53	0.53	0.55	0.56	0.56	0.54	0.59	0.50	0.45
Mobile, AL	N30.7	0.47	0.51	0.52	0.53	0.52	0.51	0.49	0.50	0.50	0.57	0.49	0.50
Montgomery, AL	N32.3	0.48	0.52	0.54	0.57	0.56	0.54	0.54	0.56	0.56	0.57	0.52	0.49
Fort Smith, AR	N35.3	0.52	0.55	0.54	0.55	0.56	0.58	0.57	0.59	0.54	0.56	0.55	0.49
Little Rock, AR	N34.7	0.48	0.50	0.54	0.55	0.56	0.56	0.57	0.59	0.55	0.57	0.47	0.47
Flagstaff, AZ	N35.1	0.61	0.64	0.63	0.62	0.63	0.66	0.58	0.53	0.64	0.65	0.63	0.61
Phoenix, AZ	N33.4	0.61	0.65	0.66	0.72	0.73	0.72	0.69	0.69	0.70	0.70	0.65	0.59
Prescott, AZ	N34.6	0.61	0.61	0.60	0.65	0.69	0.71	0.62	0.63	0.64	0.68	0.64	0.60
Tucson, AZ	N32.1	0.64	0.64	0.68	0.71	0.71	0.71	0.63	0.66	0.69	0.69	0.67	0.63
Arcata, CA	N41.0	0.45	0.46	0.49	0.53	0.52	0.50	0.53	0.50	0.53	0.50	0.51	0.48
Bakersfield, CA	N35.4	0.47	0.54	0.57	0.62	0.65	0.72	0.71	0.70	0.68	0.66	0.57	0.46
Daggett, CA	N34.9	0.65	0.65	0.70	0.74	0.72	0.74	0.72	0.71	0.72	0.70	0.66	0.63
Fresno, CA	N36.8	0.44	0.54	0.60	0.65	0.68	0.70	0.72	0.72	0.68	0.66	0.56	0.43
Long Beach, CA	N33.8	0.54	0.56	0.56	0.59	0.59	0.59	0.64	0.65	0.61	0.59	0.58	0.54
Los Angeles, CA	N33.9	0.55	0.59	0.57	0.60	0.59	0.59	0.62	0.64	0.58	0.59	0.58	0.56

Sacramento, CA	N38.5	0.42	0.51	0.55	0.61	0.65	0.68	0.70	0.70	0.69	0.62	0.49	0.43
San Diego, CA	N32.7	0.57	0.58	0.59	0.63	0.57	0.58	0.61	0.64	0.60	0.62	0.60	0.57
San Francisco, CA	N37.6	0.48	0.53	0.53	0.58	0.61	0.62	0.67	0.64	0.65	0.59	0.50	0.46
Santa Maria, CA	N34.9	0.56	0.58	0.59	0.63	0.65	0.62	0.66	0.66	0.63	0.62	0.59	0.60
Alamosa, CO	N37.5	0.65	0.64	0.65	0.68	0.64	0.67	0.63	0.64	0.65	0.69	0.66	0.64
Boulder, CO	N40.0	0.57	0.55	0.61	0.59	0.58	0.59	0.58	0.60	0.62	0.62	0.58	0.58
Colorado Springs, CO	N38.8	0.58	0.58	0.59	0.59	0.57	0.60	0.58	0.60	0.62	0.65	0.62	0.57
Eagle, CO	N39.6	0.56	0.56	0.56	0.59	0.60	0.63	0.61	0.62	0.62	0.63	0.57	0.54
Grand Junction, CO	N39.1	0.58	0.60	0.59	0.61	0.64	0.67	0.65	0.65	0.66	0.64	0.60	0.56
Pueblo, CO	N38.3	0.58	0.61	0.60	0.60	0.62	0.65	0.64	0.63	0.63	0.69	0.63	0.60
Bridgeport, CT	N41.2	0.46	0.50	0.47	0.51	0.50	0.51	0.51	0.51	0.50	0.51	0.45	0.44
Hartford, CT	N41.9	0.49	0.51	0.49	0.50	0.48	0.51	0.51	0.51	0.50	0.48	0.44	0.45
Wilmington, DE	N39.7	0.48	0.53	0.51	0.51	0.51	0.55	0.54	0.55	0.52	0.54	0.48	0.43
Daytona Beach, FL	N29.2	0.50	0.54	0.57	0.59	0.58	0.55	0.56	0.54	0.55	0.52	0.54	0.52
Jacksonville, FL	N30.5	0.51	0.49	0.54	0.58	0.56	0.53	0.53	0.52	0.51	0.52	0.53	0.48
Key West, FL	N24.6	0.55	0.59	0.58	0.62	0.57	0.55	0.55	0.55	0.54	0.55	0.55	0.54
Miami, FL	N25.8	0.53	0.57	0.56	0.59	0.55	0.51	0.54	0.54	0.52	0.54	0.52	0.54
Tallahassee, FL	N30.4	0.51	0.54	0.51	0.58	0.59	0.55	0.51	0.53	0.54	0.57	0.54	0.47
Tampa, FL	N28.0	0.52	0.55	0.57	0.62	0.57	0.54	0.53	0.55	0.52	0.56	0.55	0.51
West Palm Beach, FL	N26.7	0.53	0.53	0.55	0.55	0.53	0.50	0.52	0.53	0.52	0.53	0.53	0.51
Athens, GA	N34.0	0.48	0.53	0.55	0.56	0.55	0.55	0.55	0.54	0.54	0.60	0.53	0.50
Atlanta, GA	N33.6	0.4	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.4

		9	2	3	0	7	6	6	6	3	0	4	9
Augusta, GA	N33.4	0.48	0.53	0.52	0.57	0.53	0.54	0.55	0.55	0.54	0.55	0.53	0.51
Columbus, GA	N32.5	0.48	0.55	0.53	0.57	0.56	0.53	0.54	0.55	0.55	0.57	0.52	0.47
Macon, GA	N32.7	0.46	0.53	0.55	0.56	0.56	0.53	0.54	0.54	0.51	0.58	0.55	0.48
Savannah, GA	N32.1	0.48	0.54	0.57	0.57	0.56	0.54	0.56	0.53	0.52	0.56	0.54	0.50
Hilo, HI	N19.7	0.49	0.52	0.48	0.46	0.47	0.52	0.48	0.51	0.51	0.48	0.48	0.50
Honolulu, HI	N21.3	0.54	0.57	0.57	0.56	0.59	0.60	0.60	0.61	0.62	0.58	0.56	0.55
Kahului, HI	N20.9	0.56	0.56	0.57	0.55	0.57	0.61	0.61	0.63	0.63	0.61	0.55	0.56
Lihue, HI	N22.0	0.53	0.53	0.50	0.52	0.52	0.56	0.54	0.56	0.58	0.55	0.50	0.51
Des Moines, IA	N41.5	0.51	0.54	0.51	0.52	0.53	0.57	0.59	0.56	0.55	0.53	0.47	0.48
Mason City, IA	N43.1	0.53	0.55	0.50	0.50	0.54	0.55	0.56	0.58	0.54	0.56	0.47	0.49
Sioux City, IA	N42.4	0.54	0.53	0.53	0.53	0.55	0.57	0.58	0.57	0.54	0.54	0.50	0.47
Waterloo, IA	N42.5	0.48	0.50	0.52	0.50	0.53	0.54	0.55	0.54	0.55	0.55	0.45	0.48
Boise, ID	N43.6	0.46	0.51	0.54	0.56	0.59	0.62	0.68	0.67	0.65	0.62	0.51	0.46
Pocatello, ID	N42.9	0.46	0.48	0.54	0.55	0.58	0.60	0.66	0.66	0.62	0.62	0.47	0.43
Chicago, IL	N41.8	0.45	0.49	0.48	0.51	0.54	0.54	0.57	0.52	0.52	0.51	0.43	0.40
Moline, IL	N41.5	0.46	0.50	0.47	0.50	0.51	0.55	0.54	0.56	0.54	0.55	0.48	0.43
Peoria, IL	N40.7	0.48	0.52	0.48	0.51	0.54	0.56	0.57	0.55	0.55	0.55	0.48	0.44
Rockford, IL	N42.2	0.49	0.52	0.51	0.50	0.52	0.54	0.55	0.53	0.54	0.52	0.43	0.41
Springfield, IL	N39.8	0.50	0.53	0.50	0.54	0.54	0.57	0.58	0.56	0.54	0.56	0.47	0.45
Evansville, IN	N38.0	0.46	0.47	0.49	0.51	0.53	0.56	0.55	0.56	0.53	0.55	0.47	0.43
Fort Wayne, IN	N41.0	0.44	0.46	0.48	0.50	0.53	0.56	0.54	0.53	0.53	0.49	0.41	0.38

Indianapolis, IN	N39.7	0.47	0.51	0.49	0.51	0.55	0.56	0.57	0.55	0.54	0.55	0.45	0.41
South Bend, IN	N41.7	0.43	0.46	0.46	0.49	0.52	0.53	0.53	0.54	0.52	0.50	0.41	0.38
Dodge City, KS	N37.8	0.60	0.62	0.61	0.60	0.56	0.62	0.64	0.64	0.60	0.64	0.58	0.59
Goodland, KS	N39.4	0.58	0.57	0.60	0.59	0.55	0.63	0.63	0.62	0.62	0.64	0.58	0.59
Topeka, KS	N39.1	0.52	0.53	0.54	0.51	0.52	0.56	0.56	0.57	0.56	0.54	0.52	0.49
Wichita, KS	N37.6	0.55	0.56	0.55	0.56	0.55	0.58	0.61	0.61	0.57	0.59	0.55	0.51
Covington, KY	N39.1	0.44	0.46	0.49	0.50	0.53	0.54	0.53	0.56	0.53	0.55	0.43	0.37
Lexington, KY	N38.0	0.46	0.47	0.48	0.51	0.53	0.56	0.53	0.53	0.51	0.53	0.47	0.41
Louisville, KY	N38.2	0.44	0.48	0.51	0.52	0.53	0.56	0.54	0.54	0.54	0.55	0.47	0.45
Baton Rouge, LA	N30.5	0.47	0.48	0.51	0.53	0.54	0.53	0.51	0.54	0.51	0.60	0.52	0.48
Lake Charles, LA	N30.1	0.47	0.52	0.52	0.51	0.55	0.56	0.54	0.54	0.54	0.58	0.54	0.47
New Orleans, LA	N30.0	0.44	0.53	0.52	0.54	0.55	0.55	0.53	0.52	0.52	0.57	0.53	0.48
Shreveport, LA	N32.5	0.47	0.51	0.51	0.53	0.53	0.56	0.57	0.58	0.55	0.59	0.49	0.49
Boston, MA	N42.4	0.48	0.53	0.52	0.49	0.51	0.52	0.54	0.55	0.53	0.54	0.46	0.46
Worchester, MA	N42.3	0.48	0.54	0.52	0.49	0.51	0.51	0.54	0.52	0.52	0.51	0.47	0.45
Baltimore, MD	N39.2	0.47	0.52	0.51	0.51	0.50	0.54	0.54	0.52	0.51	0.55	0.48	0.43
Caribou, ME	N46.9	0.56	0.57	0.57	0.56	0.48	0.50	0.49	0.50	0.48	0.47	0.44	0.50
Portland, ME	N43.6	0.52	0.59	0.56	0.52	0.51	0.52	0.55	0.54	0.54	0.52	0.47	0.47
Alpena, MI	N45.1	0.46	0.52	0.54	0.52	0.51	0.53	0.55	0.50	0.48	0.44	0.41	0.42
Detroit, MI	N42.4	0.44	0.47	0.46	0.48	0.53	0.53	0.52	0.54	0.53	0.48	0.41	0.40
Flint, MI	N43.0	0.43	0.50	0.48	0.50	0.53	0.53	0.53	0.52	0.51	0.47	0.41	0.36
Grand Rapids, MI	N42.9	0.45	0.48	0.48	0.51	0.53	0.55	0.56	0.54	0.50	0.47	0.40	0.40

Houghton, MI	N47.2	0.48	0.54	0.54	0.55	0.50	0.53	0.53	0.52	0.50	0.43	0.41	0.45
Lansing, MI	N42.8	0.44	0.48	0.48	0.50	0.52	0.53	0.56	0.53	0.53	0.49	0.43	0.38
Muskegon, MI	N43.2	0.42	0.51	0.49	0.52	0.57	0.58	0.56	0.55	0.52	0.47	0.40	0.38
Sault Ste. Marie, MI	N46.5	0.51	0.56	0.60	0.50	0.53	0.53	0.52	0.52	0.46	0.44	0.41	0.45
Traverse City, MI	N44.7	0.44	0.51	0.54	0.53	0.53	0.54	0.54	0.52	0.49	0.43	0.40	0.39
Duluth, MN	N46.8	0.54	0.55	0.59	0.50	0.52	0.53	0.52	0.53	0.50	0.50	0.44	0.48
International Falls, MN	N48.6	0.51	0.59	0.59	0.54	0.51	0.52	0.54	0.53	0.47	0.46	0.43	0.46
Minneapolis, MN	N44.9	0.55	0.59	0.54	0.49	0.55	0.56	0.57	0.56	0.55	0.52	0.47	0.48
Rochester, MN	N43.9	0.51	0.57	0.52	0.51	0.50	0.54	0.56	0.55	0.52	0.48	0.45	0.47
Saint Cloud, MN	N45.5	0.53	0.61	0.59	0.52	0.53	0.54	0.55	0.55	0.52	0.52	0.49	0.46
Columbia, MO	N38.8	0.50	0.55	0.53	0.56	0.54	0.58	0.57	0.59	0.56	0.58	0.48	0.46
Kansas City, MO	N39.3	0.51	0.50	0.53	0.54	0.55	0.56	0.58	0.58	0.55	0.56	0.49	0.48
Springfield, MO	N37.2	0.51	0.50	0.54	0.54	0.54	0.56	0.57	0.58	0.55	0.55	0.50	0.46
St. Louis, MO	N38.8	0.49	0.51	0.53	0.52	0.54	0.56	0.57	0.53	0.54	0.54	0.49	0.45
Jackson, MS	N32.3	0.46	0.51	0.52	0.55	0.57	0.57	0.54	0.54	0.53	0.58	0.52	0.48
Meridian, MS	N32.3	0.46	0.54	0.51	0.55	0.54	0.54	0.55	0.53	0.52	0.57	0.52	0.50
Billings, MT	N45.8	0.50	0.54	0.56	0.53	0.56	0.57	0.63	0.61	0.61	0.57	0.54	0.50
Cut Bank, MT	N48.6	0.51	0.56	0.56	0.53	0.55	0.57	0.64	0.60	0.58	0.59	0.52	0.49
Glasgow, MT	N48.2	0.51	0.56	0.58	0.52	0.55	0.56	0.61	0.60	0.55	0.55	0.49	0.51
Great Falls, MT	N47.5	0.47	0.53	0.55	0.54	0.53	0.60	0.62	0.61	0.62	0.55	0.51	0.48
Helena, MT	N46.6	0.46	0.49	0.56	0.50	0.53	0.55	0.64	0.60	0.58	0.55	0.49	0.45
Kalispell, MT	N48.3	0.47	0.48	0.47	0.48	0.52	0.55	0.60	0.61	0.55	0.52	0.41	0.40

Lewistown, MT	N47.0	0.50	0.51	0.53	0.50	0.53	0.57	0.61	0.60	0.58	0.57	0.49	0.46
Miles City, MT	N46.4	0.53	0.55	0.55	0.51	0.56	0.58	0.63	0.63	0.59	0.57	0.51	0.50
Missoula, MT	N46.9	0.43	0.47	0.46	0.50	0.51	0.56	0.65	0.61	0.59	0.52	0.42	0.39
Asheville, NC	N35.4	0.50	0.50	0.53	0.53	0.52	0.54	0.52	0.52	0.50	0.56	0.52	0.48
Cape Hatteras, NC	N35.3	0.50	0.48	0.53	0.56	0.57	0.56	0.55	0.55	0.55	0.56	0.53	0.48
Charlotte, NC	N35.2	0.52	0.51	0.54	0.57	0.55	0.55	0.53	0.54	0.53	0.57	0.52	0.50
Greensboro, NC	N36.1	0.52	0.51	0.55	0.55	0.54	0.56	0.54	0.54	0.54	0.56	0.52	0.47
Raleigh, NC	N35.9	0.49	0.53	0.56	0.56	0.53	0.55	0.53	0.54	0.55	0.58	0.55	0.48
Wilmington, NC	N34.3	0.50	0.51	0.56	0.58	0.53	0.55	0.52	0.52	0.53	0.54	0.54	0.50
Bismarck, ND	N46.8	0.56	0.60	0.60	0.56	0.56	0.57	0.60	0.59	0.57	0.55	0.49	0.53
Fargo, ND	N46.9	0.54	0.60	0.54	0.53	0.54	0.55	0.56	0.56	0.53	0.51	0.48	0.48
Minot, ND	N48.3	0.54	0.60	0.54	0.54	0.55	0.55	0.57	0.58	0.57	0.56	0.50	0.50
Grand Island, NE	N41.0	0.55	0.56	0.56	0.57	0.55	0.59	0.60	0.60	0.58	0.60	0.56	0.53
Norfolk, NE	N42.0	0.55	0.53	0.57	0.53	0.56	0.60	0.60	0.58	0.55	0.58	0.52	0.50
North Platte, NE	N41.1	0.55	0.56	0.56	0.56	0.57	0.60	0.61	0.60	0.59	0.61	0.55	0.54
Omaha, NE	N41.4	0.53	0.57	0.53	0.52	0.56	0.59	0.57	0.57	0.58	0.54	0.47	0.48
Scottsbluff, NE	N41.9	0.56	0.55	0.57	0.57	0.57	0.61	0.62	0.61	0.61	0.60	0.55	0.55
Concord, NH	N43.2	0.53	0.55	0.53	0.52	0.52	0.53	0.53	0.54	0.52	0.49	0.47	0.47
Atlantic City, NJ	N39.5	0.48	0.50	0.51	0.51	0.52	0.53	0.53	0.53	0.54	0.53	0.48	0.46
Newark, NJ	N40.7	0.47	0.49	0.49	0.48	0.51	0.51	0.50	0.51	0.52	0.52	0.45	0.44
Albuquerque, NM	N35.0	0.62	0.65	0.65	0.69	0.71	0.70	0.69	0.67	0.66	0.69	0.66	0.63
Tucumcari,	N35.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

NM		1	1	2	4	3	8	4	3	1	5	2	1
Elko, NV	N40.8	0.52	0.52	0.53	0.53	0.59	0.62	0.64	0.66	0.67	0.63	0.52	0.52
Ely, NV	N39.3	0.61	0.58	0.62	0.59	0.61	0.66	0.67	0.64	0.69	0.68	0.59	0.60
Las Vegas, NV	N36.1	0.62	0.65	0.66	0.70	0.72	0.72	0.72	0.70	0.72	0.70	0.67	0.62
Reno, NV	N39.5	0.52	0.56	0.61	0.63	0.61	0.66	0.70	0.70	0.72	0.66	0.60	0.55
Tonopah, NV	N38.1	0.56	0.60	0.61	0.64	0.63	0.69	0.70	0.69	0.70	0.69	0.62	0.58
Winnemucca, NV	N40.9	0.52	0.53	0.57	0.58	0.58	0.63	0.67	0.67	0.68	0.63	0.54	0.51
Albany, NY	N42.8	0.47	0.53	0.48	0.50	0.53	0.51	0.54	0.54	0.52	0.50	0.40	0.42
Binghamton, NY	N42.2	0.45	0.50	0.48	0.48	0.48	0.49	0.50	0.51	0.48	0.49	0.42	0.41
Buffalo, NY	N42.9	0.41	0.45	0.49	0.49	0.52	0.52	0.53	0.52	0.47	0.46	0.37	0.38
Massena, NY	N44.9	0.49	0.54	0.54	0.51	0.49	0.54	0.54	0.52	0.49	0.47	0.42	0.44
New York City, NY	N40.8	0.45	0.51	0.50	0.52	0.51	0.54	0.54	0.54	0.53	0.53	0.43	0.45
Rochester, NY	N43.1	0.42	0.49	0.47	0.49	0.50	0.55	0.53	0.52	0.52	0.46	0.39	0.39
Syracuse, NY	N43.1	0.47	0.47	0.49	0.50	0.53	0.52	0.55	0.53	0.52	0.48	0.39	0.43
Akron, OH	N40.9	0.40	0.45	0.46	0.47	0.52	0.52	0.53	0.53	0.54	0.50	0.40	0.38
Cleveland, OH	N41.4	0.41	0.45	0.46	0.49	0.53	0.53	0.53	0.53	0.52	0.49	0.37	0.35
Columbus, OH	N40.0	0.43	0.43	0.45	0.50	0.49	0.53	0.51	0.54	0.52	0.53	0.41	0.38
Dayton, OH	N39.9	0.44	0.45	0.45	0.51	0.51	0.53	0.52	0.55	0.52	0.55	0.43	0.40
Mansfield, OH	N40.8	0.39	0.46	0.47	0.46	0.51	0.53	0.54	0.52	0.52	0.49	0.42	0.38
Toledo, OH	N41.6	0.44	0.48	0.47	0.52	0.55	0.54	0.56	0.56	0.53	0.48	0.42	0.40
Youngstown, OH	N41.3	0.38	0.43	0.47	0.47	0.48	0.50	0.51	0.51	0.46	0.47	0.37	0.37
Oklahoma City, OK	N35.4	0.54	0.56	0.56	0.58	0.55	0.58	0.60	0.61	0.58	0.60	0.55	0.56

Tulsa, OK	N36.2	0.51	0.52	0.55	0.57	0.54	0.56	0.59	0.58	0.52	0.59	0.51	0.50
Astoria, OR	N46.1	0.35	0.40	0.41	0.42	0.45	0.47	0.49	0.48	0.51	0.48	0.39	0.39
Burns, OR	N43.6	0.50	0.51	0.52	0.55	0.58	0.61	0.65	0.65	0.64	0.60	0.46	0.45
Eugene, OR	N44.1	0.39	0.39	0.45	0.45	0.51	0.54	0.61	0.62	0.57	0.50	0.38	0.33
Medford, OR	N42.4	0.40	0.45	0.55	0.54	0.60	0.62	0.70	0.68	0.64	0.57	0.40	0.38
North Bend, OR	N43.4	0.43	0.43	0.48	0.50	0.54	0.55	0.59	0.56	0.56	0.52	0.45	0.41
Pendleton, OR	N45.7	0.42	0.46	0.52	0.55	0.57	0.60	0.66	0.65	0.64	0.56	0.45	0.42
Portland, OR	N45.6	0.40	0.40	0.45	0.45	0.51	0.51	0.58	0.54	0.52	0.48	0.38	0.33
Redmond, OR	N44.3	0.46	0.49	0.53	0.58	0.58	0.63	0.68	0.68	0.68	0.60	0.52	0.47
Salem, OR	N44.9	0.33	0.40	0.47	0.47	0.51	0.54	0.60	0.60	0.59	0.49	0.39	0.39
Allentown, PA	N40.6	0.46	0.49	0.50	0.52	0.50	0.50	0.53	0.51	0.51	0.51	0.43	0.43
Bradford, PA	N41.8	0.45	0.48	0.50	0.49	0.49	0.52	0.53	0.50	0.49	0.48	0.42	0.42
Erie, PA	N42.1	0.40	0.46	0.47	0.50	0.53	0.53	0.55	0.54	0.53	0.49	0.36	0.39
Harrisburg, PA	N40.2	0.47	0.50	0.49	0.52	0.51	0.54	0.54	0.52	0.52	0.52	0.44	0.42
Philadelphia, PA	N39.9	0.45	0.50	0.50	0.50	0.50	0.52	0.53	0.55	0.52	0.53	0.47	0.42
Pittsburgh, PA	N40.5	0.41	0.46	0.47	0.49	0.50	0.52	0.51	0.53	0.49	0.50	0.42	0.36
Wilkes-Barre, PA	N41.3	0.43	0.46	0.45	0.49	0.52	0.51	0.52	0.51	0.50	0.49	0.39	0.40
Williamsport, PA	N41.3	0.46	0.46	0.49	0.46	0.50	0.51	0.52	0.51	0.49	0.46	0.40	0.41
Guam, PI	N13.6	0.55	0.52	0.57	0.55	0.55	0.53	0.49	0.47	0.48	0.51	0.51	0.53
San Juan, PR	N18.4	0.56	0.57	0.59	0.57	0.54	0.56	0.57	0.56	0.57	0.55	0.53	0.53
Providence, RI	N41.7	0.48	0.52	0.52	0.52	0.51	0.53	0.56	0.55	0.50	0.52	0.47	0.45
Charleston, SC	N32.9	0.54	0.51	0.57	0.59	0.56	0.52	0.55	0.52	0.50	0.59	0.56	0.48

Columbia, SC	N34.0	0.48	0.51	0.51	0.58	0.54	0.56	0.55	0.52	0.53	0.61	0.55	0.49
Greenville, SC	N34.9	0.49	0.53	0.55	0.58	0.53	0.54	0.54	0.56	0.55	0.57	0.51	0.50
Huron, SD	N44.4	0.54	0.56	0.56	0.54	0.54	0.55	0.60	0.60	0.57	0.56	0.51	0.48
Pierre, SD	N44.4	0.56	0.54	0.56	0.56	0.56	0.60	0.61	0.59	0.60	0.59	0.52	0.49
Rapid City, SD	N44.0	0.55	0.56	0.57	0.55	0.55	0.59	0.61	0.61	0.59	0.61	0.56	0.53
Sioux Falls, SD	N43.6	0.51	0.53	0.52	0.53	0.54	0.57	0.60	0.58	0.56	0.56	0.48	0.47
Bristol, TN	N36.5	0.42	0.47	0.48	0.52	0.52	0.51	0.50	0.52	0.52	0.56	0.45	0.45
Chattanooga, TN	N35.0	0.48	0.46	0.50	0.54	0.54	0.54	0.52	0.54	0.51	0.57	0.46	0.46
Knoxville, TN	N35.8	0.44	0.48	0.51	0.52	0.51	0.54	0.53	0.52	0.51	0.55	0.48	0.46
Memphis, TN	N35.0	0.50	0.52	0.55	0.56	0.56	0.58	0.59	0.60	0.53	0.60	0.51	0.48
Nashville, TN	N36.1	0.48	0.52	0.54	0.54	0.54	0.57	0.57	0.55	0.54	0.57	0.48	0.45
Abilene, TX	N32.4	0.57	0.59	0.60	0.62	0.59	0.61	0.62	0.60	0.57	0.64	0.61	0.57
Amarillo, TX	N35.2	0.57	0.61	0.61	0.62	0.60	0.64	0.63	0.60	0.60	0.67	0.56	0.59
Austin, TX	N30.3	0.52	0.55	0.55	0.53	0.53	0.58	0.60	0.60	0.57	0.60	0.55	0.50
Brownsville, TX	N25.9	0.46	0.47	0.50	0.51	0.54	0.57	0.59	0.56	0.53	0.59	0.50	0.43
Corpus Christi, TX	N27.8	0.46	0.48	0.48	0.48	0.50	0.54	0.56	0.56	0.54	0.53	0.50	0.46
El Paso, TX	N31.8	0.62	0.64	0.68	0.70	0.70	0.72	0.67	0.64	0.67	0.70	0.65	0.64
Fort Worth, TX	N32.8	0.53	0.53	0.56	0.57	0.58	0.61	0.62	0.61	0.58	0.59	0.54	0.53
Houston, TX	N30.0	0.46	0.47	0.49	0.48	0.51	0.54	0.52	0.53	0.53	0.56	0.52	0.44
Lubbock, TX	N33.6	0.57	0.59	0.63	0.61	0.62	0.63	0.59	0.59	0.58	0.65	0.62	0.59
Lufkin, TX	N31.2	0.48	0.50	0.51	0.53	0.55	0.56	0.56	0.57	0.56	0.58	0.54	0.48
Midland, TX	N31.9	0.60	0.62	0.66	0.64	0.62	0.62	0.65	0.62	0.60	0.65	0.62	0.59

Port Arthur, TX	N29.9	0.46	0.50	0.51	0.51	0.53	0.58	0.53	0.55	0.54	0.58	0.49	0.47
San Angelo, TX	N31.4	0.57	0.58	0.59	0.58	0.57	0.60	0.61	0.61	0.59	0.62	0.56	0.56
San Antonio, TX	N29.5	0.51	0.54	0.55	0.53	0.54	0.58	0.63	0.61	0.58	0.60	0.56	0.51
Victoria, TX	N28.9	0.47	0.50	0.49	0.49	0.52	0.54	0.57	0.56	0.56	0.56	0.54	0.48
Waco, TX	N31.6	0.51	0.57	0.54	0.51	0.54	0.60	0.63	0.59	0.58	0.61	0.57	0.53
Wichita Falls, TX	N34.0	0.55	0.57	0.58	0.58	0.57	0.61	0.62	0.60	0.60	0.60	0.57	0.55
Cedar City, UT	N37.7	0.58	0.59	0.60	0.63	0.63	0.69	0.65	0.64	0.65	0.68	0.59	0.56
Salt Lake City, UT	N40.8	0.49	0.54	0.54	0.55	0.62	0.63	0.66	0.67	0.64	0.62	0.54	0.45
Lynchburg, VA	N37.3	0.50	0.54	0.57	0.55	0.54	0.56	0.57	0.55	0.55	0.55	0.53	0.49
Norfolk, VA	N36.9	0.50	0.52	0.49	0.53	0.51	0.55	0.52	0.54	0.51	0.55	0.51	0.46
Richmond, VA	N37.5	0.52	0.51	0.52	0.52	0.52	0.53	0.54	0.52	0.54	0.52	0.50	0.49
Roanoke, VA	N37.3	0.50	0.51	0.51	0.53	0.54	0.54	0.53	0.53	0.53	0.55	0.51	0.47
Sterling, VA	N39.0	0.49	0.51	0.51	0.52	0.51	0.54	0.53	0.52	0.53	0.54	0.48	0.42
Burlington, VT	N44.5	0.50	0.54	0.52	0.51	0.53	0.52	0.53	0.54	0.51	0.48	0.42	0.42
Olympia, WA	N47.0	0.32	0.39	0.44	0.41	0.46	0.50	0.54	0.54	0.51	0.43	0.36	0.34
Quillayute, WA	N48.0	0.32	0.36	0.38	0.42	0.46	0.45	0.48	0.46	0.48	0.46	0.36	0.37
Seattle, WA	N47.5	0.31	0.37	0.44	0.45	0.51	0.52	0.56	0.52	0.52	0.41	0.35	0.29
Spokane, WA	N47.6	0.49	0.44	0.47	0.51	0.53	0.53	0.65	0.63	0.58	0.55	0.41	0.43
Yakima, WA	N46.6	0.42	0.50	0.54	0.53	0.58	0.61	0.65	0.63	0.63	0.58	0.44	0.43
Eau Claire, WI	N44.9	0.50	0.59	0.56	0.49	0.53	0.54	0.54	0.53	0.50	0.49	0.42	0.43
Green Bay, WI	N44.5	0.49	0.52	0.52	0.52	0.53	0.53	0.56	0.50	0.49	0.50	0.42	0.46
La Crosse, WI	N43.9	0.55	0.55	0.53	0.50	0.54	0.53	0.57	0.53	0.50	0.53	0.44	0.43

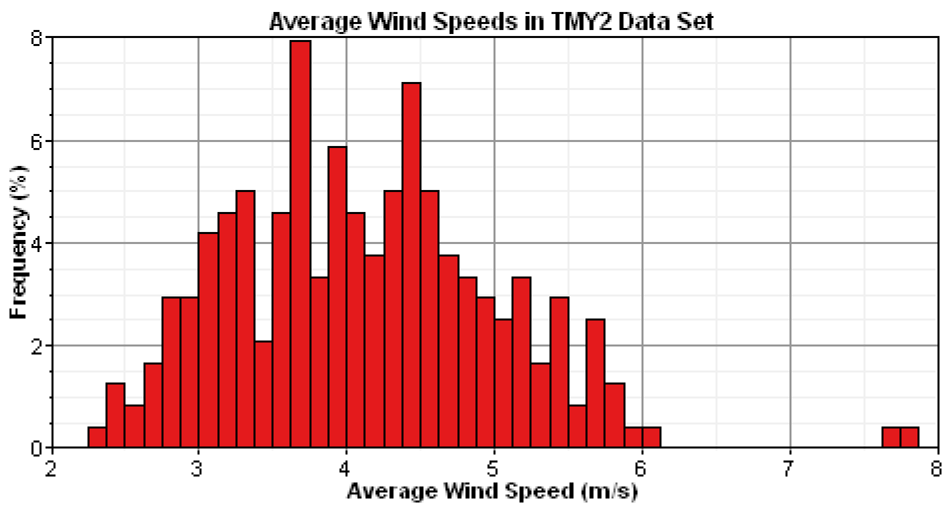
Madison, WI	N43.1	0.48	0.54	0.50	0.48	0.54	0.55	0.56	0.57	0.51	0.51	0.44	0.49
Milwaukee, WI	N43.0	0.51	0.51	0.48	0.51	0.54	0.57	0.54	0.55	0.54	0.51	0.45	0.44
Charleston, WV	N38.4	0.44	0.44	0.48	0.51	0.50	0.50	0.52	0.52	0.51	0.52	0.45	0.39
Elkins, WV	N38.9	0.44	0.45	0.45	0.48	0.49	0.49	0.49	0.49	0.48	0.50	0.43	0.39
Huntington, WV	N38.4	0.46	0.45	0.49	0.49	0.50	0.52	0.51	0.51	0.52	0.52	0.47	0.42
Casper, WY	N42.9	0.55	0.55	0.56	0.57	0.57	0.61	0.61	0.65	0.62	0.61	0.54	0.51
Cheyenne, WY	N41.1	0.54	0.56	0.58	0.57	0.56	0.60	0.58	0.59	0.62	0.60	0.57	0.53
Lander, WY	N42.8	0.57	0.62	0.61	0.59	0.59	0.63	0.63	0.62	0.66	0.63	0.59	0.58
Rock Springs, WY	N41.6	0.53	0.56	0.58	0.60	0.60	0.62	0.64	0.65	0.65	0.64	0.54	0.52
Sheridan, WY	N44.8	0.55	0.55	0.56	0.55	0.52	0.58	0.60	0.62	0.61	0.58	0.54	0.53

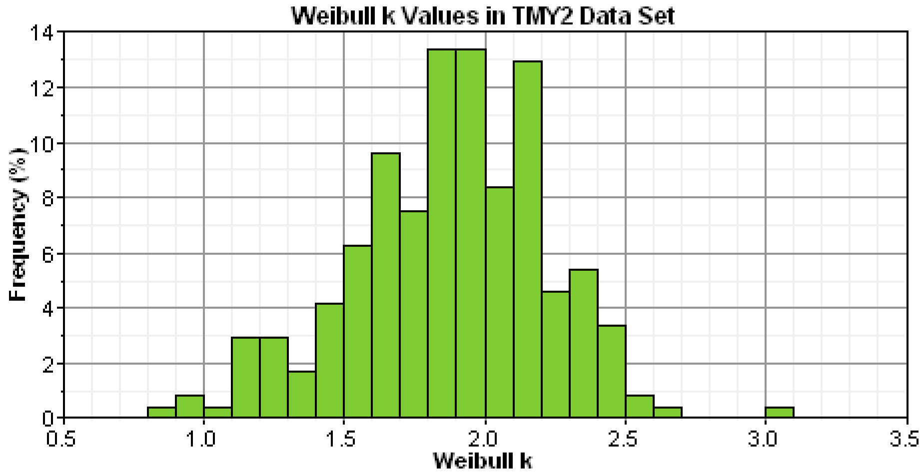
6.3 Wind Data Histograms

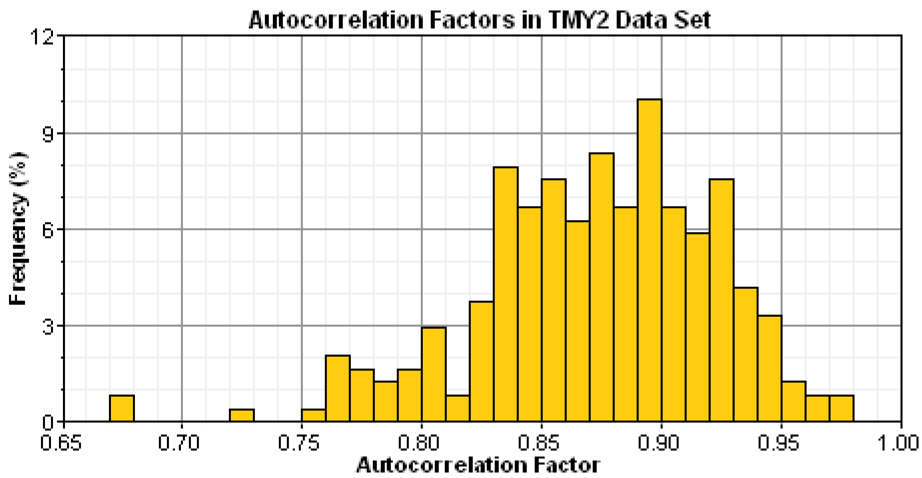
The following five wind data parameters were measured for the 239 weather stations in the U.S. National Solar Radiation Data Base:

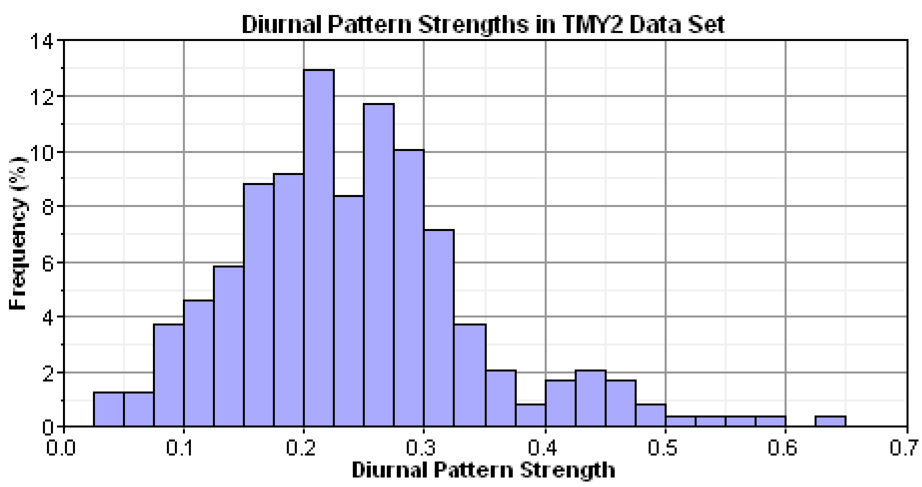
- annual average wind speed
- **Weibull *k* value**
- **autocorrelation factor**
- **diurnal pattern strength**
- **hour of peak wind speed**

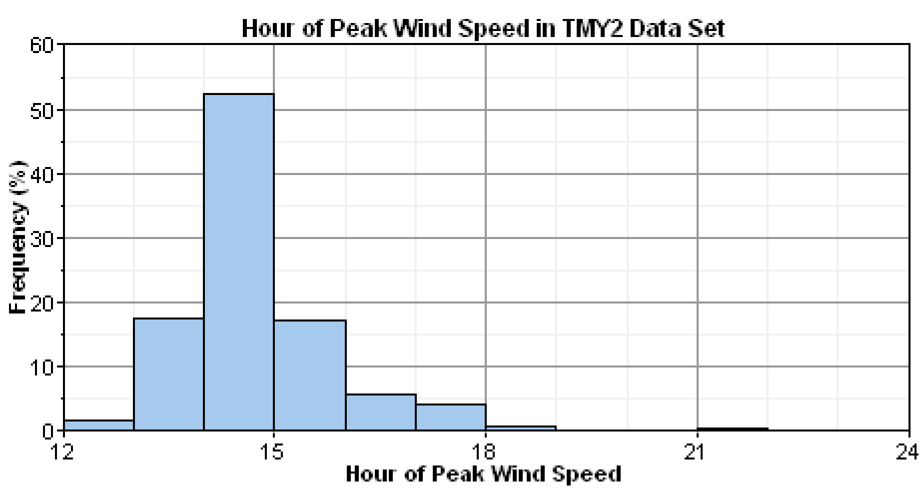
The numerical results are displayed in the **table of measured parameters**. The histograms below show the distribution of each of these parameters:











6.4 Wind Data Parameters

The following table contains the following parameters for each of the 239 stations in the US National Solar Radiation Data Base:

- annual average wind speed, v_{ave} [m/s]

- **Weibull *k* value**, k
- **one-hour autocorrelation factor**, r_1
- **diurnal pattern strength**, δ
- **hour of peak wind speed**, ϕ

You can also look at **histograms** of these parameters.

Important: The stations that make these measurements are not typically located so as to maximize the wind resource. So this data is likely to be conservative in terms of wind speed, since in siting a wind turbine you would normally seek out a ridgeline or other topographic feature to maximize average wind speeds. Also, this data is compiled from TMY (Typical Meteorological Year) data, which is chosen as "typical" largely on the basis of solar data, not wind data. So these data do not necessarily represent a typical year of wind speeds.

City	State	v_{ave}	k	r_1	δ	ϕ
Anchorage	AK	3.277	1.681	0.769	0.125	17
Annette	AK	4.206	1.650	0.973	0.132	13
Barrow	AK	5.482	2.234	0.948	0.036	15
Bethel	AK	5.659	2.166	0.950	0.059	16
Bettles	AK	3.148	1.689	0.873	0.112	14
Big Delta	AK	4.069	1.297	0.966	0.091	17
Cold Bay	AK	7.661	2.019	0.913	0.075	15
Fairbanks	AK	2.506	1.289	0.787	0.160	17
Gulkana	AK	2.651	0.809	0.934	0.183	16
King Salmon	AK	4.882	1.874	0.932	0.143	16
Kodiak	AK	4.652	1.468	0.895	0.082	15
Kotzebue	AK	6.005	1.833	0.934	0.030	14
McGrath	AK	2.482	1.428	0.894	0.202	16
Nome	AK	4.774	1.621	0.920	0.117	15
St. Paul Island	AK	7.802	2.084	0.966	0.052	14
Talkeetna	AK	2.465	1.030	0.876	0.268	15
Yakutat	AK	2.964	1.359	0.945	0.218	14
Birmingham	AL	3.163	1.521	0.831	0.345	13
Huntsville	AL	3.626	1.619	0.838	0.276	13
Mobile	AL	3.684	1.852	0.849	0.268	13

Montgomery	AL	3.023	1.658	0.794	0.338	13
Fort Smith	AR	3.235	1.845	0.901	0.307	14
Little Rock	AR	3.435	1.887	0.807	0.284	14
Flagstaff	AZ	3.238	1.537	0.922	0.447	14
Phoenix	AZ	2.984	2.016	0.727	0.148	14
Prescott	AZ	3.734	1.927	0.847	0.272	15
Tucson	AZ	3.935	2.127	0.858	0.160	15
Arcata	CA	3.051	1.366	0.911	0.424	14
Bakersfield	CA	2.852	1.750	0.830	0.267	16
Dagget	CA	4.901	1.750	0.933	0.028	21
Fresno	CA	2.986	1.880	0.867	0.194	17
Long Beach	CA	2.702	1.595	0.850	0.549	15
Los Angeles	CA	3.575	1.961	0.676	0.469	15
Sacramento	CA	3.251	1.413	0.894	0.276	15
San Diego	CA	3.224	1.983	0.798	0.412	14
San Francisco	CA	4.530	1.689	0.876	0.405	17
Santa Maria	CA	3.356	1.271	0.871	0.632	15
Alamosa	CO	3.746	1.502	0.900	0.336	17
Boulder/Denver	CO	3.639	1.849	0.678	0.208	16
Colorado Springs	CO	4.356	1.890	0.831	0.185	15
Eagle	CO	2.712	0.944	0.836	0.579	16
Grand Junction	CO	3.560	1.784	0.823	0.086	14
Pueblo	CO	4.097	1.678	0.842	0.311	16
Bridgeport	CT	5.423	2.336	0.880	0.173	14
Hartford	CT	3.831	1.878	0.882	0.275	14
Wilmington	DE	4.134	1.977	0.899	0.252	14
Daytona Beach	FL	3.811	1.795	0.895	0.416	14
Jacksonville	FL	3.283	1.555	0.775	0.463	14
Key West	FL	5.089	2.506	0.942	0.069	13
Miami	FL	4.337	2.214	0.803	0.292	14

Tallahassee	FL	2.901	1.432	0.841	0.460	14
Tampa	FL	3.579	2.147	0.762	0.336	14
West Palm Beach	FL	4.391	1.984	0.926	0.297	14
Athens	GA	3.314	2.002	0.920	0.209	14
Atlanta	GA	3.947	2.152	0.808	0.170	14
Augusta	GA	3.158	1.587	0.860	0.338	14
Columbus	GA	2.950	1.604	0.889	0.346	14
Macon	GA	3.287	1.689	0.780	0.307	14
Savannah	GA	3.565	1.969	0.918	0.324	14
Hilo	HI	3.142	2.263	0.839	0.260	14
Honolulu	HI	4.950	2.433	0.822	0.306	15
Kahului	HI	5.712	2.305	0.880	0.374	15
Lihue	HI	5.503	3.024	0.951	0.086	15
Des Moines	IA	4.696	1.999	0.922	0.216	13
Mason City	IA	5.079	2.052	0.898	0.210	13
Sioux City	IA	4.885	2.030	0.894	0.208	14
Waterloo	IA	4.763	1.904	0.897	0.235	13
Boise	ID	3.810	1.845	0.779	0.201	15
Pocatello	ID	4.728	1.731	0.881	0.192	15
Chicago	IL	4.620	2.152	0.847	0.195	14
Moline	IL	4.619	1.896	0.905	0.260	13
Peoria	IL	4.379	2.124	0.859	0.224	13
Rockford	IL	4.665	2.137	0.903	0.234	13
Springfield	IL	4.804	2.178	0.909	0.159	13
Evansville	IN	3.525	1.492	0.858	0.327	13
Fort Wayne	IN	4.468	2.115	0.899	0.200	14
Indianapolis	IN	4.063	1.966	0.890	0.209	14
South Bend	IN	4.503	2.084	0.894	0.225	14
Dodge City	KS	5.790	2.404	0.847	0.130	13
Goodland	KS	5.831	2.396	0.855	0.084	13

Topeka	KS	4.392	1.843	0.847	0.249	14
Wichita	KS	5.214	2.205	0.909	0.175	14
Covington	KY	3.950	2.076	0.856	0.207	14
Lexington	KY	3.942	2.277	0.929	0.180	13
Louisville	KY	3.672	1.876	0.831	0.268	15
Baton Rouge	LA	3.239	1.647	0.872	0.311	14
Lake Charles	LA	3.775	1.973	0.832	0.286	14
New Orleans	LA	3.582	1.828	0.864	0.258	13
Shreveport	LA	3.464	1.746	0.841	0.279	14
Boston	MA	5.430	2.401	0.838	0.126	14
Worcester	MA	4.319	1.944	0.903	0.087	13
Baltimore	MD	4.108	1.995	0.842	0.264	14
Caribou	ME	4.593	1.769	0.909	0.172	14
Portland	ME	3.904	1.908	0.856	0.295	14
Alpena	MI	3.693	1.943	0.897	0.289	14
Detroit	MI	4.507	2.123	0.848	0.243	14
Flint	MI	4.378	2.027	0.886	0.212	14
Grand Rapids	MI	4.454	2.199	0.892	0.215	14
Houghton	MI	4.060	2.338	0.909	0.161	15
Lansing	MI	4.344	1.855	0.933	0.223	14
Muskegon	MI	4.888	2.104	0.931	0.190	14
Sault Ste. Marie	MI	3.806	1.987	0.862	0.244	15
Traverse City	MI	3.993	1.818	0.868	0.241	14
Duluth	MN	4.701	2.205	0.924	0.156	14
International Falls	MN	4.019	1.977	0.871	0.221	13
Minneapolis/St. Paul	MN	4.624	2.016	0.897	0.223	14
Rochester	MN	5.789	2.441	0.926	0.130	12
St. Cloud	MN	3.661	1.730	0.942	0.274	14
Columbia	MO	4.439	2.322	0.874	0.157	13
Kansas City	MO	4.482	2.527	0.842	0.166	14

Springfield	MO	4.506	2.284	0.858	0.190	12
St. Louis	MO	4.401	2.094	0.857	0.172	14
Jackson	MS	3.322	1.607	0.857	0.324	13
Meridian	MS	2.769	1.247	0.825	0.434	13
Billings	MT	5.155	2.324	0.885	0.079	14
Cut Bank	MT	5.672	1.761	0.946	0.225	15
Glasgow	MT	4.802	2.059	0.933	0.130	14
Great Falls	MT	5.513	1.898	0.906	0.156	14
Helena	MT	3.527	1.537	0.876	0.281	16
Kalispell	MT	2.828	1.139	0.905	0.255	14
Lewistown	MT	4.245	1.745	0.917	0.149	14
Miles City	MT	4.624	2.040	0.836	0.102	14
Missoula	MT	3.023	1.296	0.831	0.327	17
Asheville	NC	3.480	1.308	0.854	0.313	14
Cape Hatteras	NC	5.157	2.419	0.954	0.100	14
Charlotte	NC	3.139	1.825	0.791	0.291	14
Greensboro	NC	3.116	1.861	0.823	0.287	13
Raleigh/Durham	NC	3.503	2.005	0.816	0.245	14
Wilmington	NC	3.670	1.822	0.904	0.309	14
Bismarck	ND	4.420	1.608	0.875	0.308	14
Fargo	ND	5.377	2.026	0.927	0.158	14
Minot	ND	5.489	2.310	0.879	0.138	14
Grand Island	NE	5.336	2.246	0.910	0.175	14
Norfolk	NE	5.455	1.710	0.924	0.229	14
North Platte	NE	4.651	1.692	0.862	0.264	15
Omaha	NE	4.493	1.838	0.922	0.176	13
Scottsbluff	NE	4.663	1.820	0.813	0.235	14
Concord	NH	2.865	1.149	0.838	0.441	14
Atlantic City	NJ	4.420	1.935	0.948	0.262	14
Newark	NJ	4.624	2.345	0.809	0.157	15

Albuquerque	NM	4.009	1.723	0.789	0.255	17
Tucumcari	NM	4.335	1.907	0.911	0.208	14
Elko	NV	2.700	1.195	0.827	0.470	15
Ely	NV	4.374	1.963	0.879	0.078	13
Las Vegas	NV	4.063	1.809	0.854	0.139	18
Reno	NV	2.839	1.124	0.856	0.555	17
Tonopah	NV	4.317	1.804	0.826	0.167	15
Winnemucca	NV	3.630	1.833	0.851	0.245	15
Albany	NY	3.958	1.567	0.856	0.259	14
Binghamton	NY	4.509	2.357	0.891	0.155	14
Buffalo	NY	5.135	2.152	0.889	0.181	14
Massena	NY	3.632	1.520	0.885	0.267	13
NYC (Central Park)	NY	5.185	2.676	0.933	0.130	15
Rochester	NY	4.377	1.983	0.916	0.183	14
Syracuse	NY	4.100	1.903	0.877	0.202	14
Akron/Canton	OH	4.173	2.179	0.890	0.210	13
Cleveland	OH	4.506	2.186	0.842	0.191	14
Columbus	OH	3.728	1.898	0.847	0.288	14
Dayton	OH	4.311	2.106	0.847	0.185	14
Mansfield	OH	4.786	2.342	0.930	0.159	13
Toledo	OH	4.150	1.914	0.898	0.266	14
Youngstown	OH	4.407	2.312	0.893	0.178	14
Oklahoma City	OK	5.352	2.253	0.937	0.183	13
Tulsa	OK	4.811	2.173	0.902	0.222	14
Astoria	OR	3.987	1.876	0.916	0.254	15
Burns	OR	3.213	1.652	0.946	0.240	15
Eugene	OR	3.366	1.904	0.890	0.273	14
Medford	OR	2.255	1.262	0.765	0.484	16
North Bend	OR	4.276	1.768	0.911	0.322	15
Pendleton	OR	3.826	1.749	0.885	0.125	16

Portland	OR	3.580	1.560	0.872	0.230	16
Redmond/Bend	OR	3.640	1.913	0.835	0.295	15
Salem	OR	3.127	1.387	0.897	0.291	14
Allentown	PA	4.143	1.684	0.884	0.289	14
Bradford	PA	3.660	1.765	0.921	0.260	14
Erie	PA	5.141	2.216	0.910	0.104	12
Harrisburg	PA	3.353	1.513	0.845	0.278	14
Philadelphia	PA	4.307	2.190	0.831	0.203	14
Pittsburgh	PA	3.922	1.760	0.850	0.284	14
Wilkes-Barre	PA	3.641	2.146	0.836	0.222	14
Williamsport	PA	3.442	1.295	0.870	0.297	14
Guam	PI	4.205	2.189	0.973	0.307	13
San Juan	PR	3.823	1.788	0.869	0.504	15
Providence	RI	4.702	2.157	0.881	0.257	14
Charleston	SC	3.892	2.069	0.821	0.318	14
Columbia	SC	3.035	1.555	0.773	0.382	14
Greenville	SC	2.982	1.810	0.896	0.277	13
Huron	SD	4.842	1.956	0.918	0.202	14
Pierre	SD	5.102	1.884	0.920	0.194	14
Rapid City	SD	5.342	1.677	0.928	0.231	13
Sioux Falls	SD	5.023	2.021	0.927	0.217	14
Bristol	TN	2.397	1.174	0.833	0.437	15
Chattanooga	TN	2.507	1.108	0.801	0.493	15
Knoxville	TN	3.023	1.545	0.845	0.262	15
Memphis	TN	3.998	1.903	0.887	0.229	13
Nashville	TN	3.642	1.902	0.803	0.250	14
Abilene	TX	5.205	2.418	0.915	0.119	14
Amarillo	TX	5.929	2.411	0.878	0.129	14
Austin	TX	4.062	1.895	0.835	0.238	14
Brownsville	TX	5.266	2.130	0.924	0.361	14

Corpus Christi	TX	5.377	2.197	0.918	0.303	15
El Paso	TX	3.534	1.612	0.798	0.241	16
Fort Worth	TX	4.433	1.984	0.909	0.191	14
Houston	TX	3.777	2.112	0.775	0.321	14
Lubbock	TX	5.196	2.164	0.890	0.184	15
Lufkin	TX	3.068	1.515	0.854	0.395	14
Midland/Odessa	TX	5.050	2.184	0.832	0.225	14
Port Arthur	TX	4.367	2.176	0.885	0.261	14
San Angelo	TX	4.638	2.150	0.863	0.199	14
San Antonio	TX	4.200	2.332	0.864	0.202	15
Victoria	TX	4.487	2.158	0.929	0.308	14
Waco	TX	4.842	2.323	0.906	0.138	14
Wichita Falls	TX	5.675	2.414	0.944	0.164	14
Cedar City	UT	3.554	1.179	0.861	0.439	16
Salt Lake City	UT	3.968	1.667	0.762	0.119	13
Lynchburg	VA	3.061	1.454	0.867	0.359	14
Norfolk	VA	4.883	2.207	0.862	0.183	13
Richmond	VA	3.653	2.110	0.897	0.227	14
Roanoke	VA	3.630	1.662	0.859	0.265	15
Sterling	VA	3.490	1.694	0.821	0.291	14
Burlington	VT	4.064	2.004	0.806	0.204	13
Olympia	WA	3.060	1.441	0.883	0.303	14
Quillayute	WA	2.787	1.559	0.871	0.372	14
Seattle	WA	3.897	2.108	0.760	0.121	15
Spokane	WA	4.333	1.934	0.875	0.122	12
Yakima	WA	3.296	1.725	0.870	0.139	18
Eau Claire	WI	3.974	1.888	0.872	0.275	14
Green Bay	WI	4.438	1.999	0.918	0.232	13
La Crosse	WI	3.706	1.645	0.887	0.199	14
Madison	WI	4.223	1.860	0.892	0.260	13

Milwaukee	WI	4.944	2.087	0.868	0.194	13
Charleston	WV	2.764	1.433	0.860	0.326	14
Elkins	WV	2.932	0.971	0.906	0.370	14
Huntington	WV	3.101	1.917	0.822	0.241	14
Casper	WY	5.652	2.075	0.929	0.216	13
Cheyenne	WY	5.735	1.996	0.868	0.173	13
Lander	WY	3.363	1.459	0.759	0.255	17
Rock Springs	WY	5.097	1.629	0.874	0.280	15
Sheridan	WY	3.367	1.494	0.833	0.265	14

6.5 References

This page lists sources of information on the algorithms used within HOMER and sources you can use to develop the inputs you need to run HOMER.

Solar Power

- Duffie JA, Beckman WA (1991) Solar Engineering of Thermal Processes 2nd edition, Wiley, New York, NY
- Erbs DG, Klein SA, Duffie JA (1982) Estimation of the diffuse radiation fraction for hourly, daily, and monthly-average global radiation, *Solar Energy*, **28**, 293
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Wind Power

- Manwell JF, McGowan JG, Rogers AL (2002) Wind Energy Explained, Wiley, New York, NY
- Stevens MJM, Smulders PT (1979) The estimation of the parameters of the Weibull wind speed distribution for wind energy utilization purposes, *Wind Engineering*, **3**, 132-145
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Storage

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- Neubauer J (2014) Battery Lifetime Analysis and Simulation Tool (BLAST) Documentation, NREL/TP-5400-63246. Retrieved from http://www.nrel.gov/docs/fy15osti/63246.pdf
- Smith K, Earleywine M, et. al. (2012) Comparison of Plug-In Hybrid Electric Vehicle Battery Life Across Geographies and Drive Cycles, *SAE World Congress and Exhibition*, Detroit, Michigan, April 24-26, 2012

- ASTM E1049-85(2011)e1, Standard Practices for Cycle Counting in Fatigue Analysis, ASTM International, West Conshohocken, PA, 2011, www.astm.org
- Manwell, J. F., McGowan, J. G., Abdulwahid, U., & Wu, K. (2005, May). Improvements to the hybrid2 battery model. In Windpower 2005 Conference. American Wind Energy Association.

System Operation/Dispatch

- Barley CD, Winn CB (1996) Optimal dispatch strategy in remote hybrid power systems, *Solar Energy*, **58**, 165-179

See also

6.6 Recommended Reading

6.6 Recommended Reading

This page lists sources of information that you might find helpful in learning about micropower systems. None of this information is essential to running HOMER.

Renewable and Micropower Systems

- Masters G (2004) Renewable and Efficient Electric Power Systems, Wiley-IEEE Press, ISBN: 0471280607
- Borbely AM, Kreider JF, (2001) Distributed Generation: The Power Paradigm for the New Millennium, CRC Press, ISBN: 0849300746

Solar Resource

- Chapters 1 and 2 of Duffie JA, Beckman WA (1991) Solar Engineering of Thermal Processes 2nd edition, Wiley, New York, NY, ISBN: 0471510564

Wind Resource

- An excellent and multilingual source of information on the wind resource, wind turbine technology, economics and more is **www.windpower.org**, the Danish Wind Industry Association's website.
- Chapter 2 of Manwell JF, McGowan JG, Rogers AL (2002) Wind Energy Explained, Wiley, New York, NY, ISBN: 0471499722

Biomass Resource

- McKendry P (2002a) Energy production from biomass (part 1): overview of biomass, *Bioresource Technology*, **83**, 37-46

Biomass Power

- McKendry P (2002b) Energy production from biomass (part 2): conversion technologies, *Bioresource Technology*, **83**, 47-54

Hydro Power

- For a helpful introduction to small hydro, see Paish O (2002) Small hydro power: technology and current status, *Renewable and Sustainable Energy Reviews*, **6**, 537-556
- For a useful website on all things microhydro, see **www.microhydropower.net**.
- Some useful calculation tools are available at the website of VA Tech Hydro, **www.compact-hydro.com**.

See also

6.5 References

7. Glossary

7.1 English-Spanish Glossary

This glossary includes words and terms that are part of the HOMER user interface with their equivalents in Spanish. The words appear in alphabetical order, based on the English spelling.

To see a definition, click on a letter below to go to the section of the glossary for that letter.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

English	Spanish
A	
Abbreviation	Abreviación
AC	CA
Add noise	Agregar ruido
Add/RemoveAgregar/Eliminar	
Advanced parameters	Parámetros avanzados
Allow multiple generators to operate simultaneously	Permite múltiples generadores para operar simultáneamente
Allow systems with generator capacity less than peak load	Permite sistemas con generadores de capacidad inferior a picos de demanda
Allow systems with multiple generators	Permite sistemas con múltiples generadores
Annual electric energy production	Producción anual de energía eléctrica
Annual electric loads	Cargas eléctricas anuales
Annual fuel consumption	Consumo anual de combustible
Annual peak	Pico anual
Annual peak load	Carga anual pico
Annual real interest rate	Tasa de interés real anual
Apply setpoint SOC	Aplica punto de ajuste EDC (Estado De Carga)
As percent of load	Como porcentaje de la carga

As percent of renewable output	Como porcentaje de producción renovable
Author	Autor
Autocorrelation factor	Factor de auto corrección
Automatically check for updates on startup	Revisa automáticamente para actualizarse al inicio
Available biomass	Biomasa disponible
Average electrical efficiency	Eficiencia eléctrica promedio
Average electrical output	Producción eléctrica promedio
Average Hydrogen Load	Carga promedio de hidrógeno
Average price	Precio promedio
Average total efficiency	Promedio de eficiencia total
Azimuth	Azimut
B	
Baseline data	Datos base
Batt. (battery)	Batería
Batt. cap. mult.	Multiplicador del costo inversión de la batería
Batt. capital cost Multiplier	Multiplicador del costo inversión de la batería
Batt. O&M mult.	Multiplicador del costo operación y mantenimiento de la batería
Batt. O&M cost multiplier	Multiplicador del costo operación y mantenimiento de la batería
Batt. repl. mult.	Multiplicador del costo reemplazo batería
Batt. replacement cost multiplier	Multiplicador del costo reemplazo de la batería
Battery	Batería
Battery capital cost multiplier	Multiplicador del costo inversión de la batería
Battery O&M cost multiplier	Multiplicador del costo operación y mantenimiento de la batería
Battery replacement cost multiplier	Multiplicador del costo reemplazo de la batería

Bio. gas. ratio	Razón de biogás
Bio. GR	Razón de biogás
Biogas	Biogás
Biogas LHV	Valor calórico mas bajo de biogás (VCB)
Biogas lower heating value	Valor calórico mas bajo de biogás
Biomass carbon content	Contenido de carbón biomasa
Biomass data scaled average	Promedio escalado de datos de biomasa
Biomass gasification ratio	Razón de gasificación de la biomasa
Biomass price	Precio de la biomasa
Biomass resource	Recurso de biomasa
Biomass resource price	Precio del recurso biomasa
Boiler	Calentador
Boiler cap.	Capacidad de la caldera
Boiler capacity	Capacidad de la caldera
Boiler eff.	Eficiencia de la caldera
Boiler efficiency	Eficiencia de la caldera

C

Calculate	Calcular
Calculated parameters	Parámetros calculados
Cancel	Cancelar
Capacity curve	Curva de capacidad
Capacity ratio	Razón de capacidad
Capacity relative to inverter	Capacidad relativa al inversor
Capacity shortage	Falta de capacidad
Capital	Capital
Carbon content	Contenido de carbón
Carbon emissions	Emisiones de carbón

Clear	Borrar
Clearness index	Índice de claridad
COE (cost of energy)	CE (costo de la energía)
Cofire inputs	Datos del combustible alterno
Cofire with biogas	Combustible con biogás
Component	Componente
Constraints	Consideraciones
Consumption limit	Limite de consumo
Conv. (converter)	Convertidor
Conv. cap. mult.	Multiplicador del costo inversión del convertidor
Conv. O&M mult.	Multiplicador del costo operación y mantenimiento del convertidor
Conv. repl. mult.	Multiplicador del costo reemplazo del convertidor
Converter	Convertidor
Converter capital cost multiplier	Multiplicador del costo inversión del convertidor
Converter capital multiplier	Multiplicador del costo inversión del convertidor
Converter O&M cost multiplier	Multiplicador del costo operación y mantenimiento del convertidor
Converter O&M multiplier	Multiplicador del costo operación y mantenimiento del convertidor
Converter replacement cost multiplier	Multiplicador del costo reemplazo del convertidor
Converter replacement multiplier	Multiplicador del costo reemplazo del convertidor
Cost curve	Curva de costo
Costs	Costos
Current	Corriente
Cycle charging	Ciclos de carga

Cycles to failure	Ciclos de falla
D	
Daily noise	Ruido diario
Daily radiation	Radiación diaria
Day type	Tipo de día
DC	CD
Default author	Autor por definición
Def. load min.	Carga Mínima diferida
Def. load peak	Carga Pico diferida
Def. load storage	Capacidad de almacenamiento diferida
Deferrable load	Cargas diferidas
Deferrable load min.	Carga mínima diferida
Deferrable load minimum	Carga mínima diferida
Deferrable load peak	Carga pico diferida
Deferrable load served	Cargas diferidas servidas
Deferrable load storage capacity	Capacidad de almacenamiento diferida
Degrees	Grados
Delete	Eliminar
Demand	Demanda
Demand rate	Razón de demanda
Density	Densidad
Depth of discharge	Profundidad de descarga
Derating factor	Factor de reducción
Design flow rate	Razón de flujo de diseño
Details	Detalles
Dispatch strategy	Estrategia de despacho
Diurnal pattern strength	Patrón diurno de intensidad

Document	Documento
E	
Economics	Económicos
Efficiency curve	Curva de eficiencia
Efficiency inputs	Datos de eficiencia
Elec. (electrolyzer)	Elec. (fluido electrolítico)
Elec. cap. mult.	Multiplicador del costo inversión del electrolizador
Elec. eff.	Eficiencia electrolizador
Elec. min.	Mínimo electrolizador
Elec. min. load	Carga mínima electrolizador
Elec. O&M mult.	Multiplicador del costo operación y mantenimiento del electrolizador
Elec. repl. mult.	Multiplicador del costo reemplazo del electrolizador
Electrolyzer	Fluido electrolítico
Electrolyzer capital cost multiplier	Multiplicador del costo de inversión del electrolizador
Electrolyzer capital multiplier	Multiplicador del costo de inversión del electrolizador
Electrolyzer eff.	Eficiencia electrolítica
Electrolyzer efficiency	Eficiencia electrolítica
Electrolyzer life	Vida del electrolito
Electrolyzer lifetime	Tiempo de vida del electrolito
Electrolyzer load served	Cargas cubiertas por el electrolizador
Electrolyzer minimum load ratio	Razón carga mínima del electrolizador
Electrolyzer O&M cost multiplier	Multiplicador del costo operación y mantenimiento del electrolizador
Electrolyzer O&M multiplier	Multiplicador del costo operación y mantenimiento del electrolizador
Electrolyzer replacement	Multiplicador del costo reemplazo del

cost multiplier	electrolizador
Electrolyzer replacement multiplier	Multiplicador del costo reemplazo del electrolizador
Equipment to consider	Equipo a considerar
Excess electricity	Excedente de electricidad
Excess electricity can serve thermal load	Excedente de electricidad puede servir a cargas térmicas
Export	Exportar
F	
File version	Versión del archivo
Fixed (variables)	Fijo (variables)
Fixed cap. cost	Costo de inversión fijo
Fixed O&M cost	Costo de operación y mantenimiento fijo
Fuel curve	Curva de combustible
G	
Generator	Generador
Generator control	Control del generador
Generator fuel curve intercept coefficient	Coeficiente de intercepción de la curva de combustible del generador
Generator fuel curve slope	Pendiente de la curva de combustible del generador
Generator heat recovery ratio	Razón de recuperación de calor generador
Generator lifetime	Tiempo de vida generador
Generator minimum fossil fraction	Fracción combustible mínimo generador
Generator minimum load	Carga mínima generador
Generator substitution ratio	Razón de sustitución generador
Generator type	Tipo de generador
Global solar	Radiación solar global
Graphic	Grafica

Grid	Red
Grid cap.	Capacidad de la red
Grid capital cost	Costo de la red
Grid demand rate	Razón de demanda de la red
Grid extension cost	Costo extensión de la red
Grid extension capital cost	Costo por extensión de la red
Grid extension O&M Cost	Costo por operación y mantenimiento de extensión de la red
Grid extension power price	Precio de la energía por extensión de la red
Grid interconnection charge	Cargo por interconexión con la Red
Grid O&M	Costo por operación y mantenimiento de la red
Grid O&M cost	Costo por operación y mantenimiento de la red
Grid power	Capacidad de la red
Grid power price	Precio de la energía de la red
Grid power price	Precio de la energía de la red
Grid sellback rate	Razón de repago de la red
Grid standby charge	Cargo por tiempo de espera de la red
Grid-connected system	Sistema conectado a la red
Grnd. ref.	Reflexión de tierra
Ground reflectance	Reflexión de tierra
H	
H2 Load	Carga hidrogeno
H2 tank capital multiplier	Multiplicador del costo inversión del tanque de hidrogeno
H2 tank life	Tiempo de vida del tanque de hidrogeno
H2 tank O&M multiplier	Multiplicador del costo de operación y mantenimiento del tanque de hidrogeno
H2 tank replacement multiplier	Multiplicador de reemplazo del tanque de

	Hidrogeno
Help	Ayuda
Hour of peak wind speed	Hora de velocidad de viento pico
Hourly data	Datos horarios
Hourly load	Carga horaria
Hourly noise	Ruido horario
Hours of operations	Horas de operación
HT cap. mult.	Multiplicador del costo inversión del tanque de hidrogeno
HT O&M mult.	Multiplicador del costo de operación y mantenimiento del tanque de hidrogeno
HT repl. mult.	Multiplicador del costo de reemplazo del tanque de Hidrogeno
Hydro	Hidroeléctrica
Hydro capital	Costo de la hidroeléctrica
Hydro capital Cost	Costo de la hidroeléctrica
Hydro data scaled Average	Promedio de datos escalados de hidro
Hydro design Flow Rate	Tasa de flujo de diseño de la hidro
Hydro eff.	Eficiencia de la Hidro
Hydro head	Carga (Salto) de la hidro
Hydro head loss	Perdida de carga de la hidro
Hydro life	Vida de la hidro
Hydro lifetime	Tiempo de vida de la hidro
Hydro maximum flow ratio	Tasa de flujo máximo de la hidro
Hydro minimum flow ratio	Tasa de flujo mínimo de la hidro
Hydro O&M	operación y mantenimiento de la hidro
Hydro O&M cost	Costo de operación y mantenimiento de la hidro
Hydro repl.	Reemplazo de la hidro

Hydro replacement	Reemplazo de la hidro
Hydro replacement cost	Costo del reemplazo de la hidro
Hydro resource	Recurso hidráulico
Hydro turbine efficiency	Eficiencia de la turbina hidro
Hydrogen load	Carga de hidrógeno
Hydrogen tank capital cost multiplier	Multiplicador del costo inversión del tanque del hidrógeno
Hydrogen tank lifetime	Tiempo de vida del tanque de hidrógeno
Hydrogen tank O&M cost multiplier	Multiplicador del costo de operación y mantenimiento del tanque de hidrógeno
Hydrogen tank replacement cost multiplier	Multiplicador del costo de reemplazo del tanque de hidrógeno
Hydrogen consumption	Consumo de hidrógeno
I	
Import file	Importar archivo
Intake pipe	Tubo de admisión
Intercept	Interceptar
Interconn. charge	Cargo por interconexión
Interconnection charge	Cargo por interconexión
Interest rate	Tasa de interés
Inverter	Inversor
Inverter eff.	Eficiencia del inversor
Inverter efficiency	Eficiencia del inversor
Inverter life	Vida del inversor
Inverter lifetime	Tiempo de vida del inversor
J	
K	
L	
Label	Etiqueta

Latitude	Latitud
Legend	Leyenda
LHV of biogas	Valor calórico bajo del biogás
Lifetime	Tiempo de vida
Lifetime curve	Curva de tiempo de vida
Lifetime throughput	Rendimiento en el tiempo de vida
Limit consumption to	Limite de consumo para
Link with	Enlace con
Load	Carga
Load factor	Factor de carga
Load following	Seguimiento de la carga
Load profile	Perfil de carga
Load type	Tipo de carga
Longitude	Longitud
Lower heating value	Valor calórico bajo
M	
Manufacturer	Fabricante
Max. annual capacity shortage	Máxima falta de capacidad anual
Max. cap. shortage	Máxima falta de capacidad
Max. flow ratio	Tasa de flujo máximo
Max. grid demand	Demanda máxima de la red
Max. grid sale	Venta máxima de la red
Maximum annual capacity shortage	Máxima falta de capacidad anual
Maximum capacity	Capacidad máxima
Maximum electrical output	Producción eléctrica máxima
Maximum grid demand	Demanda máxima de la red
Maximum grid power sale	Venta máxima de la red

Minimum battery life	Vida mínima de la batería
Minimum electrical output	Producción eléctrica mínima
Minimum renewable fraction	Fracción renovable mínima
Minutes	Minutos
Min. batt. life	Vida mínima de la batería
Min. battery life	Vida mínima de la batería
Min. flow ratio	Tasa mínima de flujo
Min. ren. fraction	Fracción renovable mínima
Min. RF	Fracción renovable mínima
Month	Mes
Monthly average electric production	Producción eléctrica promedio mensual
N	
Net generation calculated ually	Generación calculada neta anual
Net generation calculated monthly	Generación calculada neta mensual
Net metering	Medición neta
New	Nuevo
New window	Ventana nueva
Nominal capacity	Capacidad nominal
Nominal power	Potencia nominal
Nominal voltage	Voltaje nominal
North	Norte
Notes	Notas
Number of starts	Numero de arranques
O	
OK	OK
Operating reserve	Reserva operativa

Operating reserve hourly load	Carga horaria reserva operativa
Operating reserve peak load	Carga pico reserva operativa
Operating reserve solar	Reserva operativa solar
Operating reserve wind	Reserva operativa eólica
Operational life	Vida Operacional
Optimal system type	Tipo de sistema optimo
Optimization results	Resultados de la optimización
OR hourly load	Carga horaria reserva operativa
OR peak load	Carga pico reserva operativa
OR solar	Reserva operativa solar
OR wind	Reserva operativa eólica
Other	Otro
Overall rankings list size	Lista general clasificada por tamaño
P	
Pipe head loss	Perdida de carga en tubería
Plot	Graficar
Power price	Precio de la energía
Preferences	Preferencias
Price	Precio
Primary	Primaria
Primary load	Carga primaria
Primary load served	Carga primaria servida
Progress	Progreso
Project lifetime	Tiempo de vida del proyecto
Properties	Propiedades
PV	FV
PV cap. mult.	Multiplicador del costo inversión del FV

PV capital cost multiplier	Multiplicador del costo inversión del FV
PV capital multiplier	Multiplicador del costo inversión del FV
PV O&M cost multiplier	Multiplicador del costo de operación y mantenimiento del FV
PV O&M mult.	Multiplicador del costo de operación y mantenimiento del FV
PV O&M multiplier	Multiplicador del costo de operación y mantenimiento del FV
PV repl. mult.	Multiplicador del costo de remplazo del FV
PV replacement cost multiplier	Multiplicador del costo de reemplazo del FV
PV replacement multiplier	Multiplicador del costo de reemplazo del FV
Q	
Quantity	Cantidad
R	
Rate constant	Razón constante
Rectifier	Rectificador
Rectifier cap.	Capacidad del Rectificador
Rectifier eff.	Eficiencia del rectificador
Rectifier efficiency	Eficiencia del rectificador
Rectifier rel. cap.	Capacidad relativa del rectificador
Relative rectifier capacity	Capacidad relativa del rectificador
Reload last project on startup	Recarga del ultimo proyecto al inicio
Ren. frac. (renewable fraction)	Fracción renovable
Renewable fraction	Fracción renovable
Replacement	Reemplazar
Resources	Recursos
S	
Scaled average	Promedio escalado
Scaled data for simulation	Datos escalados para simulación

Scaled peak	Pico escalado
Search space	Busca espacio - mas opciones
Search space usage	Uso de búsqueda de espacio
Sellback	Retorno por venta
Sellback Rate	Tasa de retorno por venta
Sensitivities	Sensibilidad
Sensitivity results	Resultados sensibles
Sensitivity variables	Variables sensibles
Setpoint SOC	Punto de ajuste de estado de carga
Setpoint state of charge	Punto de ajuste de estado de carga
Simulation results	Resultados de la simulación
Simulations	Simulaciones
Size	Tamaño
Sizes to consider	Tamaño a considerar
Slope	Pendiente
Solar Data Scaled Average	Promedio escalado de datos solares
Solar power output	Producción de energía solar
Solar resource	Recurso solar
South	Sur
Specific fuel consumption	Consumo de combustible especifico
Standby Charge	Carga en modo de espera
Stand-alone system	Sistema autónomo
Status	Estatus
Stored hydrogen	Hidrógeno almacenado
Stream Flow	Flujo de vapor
Suggested value	Valor sugerido
Superimposed	Superpuesto

Synthesize data	Dato generado
Synthesized	Sintetizado
System architecture	Arquitectura del sistema
System fixed capital cost	Costo inversión fijo del sistema
System fixed O&M cost	Costo de operación y mantenimiento fijo del sistema
T	
Tabular	Tabular
Thermal load	Carga térmica
Total load served	Total de la carga servida (satisfecha)
Total NPC (total net present cost)	CNP total (costo neto presente total)
Total production	Producción total
Tracking system	Sistema de seguimiento
U	
Units	Unidades
Unmet load	Carga insatisfecha
Unmet load cost	Costo carga no satisfecha
Utility rate structure	Estructura tarifaria de la energía
V	
Values	Valores
Variable	Variable
Variables to plot	Variables para graficas
W	
Warnings	Advertencia
Weekday	Día de la semana
Weekend	Fin de semana
Weibull k	K Weibull

Wind data scaled average	Promedio escalado de velocidad de viento
Wind power output	Producción de energía eólica
Wind resource	Recurso eólico
Wind speed	Velocidad de viento
Wind turbine	Turbina eólica
X	
Y	
Z	

Translations by: Arturo Romero Paredes, Ignacio Cruz Cruz

7.2 Absolute State of Charge

The absolute state of charge is the total amount of energy currently contained in the storage bank, measured in kWh. When the batteries are fully charged, the absolute state of charge is equal to the maximum capacity of the storage bank.

State of charge is often abbreviated as SOC.

See also

7.131 Relative State of Charge

7.3 AC Primary Load Served

Type: Output Variable

Units: kWh/yr

Symbol: $E_{prim,AC}$

The AC primary load served is the total amount of energy that went towards serving the AC primary load(s) during the year.

7.4 Altitude

Type: Input Variable

Units: m

Symbol: z

The altitude is the elevation above mean sea level. Altitude affects air density, which in turn affects wind turbine output. HOMER therefore considers the altitude when calculating the output of the wind turbine.

According to the ideal gas law, air density is given by the following equation:

$$\rho = \frac{P}{RT}$$

where
:

ρ = air density [kg/m3]

P = pressure [Pa]

R = gas constant [287 J/kgK]

T = temperature [K]

The quantity that HOMER uses is the *air density ratio*, which is the actual air density divided by the air density under standard conditions (sea level, 15 degrees Celsius). When calculating the output of the wind turbine at the specified altitude, HOMER multiplies the power output obtained from the wind turbine power curve by the air density ratio. Using the ideal gas law, the air density ratio can be expressed as follows:

$$\frac{\rho}{\rho_0} = \frac{P}{P_0}\left(\frac{T_0}{T}\right)$$

where
:

P_0 = standard pressure [101,325 Pa]

T_0 = standard temperature [288.16 K]

Altitude affects both pressure and temperature. The US Standard Atmosphere uses the simplifying assumption that, up to an altitude of 11,000m, temperature decreases linearly with altitude according to the following equation:

$$T = T_0 - Bz$$

where
:

B = lapse rate [0.00650 K/m]

z = altitude [m]

Using the assumption that temperature decreases linearly with altitude, the air pressure can be shown to depend on the altitude according to the following equation:

$$P = P_0\left(1 - \frac{Bz}{T_0}\right)^{g/RB}$$

where

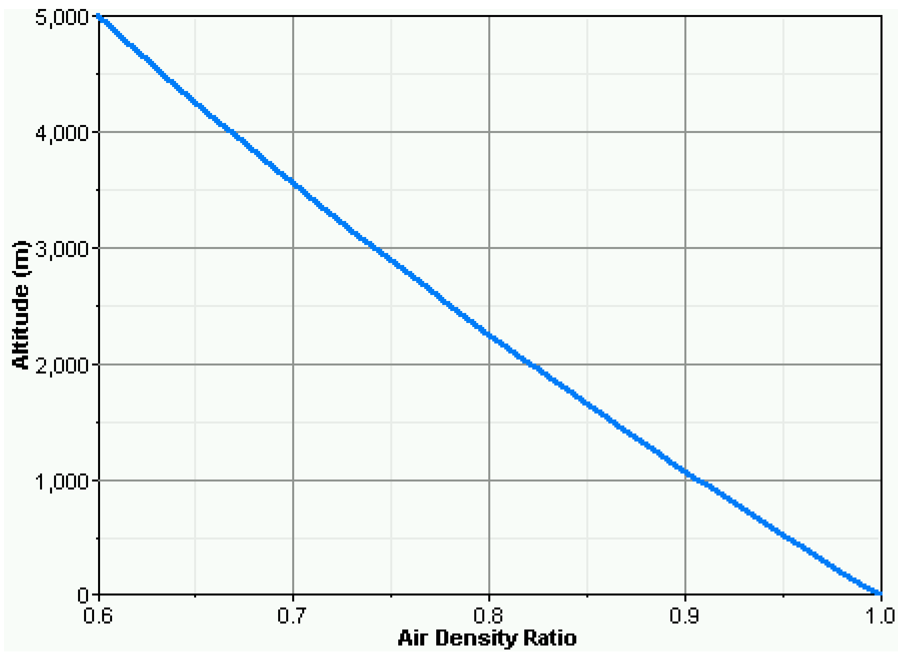
:

g = gravitational acceleration [9.81 m/s^2]

By substituting these equations for P and T into the equation defining the air density ratio, we get the following equation for the air density ratio:

$$\frac{\rho}{\rho_0} = \left(1 - \frac{Bz}{T_0}\right)^{g/RB} \left(\frac{T_0}{T_0 - Bz}\right)$$

On the right hand side of the above equation, only z, the altitude, is not constant. So with the assumptions we have used, the air density ratio is a function of altitude alone. We can use this equation to produce a graph of air density ratio versus altitude, as shown below:



The graph shows that at an altitude of 2000m, the air density ratio is about 0.82, meaning that air at that altitude is 82% as dense as air at standard temperature and pressure.

See also:

5.10 How HOMER Calculates Wind Turbine Power Output

7.5 Anemometer Height

Type: Input Variable

Units: m

Symbol: z_{anem}

The anemometer height is the height above ground at which the wind speed data are measured. Wind speeds tend to increase with height above ground, so if the wind turbine hub height is not the same as the anemometer height, HOMER adjusts the wind speed data accordingly. A common anemometer height for meteorological measurements is 10m. Anemometers installed specifically to determine wind power potential are often placed higher than 10m, since wind turbine towers are typically between 25m and 100m in height. The closer the anemometer is placed to the eventual hub height of the wind turbine, the more accurately it measures the wind resource to which the wind turbine will be exposed.

For details on how HOMER calculates the wind speed at the hub height of the wind turbine, see **Wind Resource Variation with Height**.

See also:

7.176 Wind Turbine Hub Height

7.6 Annualized Cost

The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component.

HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor, as in the following equation:

$$C_{ann} = \mathrm{CRF}\left(i, R_{proj}\right) \cdot C_{NPC}$$

where
:

C_{NPC} = the **net present cost** [$]

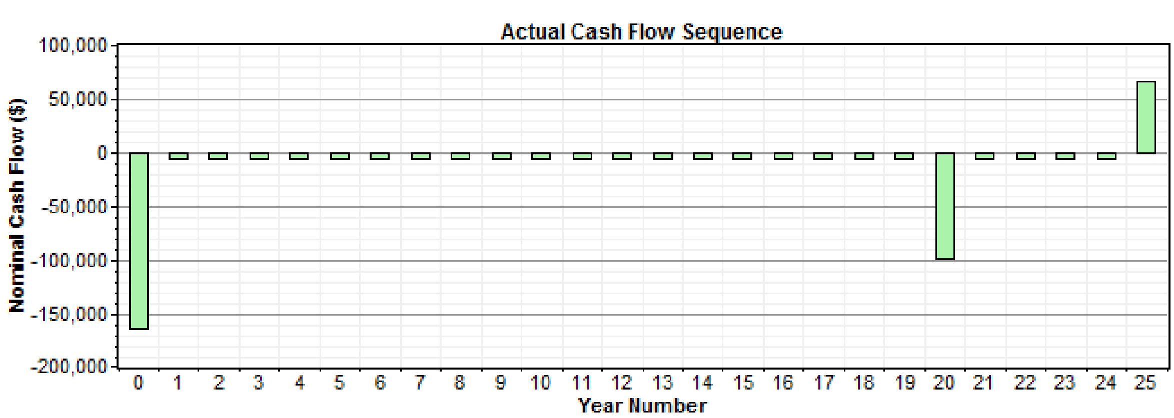
i = the **annual real discount rate** [%]

R_{proj} = the **project lifetime** [yr]

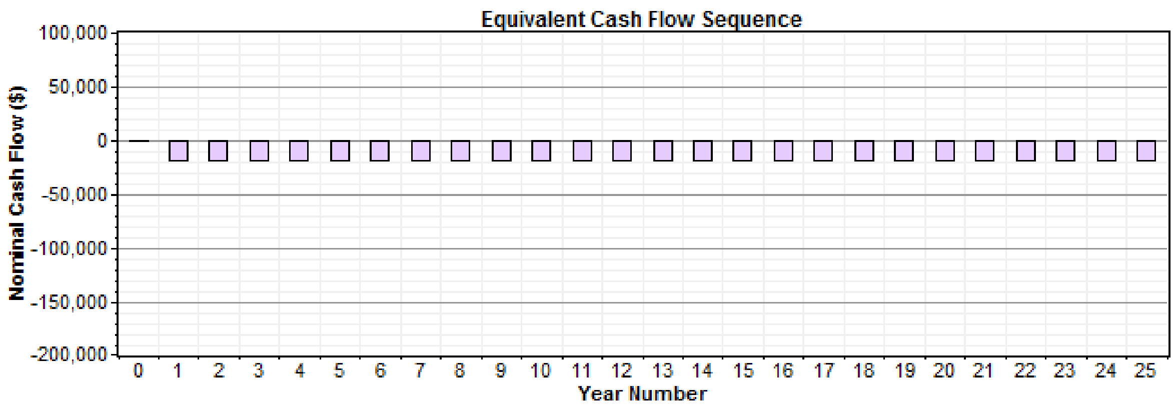
CRF() = a function returning the **capital recovery factor**

Example: A wind turbine has an initial capital cost of $165,000, a replacement cost of $95,000, a lifetime of 20 years, and an operation and maintenance (O&M) cost of $5,000/yr . What is its annualized cost over a 25-year project lifetime at an annual real interest rate of 6%?

The actual cash flow sequence associated with this wind turbine appears in the graph below. This graph shows the large capital expense in year zero, the small O&M cost that appears in every year, the large replacement cost that occurs after 20 years, and the salvage value that occurs at the end of the project:



We want to calculate an equivalent cash flow sequence, meaning one that gives the same net present cost, in which a single cost occurs in every year of the project. That single cost is the annualized cost, and the equivalent cash flow sequence would look like the one that appears below:



To calculate the net present cost of the wind turbine, we create a cash flow table as shown below. For each year, we calculate the discount factor, the nominal cash flow, and discounted cash flow, which is equal to the nominal cash flow multiplied by the discount factor. The sum of the discounted cash flows is the net present cost of the wind turbine over the project lifetime: $241,938. We multiply this by the capital recovery factor, which for 25 years and 6% is equal to 0.0782, giving an annualized cost of $18,926/yr.

Year	Discount Factor	Actual Cash Flows	
		Nominal	Discounted
0	1.000	-165,000	-165,000
1	0.943	-5,000	-4,717
2	0.890	-5,000	-4,450
3	0.840	-5,000	-4,198
4	0.792	-5,000	-3,960
5	0.747	-5,000	-3,736
6	0.705	-5,000	-3,525
7	0.665	-5,000	-3,325
8	0.627	-5,000	-3,137
9	0.592	-5,000	-2,959
10	0.558	-5,000	-2,792
11	0.527	-5,000	-2,634
12	0.497	-5,000	-2,485
13	0.469	-5,000	-2,344

14	0.442	-5,000	-2,212
15	0.417	-5,000	-2,086
16	0.394	-5,000	-1,968
17	0.371	-5,000	-1,857
18	0.350	-5,000	-1,752
19	0.331	-5,000	-1,653
20	0.312	-100,000	-31,181
21	0.294	-5,000	-1,471
22	0.278	-5,000	-1,388
23	0.262	-5,000	-1,309
24	0.247	-5,000	-1,235
25	0.233	66,250	15,436
Total			**-241,938**

To check our work, we can create a cash flow table for this equivalent cash flow sequence, and verify that it gives the same net present cost. The table below shows that the equivalent cash flow does indeed lead to the correct net present cost.

Year	**Discount Factor**	**Equivalent Cash Flows**	
		Nominal	**Discounted**
0	1.000	0	0
1	0.943	-18,926	-17,855
2	0.890	-18,926	-16,844
3	0.840	-18,926	-15,891
4	0.792	-18,926	-14,991
5	0.747	-18,926	-14,143
6	0.705	-18,926	-13,342
7	0.665	-18,926	-12,587
8	0.627	-18,926	-11,874
9	0.592	-18,926	-11,202
10	0.558	-18,926	-10,568
11	0.527	-18,926	-9,970
12	0.497	-18,926	-9,406

13	0.469	-18,926	-8,873
14	0.442	-18,926	-8,371
15	0.417	-18,926	-7,897
16	0.394	-18,926	-7,450
17	0.371	-18,926	-7,028
18	0.350	-18,926	-6,631
19	0.331	-18,926	-6,255
20	0.312	-18,926	-5,901
21	0.294	-18,926	-5,567
22	0.278	-18,926	-5,252
23	0.262	-18,926	-4,955
24	0.247	-18,926	-4,674
25	0.233	-18,926	-4,410
Total			**-241,937**

The annualized cost serves as a useful metric for comparing the costs of different components because it measures their relative contribution to the total net present cost. It allows for a fair cost comparison between components with low capital and high operating costs (such as diesel generators) and those with high capital and low operating costs (such as PV arrays or wind turbines).

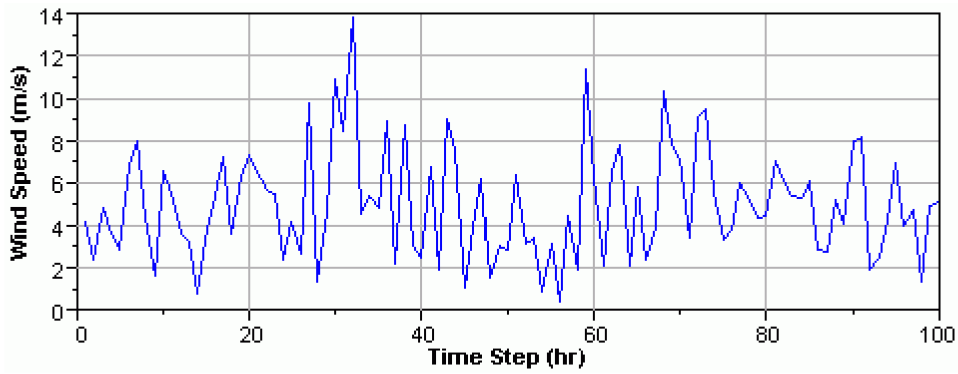
The annualized costs of each system component and of the system as a whole appear on the Cost Summary tab of the Simulation Results window.

See also

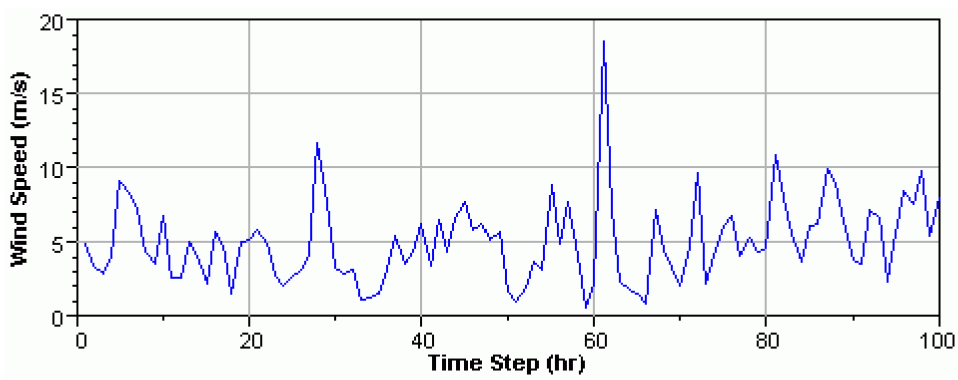
7.105 Net Present Cost
7.46 Discount Factor
7.31 Capital Recovery Factor
3.1.1 Cost Summary Outputs
7.163 Total Annualized Cost

7.7 Autocorrelation

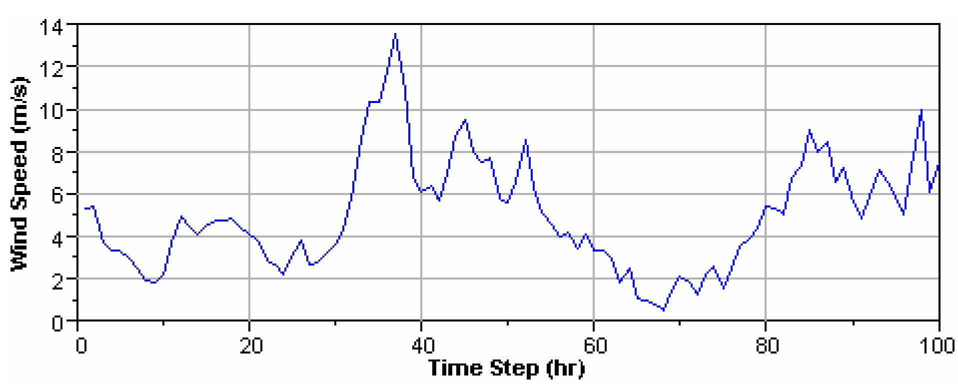
Wind speed time series data typically exhibit autocorrelation, which can be defined as the degree of dependence on preceding values. The effect of autocorrelation is demonstrated in Figure 1. In the absence of autocorrelation, each data point is completely independent of the previous values and the data points jump up and down at random, as in part a) of Figure 1. In a strongly autocorrelated time series, the value in any one time step is strongly influenced by the values in previous time steps, so long periods of high or low values emerge, as in part c) of Figure 1. Note that each data set in Figure 1 has the same average and the same Weibull k value. The degree of autocorrelation is the only distinction between the data sets.



a) Synthetic wind speed time series with no autocorrelation (r_1 = 0.0)



b) Synthetic wind speed time series with moderate autocorrelation (r_1 = 0.5)



c) Synthetic wind speed time series with strong autocorrelation (r_1 = 0.96)

Figure 1: The effect of autocorrelation. All three time series have a mean wind speed of 5 m/s and a Weibull k value of 2.

We know from experience that the wind exhibits autocorrelation. If the wind is blowing strongly at 10 a.m., it is quite likely that it will still be blowing strongly at 11 a.m. But the autocorrelation characteristics of the wind vary from place to place. Before we can explore this any further, we need to learn some fundamentals of autocorrelation.

For a time series z_1, z_2, z_3, ..., z_n, we can define an autocorrelation coefficient r_k as follows:

$$r_k = \frac{\sum_{i=1}^{n-k}\left(z_i - \bar{z}\right)\left(z_{i+k} - \bar{z}\right)}{\sum_{i=1}^{n}\left(z_i - \bar{z}\right)^2}$$

The value r_k is the autocorrelation between any two time series values separated by a "lag" of k time units. For a particular time series, we can measure r_k for several values of k. The resulting function is known as the autocorrelation function. By definition, $r_0 = 1$.

The autocorrelation function of the wind data measured at Kotzebue, Alaska is shown in Figure 2. This simple autocorrelation function shows that wind speeds at Kotzebue are strongly autocorrelated at short lags and less strongly autocorrelated at longer lags, which is intuitive.

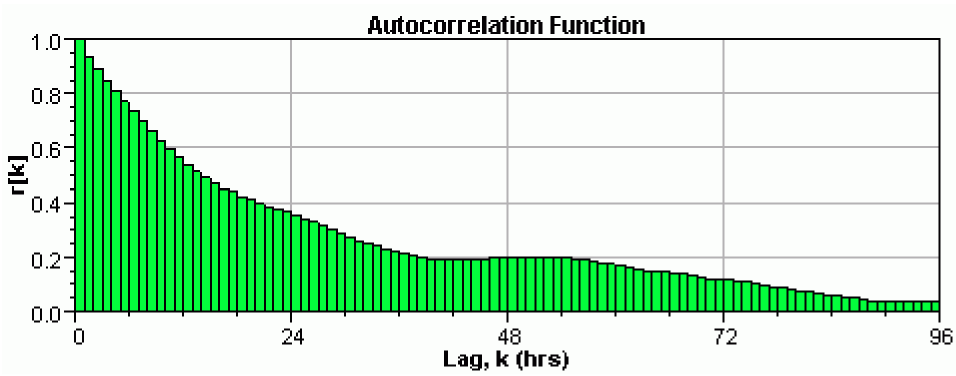


Figure 2: Autocorrelation function for the hourly wind speed data measured at Kotzebue, Alaska.

Kotzebue, however, is an unusual case because there is almost no daily pattern to its wind. A much more common example of a wind speed autocorrelation function is that of San Diego, California, which is shown in Figure 3. The wind speeds at San Diego show a distinct daily pattern, with the afternoons being on average much windier than the mornings. This recurring pattern in the wind speed causes the autocorrelation function to oscillate on a 24 hour period. Since it is usually windy at 3 p.m., the wind speed at 3 p.m. today is strongly autocorrelated with the wind speed at 3 p.m. yesterday, and therefore with the wind speed at 3 p.m. two days ago, etc.

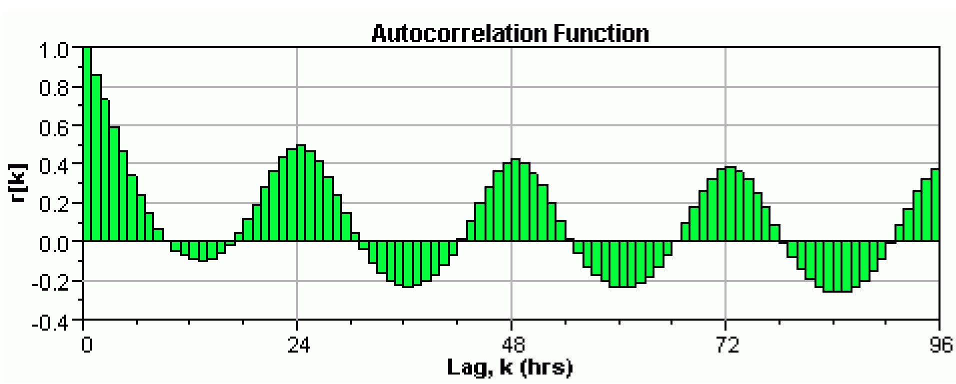


Figure 3: Autocorrelation function for the hourly wind speed data measured at San Diego, California.

HOMER describes the autocorrelation characteristics of wind data with a single number, the autocorrelation factor.

See also

7.112 One-Hour Autocorrelation Factor

7.8 Available Head

Type: Input Variable

Units: m

Symbol: h

The total available vertical drop between the intake and the turbine. Friction losses in the pipeline between the intake and the turbine make the effective head somewhat less than the available head.

HOMER uses the available head to calculate the nominal hydro power and the effective head. It uses the effective head to calculate the power output of the hydro turbine.

See also

7.50 Effective Head

7.107 Nominal Hydro Power

5.4 How HOMER Calculates the Hydro Power Output

7.9 Battery Bank Autonomy

Type: Output Variable

Units: hr

Symbol: A_{batt}

The storage bank autonomy is the ratio of the storage bank size to the electric load. HOMER calculates the storage bank autonomy using the following equation:

$$A_{batt} = \frac{N_{batt} V_{nom} Q_{nom} \left(1 - {q_{min}}/{100}\right)(24\, h/d)}{L_{prim,ave}(1000\, Wh/kWh)}$$

where
:

N_{batt} = number of batteries in the storage bank

V_{nom} = nominal voltage of a single storage [V]

Q_{nom} = nominal capacity of a single storage [Ah]

q_{min} = minimum state of charge of the storage bank [%]

$L_{prim,ave}$ = average primary load [kWh/d]

7.10 Battery Bank Life

Type: Output Variable

Units: years

Symbol: R_{batt}

In HOMER, two independent factors may limit the lifetime of the storage bank: the lifetime throughput and the storage float life. In other words, batteries can die either from use or from old age. When you create a new storage, you can choose whether the storage lifetime is limited by time, throughput, or both.

HOMER calculates the storage bank life using the following equation:

$$R_{batt} = \begin{cases} \dfrac{N_{batt} \cdot Q_{lifetime}}{Q_{thrpt}} & \text{if limited by throughput} \\ R_{batt,f} & \text{if limited by time} \\ \mathrm{MIN}\left(\dfrac{N_{batt} \cdot Q_{lifetime}}{Q_{thrpt}}, R_{batt,f} \right) & \text{if limited by throughput and time} \end{cases}$$

where
:

R_{batt} = storage bank life [yr]

N_{batt} = number of batteries in the storage bank

$Q_{lifetime}$ = **lifetime throughput** of a single storage [kWh]

Q_{thrpt} = **annual storage throughput** [kWh/yr]

$R_{batt,f}$ = **storage float life** [yr]

See also

7.14 Battery Float Life

7.94 Lifetime Throughput

7.11 Battery Charge Efficiency

HOMER assumes the battery charge efficiency is equal to the square root of the battery round trip efficiency, hence:

$$\eta_{batt,c} = \sqrt{\eta_{batt,rt}}$$

where
:

$\eta_{batt,c}$ = battery charge efficiency, and

$\eta_{batt,rt}$ = **battery round trip efficiency**.

See also

7.12 Battery Discharge Efficiency

7.12 Battery Discharge Efficiency

HOMER assumes the storage discharge efficiency is equal to the square root of the storage round trip efficiency, hence:

$$\eta_{batt,d} = \sqrt{\eta_{batt,rt}}$$

where
:

$\eta_{batt,d}$ = storage discharge efficiency, and

$\eta_{batt,rt}$ = **storage round trip efficiency**.

See also

7.11 Battery Charge Efficiency

7.13 Battery Energy Cost

Type: Intermediate Variable

Units: $/kWh

Symbol: $c_{be,n}$

In any time step, the storage energy cost is the average cost of the energy that the system has put into the storage bank up until that time step. HOMER uses the following equation to calculate the storage energy cost in each time step:

$$c_{be,n} = \frac{\sum_{i=1}^{n-1} C_{cc,i}}{\sum_{i=1}^{n-1} E_{cc,i}}$$

where
:

$c_{be,n}$ = the storage energy cost in time step n [$/kWh]

$C_{cc,i}$ = the cost of cycle charging the storage in time step i[$]

$E_{bc,i}$ = the amount of energy that went into the storage bank in time step i [kWh]

The storage energy cost reflects the average cost that the system has incurred for *deliberately* charging the storage bank. The "cost of cycle charging," which appears in the numerator of the above equation, is the extra cost incurred by the system specifically for charging the storage. Excess electricity that charges the storage bank in some time step represents no such cost. But if the generator produced more power than required to serve the load, and it did so specifically to charge the storage, then that act of charging the storage bank does cause the system to incur extra cost. The same is true if the system purchases extra grid power expressly to charge the storage. Such events occur routinely under the cycle charging strategy.

In any time step in which a generator or the grid cycle charges the storage, HOMER calculates the cycle charge cost by taking the actual cost of operating the system in that time step and subtracting the cost that would have occurred in that time step had the system not charged the storage.

The storage energy cost will always be zero under the load following dispatch strategy, because under load following the system never pays to charge the storage bank, it only uses excess electricity to charge the storage bank.

The storage bank's marginal cost of generation is equal to the sum of the storage wear cost and the storage energy cost.

See also

7.19 Battery Wear Cost
7.39 Cycle Charging Strategy
7.97 Load Following Strategy

7.14 Battery Float Life

Type: Input Variable

Units: yr

Symbol: $R_{batt,f}$

The float life of the storage is the length of time that the storage will last before it needs replacement. When you create a storage you can choose whether to limit its life by time, by throughput, or by both. The float life does not apply if you have chosen to limit the storage lifetime by throughput only.

HOMER uses the float life to calculate the **storage bank life**.

See also

7.10 Battery Bank Life
7.94 Lifetime Throughput

7.15 Battery Maximum Charge Rate

Type: Input Variable

Units: A/Ah of unfilled capacity

Symbol: α_c

The maximum charge rate variable imposes a limit on the rate at which the system can charge the storage bank. That limit is directly proportional to the amount of "unfilled capacity" in the storage, where the unfilled capacity is defined as the storage's maximum capacity minus its current absolute state of charge.

For example, consider a storage whose maximum capacity is 350 Ah and whose maximum charge rate is 0.4 A/Ah. If at some point in time the storage's absolute state of charge is 310 Ah, then it has 40 Ah of unfilled capacity, so the highest charge current it could accept would be 40 Ah * 0.4 A/Ah = 16 A. If at some other point in time its state of charge was 335 Ah, then the highest charge current it could accept would be only 6 A. So the allowable charge current decreases with increasing state of charge.

Another variable, the maximum charge current, imposes an upper limit on the allowable charge current, regardless of the state of charge. If our example storage were empty, the maximum charge rate variable would imply that it could accept a charge current of as high as 350 Ah * 0.4 A/Ah = 140 A. But a current that high might be very damaging to the storage. If you set the maximum charge current variable to 25 A, then HOMER ensures that the charge current never exceeds 25 A, no matter what the state of charge.

Notes:

1. The **kinetic storage model** imposes a separate limit on the rate of charge.
2. This discussion relates to a single storage. To find the maximum storage charge power, HOMER calculates the product of the maximum charge current times the nominal voltage times the number of batteries in the storage bank.

7.16 Battery Minimum State Of Charge

The **relative state of charge** below which the storage bank is never drawn - specified as a percentage of the total capacity. Most rechargeable batteries are not meant to be fully discharged. In fact, fully discharging some batteries can permanently damage them. The minimum state of charge is typically set to 30-50% in order to avoid damaging the storage bank by excessive discharge.

7.17 Battery Roundtrip Efficiency

Type: Input Variable

Units: %

Symbol: $\eta_{batt,rt}$

The round trip DC-to-storage-to-DC energetic efficiency of the storage bank, or the fraction of energy put into the storage that can be retrieved. Typically this is about 80%. HOMER assumes the storage charge efficiency and the storage discharge efficiency are both equal to the square root of the roundtrip efficiency.

See also

7.11 Battery Charge Efficiency
7.12 Battery Discharge Efficiency

7.18 Battery Throughput

Type: Output Variable

Units: kWh/yr

Symbol: Q_{thrpt}

The storage throughput is the amount of energy that cycles through the storage bank in one year. Throughput is defined as the change in energy level of the storage bank, measured after charging losses and before discharging losses. This value is used to calculate the **life of the storage bank**.

7.19 Battery Wear Cost

Type: Intermediate Variable

Units: $/kWh

Symbol: c_{bw}

The storage wear cost is the cost of cycling energy through the storage bank. If the storage properties indicate that the storage life is limited by throughput, then HOMER assumes the storage bank will require replacement once its total throughput equals its lifetime throughput. Each kWh of throughput therefore brings the storage bank that much closer to needing replacement. HOMER calculates the storage wear cost using the following equation:

$$c_{bw} = \frac{C_{rep,batt}}{N_{batt} \cdot Q_{lifetime} \cdot \sqrt{\eta_{rt}}}$$

where
:

$C_{rep,batt}$ = replacement cost of the storage bank [$]

N_{batt} = the number of batteries in the storage bank

$Q_{lifetime}$ = the **lifetime throughput** of a single storage [kWh]

η_{rt} = **storage roundtrip efficiency** [fractional]

The storage bank's marginal cost of generation is equal to the sum of the storage wear cost and the storage energy cost.

See also

7.13 Battery Energy Cost
7.39 Cycle Charging Strategy
7.97 Load Following Strategy

7.20 Biogas

In HOMER, the term *biogas* refers to gasified biomass. Biomass feedstock (such as wood waste, agricultural residue, or energy crops) can be gasified by thermo-chemical or biological processes, and the product may be called one of several different names, including synthesis gas, syngas, producer gas, and wood gas.

Whatever the feedstock and the means of gasification, the major constituent gases of biogas are typically carbon monoxide, hydrogen, and carbon dioxide, plus a significant amount of nitrogen (about 50% by weight) if thermal gasification is performed in the presence of air. Minor constituent gases include methane and water vapor.

Biogas typically has a low heating value compared with fossil fuels, particularly if it contains a large amount of nitrogen, which is noncombustible. But it has several advantages over solid biomass, including cleaner combustion, higher efficiency, and better control.

7.21 Biomass Carbon Content

Type: Input Variable

Units: %

Symbol: k_{bio}

The amount of carbon contained in the biomass feedstock, expressed as a mass-based percentage. HOMER uses this value to calculate the emissions of CO_2, CO, and unburned hydrocarbons.

Tip: If you want HOMER to calculate the system's *gross* carbon emissions, then you should enter the gross carbon content of the biomass feedstock, which is typically on the order of 50%. On the other hand, if you want HOMER to calculate the system's *net* carbon emissions, then you should enter the net carbon content of the feedstock, which is typically near zero. The net value takes into account the fact that the carbon in the biomass feedstock was originally absorbed from the atmosphere, and consuming that feedstock as fuel simply puts that carbon back into the atmosphere. The net effect on the atmosphere is near zero if the feedstock is harvested in a sustainable manner, meaning that the rate of consumption of biomass feedstock does not exceed the biosphere's ability to regenerate that feedstock.

A precise estimate of the net carbon content of a biomass feedstock will take into account the carbon emissions associated with the harvesting and processing of the feedstock. It may also account for avoided methane emissions related to the natural decomposition of the feedstock that would have occurred were it not for the consumption of that feedstock to produce energy.

See also:

7.22 Biomass Gasification Ratio

Type: Input Variable

Units: kg gas / kg biomass

Symbol: f_{gas}

The ratio of **biogas** generated to biomass feedstock consumed in the gasifier. HOMER assumes this value is constant.

For more information, see the article **Operation of a Co-fired Generator**.

7.23 Biomass Resource Cost

Type: Input Variable

Units: $/t

Symbol: c_{bio}

The cost per tonne (1000 kg) of biomass feedstock.

For more information

*The **HOMER Support Site** has a searchable knowledgebase and additional support options.*

***HOMER online** contains the latest information on model updates, as well as sample files, resource data, and contact information.*

7.24 Biomass Substitution Ratio

Type: Input Variable

Units: none

Symbol: z_{gas}

The ratio with which the **biogas** replaces fossil fuel in a cofired generator. If 8 kg/hr of biogas is required to replace 1 kg/hr of fossil fuel to maintain output power, the substitution ratio is 8. This ratio is assumed to be constant, independent of fuel mixture or output power.

If the fossil fuel burned by the generator is gaseous, the substitution ratio will be roughly equal to the ratio of the lower heating values of the fossil fuel and biogas. For example, if the cofired generator runs on a mixture of propane and biogas and the LHV of the biogas is one-third that of propane, the substitution ratio will likely be approximately 3.

For liquid fossil fuels, the substitution ratio is typically somewhat higher than the LHV ratio because the generator does not operate as efficiently on the mixture of biogas and liquid fuel as it would on liquid fuel alone.

For more information, see the article **Operation of a Co-fired Generator**.

7.25 Boiler Marginal Cost

Type: Intermediate Variable

Units: $/kWh

Symbol: c_{boiler}

The marginal cost of thermal energy from the boiler. HOMER uses this value when calculating the **levelized cost of energy**. HOMER calculates the boiler marginal cost with the following equation:

$$c_{boiler} = \frac{3.6 \cdot \left(c_{fuel} + c_{boiler,emissions}\right)}{\eta_{boiler} \cdot \mathrm{LHV}_{fuel}}$$

where:

c_{fuel}	= cost of fuel [$/kg of fuel]
$c_{boiler,emissions}$	= cost penalty associated with emissions from the boiler [$/kg of fuel]
η_{boiler}	= boiler efficiency [unitless]
LHV_{fuel}	= the lower heating value of the boiler fuel [MJ/kg]

The factor of 3.6 in the above equation arises because 1 kWh = 3.6 MJ.

Note: The fuel cost in the above equation is per kg, not per L or m^3. For fuels denominated in volumetric units, HOMER calculates the cost per kg using the fuel density.

HOMER calculates the cost penalty associated with boiler emissions using the following equation:

$$c_{boiler,emissions} = \frac{c_{CO_2}\gamma_{CO_2} + c_{CO}\gamma_{CO} + c_{UHC}\gamma_{UHC} + c_{PM}\gamma_{PM} + c_{SO_2}\gamma_{SO_2} + c_{NO_x}\gamma_{NO_x}}{1000}$$

where:

c_{CO2}	= penalty for emissions of CO_2 [$/t]
c_{CO}	= penalty for emissions of CO [$/t]
c_{UHC}	= penalty for emissions of unburned hydrocarbons (UHC) [$/t]
c_{PM}	= penalty for emissions of particulate matter (PM) [$/t]
c_{SO2}	= penalty for emissions of SO_2 [$/t]
c_{NOx}	= penalty for emissions of NO_x [$/t]

γ_{CO2} = boiler's carbon dioxide emissions coefficient [kg CO_2 / kg fuel]

γ_{CO} = boiler's carbon monoxide emissions coefficient [kg CO / kg fuel]

γ_{UHC} = boiler's unburned hydrocarbons emissions coefficient [kg UHC / kg fuel]

γ_{PM} = boiler's particulate matter emissions coefficient [kg PM / kg fuel]

γ_{SO2} = boiler's SO_2 emissions coefficient [kg SO_2 / kg fuel]

γ_{NOx} = boiler's NO_x emissions coefficient [kg NO_x / kg fuel]

HOMER calculates the CO_2 emissions coefficient using the following equation:

$$\gamma_{CO_2} = \frac{44}{12}\left[f_{C,fuel}\left(1-\gamma_{UHC}\right)-\left(\frac{12}{28}\right)\gamma_{CO}\right]$$

where
:

$f_{C,fuel}$ = the carbon content of the fuel [unitless]

γ_{CO} = boiler's carbon monoxide emissions coefficient [kg CO / kg fuel]

γ_{UHC} = boiler's unburned hydrocarbons emissions coefficient [kg UHC / kg fuel]

Note that the factors of 44/12 and 12/28 in the above equation arise because the molecular weights of C, CO, and CO_2 are equal to 12, 28, and 44 respectively.

HOMER calculates the SO_2 emissions coefficient using the following equation:

$$\gamma_{SO_2} = 2 f_{S,fuel}\left(1-\gamma_{UHC}-x_{PM}\right)$$

where
:

$f_{S,fuel}$ = the sulfur content of the fuel [unitless]

γ_{UHC} = boiler's unburned hydrocarbons emissions coefficient [kg UHC / kg fuel]

x_{PM} = the proportion of fuel sulfur converted to particulate matter [unitless]

Note that the factor of 2 in the above equation arises because the molecular weight of SO_2 (64) is twice that of S (32).

See also:
7.92 Levelized Cost of Energy

7.26 Break-even Grid Extension Distance

Type: Output Variable

Units: km

Symbol: D_{grid}

The distance from the grid which makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Farther away from the grid, the stand-alone system is optimal. Nearer to the grid, grid extension is optimal.

HOMER calculates the break-even grid extension distance using the following equation:

$$D_{grid} = \frac{C_{NPC} \cdot \mathrm{CRF}(i, R_{proj}) - c_{power} \cdot E_{demand}}{c_{cap} \cdot \mathrm{CRF}(i, R_{proj}) + c_{om}}$$

where
:

C_{NPC} = **total net present cost** of the stand-alone power system [$]

CRF() = **capital recovery factor**

i = **real discount rate** [%]

R_{proj} = **project lifetime** [yr]

E_{demand} = total annual electrical demand (primary plus deferrable) [kWh/yr]

c_{power} = cost of power from the grid [$/kWh]

c_{cap} = capital cost of grid extension [$/km]

c_{om} = O&M cost of grid extension [$/yr/km]

7.27 Bus

A bus carries energy from one component to another. HOMER has four buses: AC, DC, Thermal, and Hydrogen. Certain components allow power to flow from one bus to another.

		From			
		AC	**DC**	**Thermal**	**Hydrogen**
To	**AC**		**Converter**	None	**Generator** (hydrogen)
	DC	**Converter**		None	**Generator** (hydrogen)
	Thermal	**Thermal load controller**	**Thermal load controller**		None
	Hydrogen	**Electrolyzer**	**Electrolyzer**	None	

See also

5.5 How HOMER Calculates Clearness Index

7.28 Capacity Shortage

A capacity shortage is a shortfall that occurs between the **required operating capacity** and the actual amount of operating capacity the system can provide. HOMER keeps track of such shortages and calculates the total amount that occurs over the year.

For example, consider a simple system consisting of a 50 kW AC generator serving an AC load:

- If the load is 30 kW and the required operating reserve is 15 kW, the required operating capacity is 45 kW and the actual operating capacity is 50 kW, so there is no capacity shortage. The generator would operate at 30 kW to meet the load, and the 20 kW of operating reserve it provides would satisfy the requirement.
- If the load is 40 kW and the required operating reserve is 12 kW, the required operating capacity is 52 kW and the actual operating capacity is 50 kW, so the capacity shortage is 2 kW. The generator provides only 10 kW of operating reserve in this situation, not enough to satisfy the requirement.
- If the load is 55 kW and the required operating reserve is 0 kW, the required operating capacity is 55 kW and the actual operating capacity is 50 kW, so the capacity shortage is 5 kW (and the unmet load is also 5 kW).
- If the load is 55 kW and the required operating reserve is 20 kW, the required operating capacity is 75 kW and the actual operating capacity is 50 kW, so the capacity shortage is 25 kW (and the unmet load is 5 kW).

Note: It is possible to have a capacity shortage on one bus and excess electricity on the other in the same time step. An undersized converter, or one with the "Parallel with AC generator?" option **not** selected, can cause this to happen.

See also:

7.138 Required Operating Reserve
7.98 Maximum Annual Capacity Shortage
7.164 Total Capacity Shortage
7.29 Capacity Shortage Fraction

7.29 Capacity Shortage Fraction

Type: Output Variable

Units: none

Symbol: f_{cs}

The capacity shortage fraction is equal to the total capacity shortage divided by the total electrical demand. HOMER considers a system feasible (or acceptable) only if the capacity shortage fraction is less than or equal to the **maximum annual capacity shortage**. HOMER uses the following equation to calculate the capacity shortage fraction:

$$f_{cs} = \frac{E_{cs}}{E_{demand}}$$

where
:

E_{cs} = **total capacity shortage** [kWh/yr]

E_{demand} = total electrical demand (primary and deferrable load) [kWh/yr]

7.30 Capacity Shortage Penalty

Type: Input Variable

Units: $/kWh

Symbol: c_{cs}

The capacity shortage penalty is a cost penalty that HOMER applies to the system for any **capacity shortage** that occurs during the year. HOMER uses this value to calculate the **other O&M cost**.

7.31 Capital Recovery Factor

The capital recovery factor is a ratio used to calculate the **present value** of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$\mathrm{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

where
:

i = **real discount rate**

N = number of years

Example: for i = 7% and N = 5 years, the capital recovery factor is equal to 0.2439. A $1000 loan at 7% interest could therefore be paid back with 5 annual payments of $243.90. The **present value** of the five annual payments of $243.90 is $1000.

See also
7.151 Sinking Fund Factor

7.32 CC

Abbreviation for the **Cycle Charging** dispatch strategy.

See also
7.39 Cycle Charging Strategy
7.97 Load Following Strategy

7.33 Clearness Index

The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions.

The clearness index can be defined on an instantaneous, hourly, or monthly basis. The clearness index values in HOMER's Solar Resource Inputs window are monthly average values. The symbol for the monthly average clearness index is K_t.

Typical values of K_t range from 0.25 (a very cloudy month, such as an average December in London) to 0.75 (a very sunny month, such as an average June in Phoenix).

The **table of solar data** contains monthly average clearness indices for numerous locations around the world.

See also

5.5 How HOMER Calculates Clearness Index

7.34 CO Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{CO}

Use the CO emissions penalty to penalize systems for their production of carbon monoxide. HOMER uses this input value when calculating the **Other O&M cost**.

7.35 CO2 Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{CO2}

Use the CO_2 emissions penalty to penalize systems for their production of carbon dioxide. HOMER uses this input value when calculating the **Other O&M cost**.

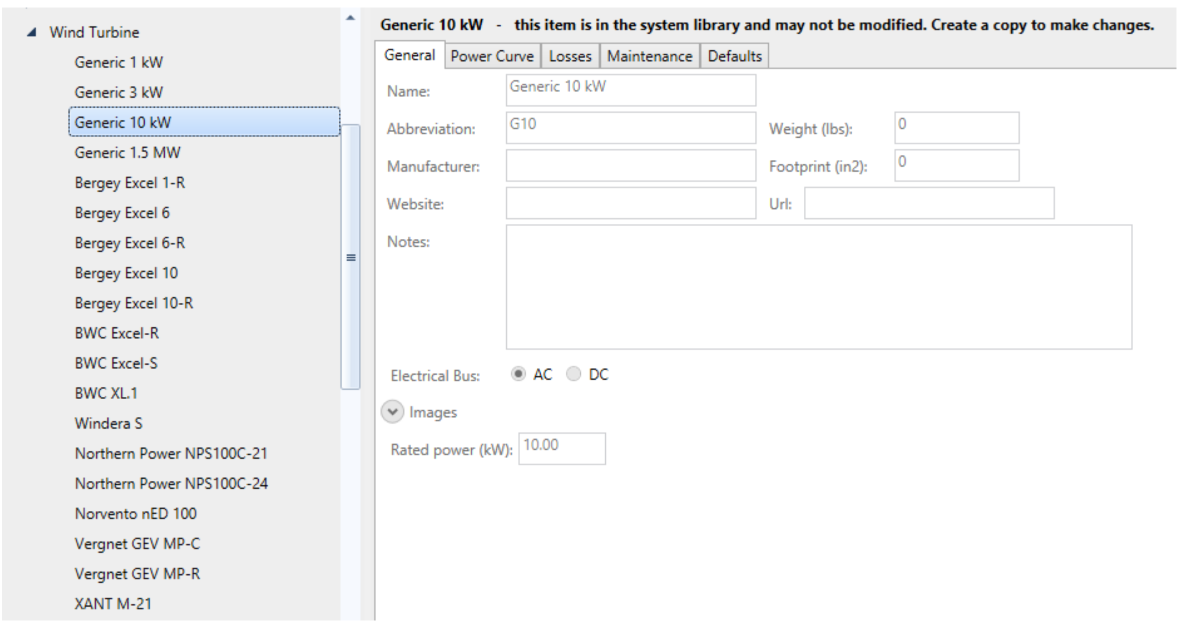
7.36 Component

In HOMER, the term "component" refers to any part of the system that generates, stores or transfers electric or thermal energy, and whose size or quantity is an optimization variable.

Photovoltaic panels, diesel generators and wind turbines are examples of components. Less obvious are things like converters, electrolyzers and the utility grid.

7.37 Component Library

The component library is a collection of properties of batteries, flywheels, wind turbines, and fuels. Wherever you need to select a type of storage, wind turbine, or fuel, HOMER uses the component library to generate a list of available types. In the example shown below, taken from the Wind Turbine window, HOMER is displaying a list of the wind turbine types contained in the component library.



You can add and remove items from the component library using the New and Delete buttons on the storage, wind turbine, generator, and boiler windows.

Note that the component library contains performance data, but no cost data.

7.38 Concentraing Photovoltaic (CPV)

HOMER can model two popular types of photovoltaic (PV) arrays: flat panel and concentrating. Flat panel PVs are common and are lower in cost compared to the higher cost, higher performance concentrating PV arrays. Concentrating PV arrays have reached above 40% efficiency in commercial installations. An efficiency of 15% is typical of flat panel PV arrays.

Since CPVs use optics to focus solar irradiation, they generally also require active tracking to follow the sun. Only direct solar radiation incident normal to the surface of the panel is collected, in contrast to flat panel PVs that can capture radiation striking the panel at a range of angles. This irradiance of flat panel PV is calculated using the solar global horizontal irradiance (GHI) which includes direct and indirect radiation. Concentrating PV uses the direct normal irradiance (DNI) solar resource that only includes the portion of solar that can be captured by CPV.

See also

2.3.2 Solar DNI Resource

2.2.2 Photovoltaic Panels (PV)

7.39 Cycle Charging Strategy

The cycle charging strategy is a **dispatch strategy** whereby whenever a generator needs to operate to serve the primary load, it operates at full output power. Surplus electrical production goes toward the lower-priority objectives such as, in order of decreasing priority: serving the **deferrable load**, charging the storage bank, and serving the electrolyzer.

Note: A generator will not produce surplus power just to dump it as **excess electricity**. There must be some use for its surplus power for HOMER to operate it above the level needed to serve the primary load.

When using the cycle charging strategy, HOMER dispatches the controllable power sources (generators, storage bank, grid) each time step of the simulation in a two-step process. First, HOMER selects the optimal combination of power sources to serve the primary load and the thermal load at the least total cost, while satisfying the operating reserve requirement. To accomplish this, HOMER calculates the fixed and marginal cost of each dispatchable power source:

- A generator's fixed cost is equal to its hourly operation and maintenance cost plus its **hourly replacement cost** plus the cost of its no-load fuel consumption. Its marginal cost is equal to its fuel curve slope times the fuel price. If waste heat can be recovered from the generator **and** the waste heat is needed to serve the thermal load, the generator's marginal cost is reduced by the value of the thermal energy it produces (which is equal to the marginal cost of thermal energy from the **boiler**). If a cost is assigned to carbon emissions, the generator's marginal cost is increased accordingly.
- The storage bank's fixed cost is zero and its marginal cost is equal to the **storage wear cost**.
- The grid's fixed cost is zero and its marginal cost is equal to the grid power price. If a cost is assigned to carbon emissions, the grid's marginal cost is increased accordingly.

This first step is identical to the **load-following strategy**.

Next, HOMER ramps up the output of each generator in that optimal combination to its rated capacity, or as close as possible without causing **excess electricity**.

If a **setpoint state of charge** is applied to the cycle charging strategy, then when the storage state of charge is below the setpoint and the storage was not discharging in the previous time step, HOMER will avoid discharging the storage in this time step. A generator will likely be called upon to serve the primary load and produce excess electricity to charge the storage bank. So once the system starts charging the storage bank it continues to do so until it reaches the setpoint state of charge.

See also

7.97 Load Following Strategy

7.149 Setpoint State of Charge

7.40 DC Primary Load Served

Type: Output Variable

Units: kWh/yr

Symbol: $E_{prim, DC}$

The DC primary load served is the total amount of energy that went towards serving the DC primary load(s) during the year.

7.41 Decision Variable

A decision variable is a variable whose optimal value is determined during the course of the optimization process. An example is the size of the PV array. If you are specifying your own **Search Space** , HOMER considers each different PV array size you specify and finds the value that results in the least net present cost.

The decision variables in HOMER are:

- the size of the PV array
- the number of wind turbines
- the size of the hydro system
- the size of each generator
- the number of batteries
- the size of the converter
- the size of the electrolyzer
- the size of the hydrogen storage tank
- the dispatch strategy
- the maximum grid demand

Decision variables are also known as *optimization variables*.

7.42 Deferrable Load Served

Type: Output Variable

Units: kWh/yr

Symbol: E_{def}

The deferrable load served is the total amount of energy that went towards serving the deferrable load during the year.

7.43 Deltaplot

The deltaplot shows the frequency of changes in any variable over some length of time. Choose the variable from the drop-down box, and choose the length of time using the slider control.

7.44 Design Flow Rate

Type: Input Variable

Units: L/s

Symbol: $\dot{Q}_{design}$

The design flow rate is the flow rate for which the hydro turbine is designed. This is also typically the flow rate at which the turbine operates at its maximum efficiency, although HOMER assumes the turbine efficiency is constant.

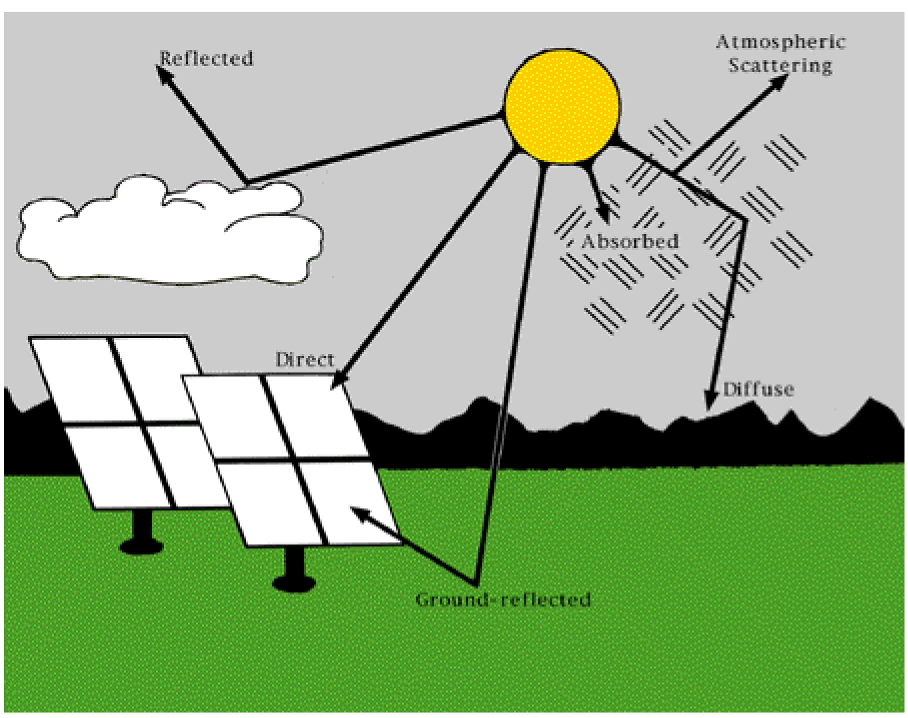
HOMER uses the design flow rate to calculate the **hydro turbine flow rate** and the **nominal hydro power**.

See also

7.103 Minimum Flow Rate
7.100 Maximum Flow Rate

7.45 Direct Normal Irradiance (DNI)

Global Horizontal Irradiance is the total solar radiation incident on a horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and ground-reflected radiation. HOMER uses Solar GHI to compute flat-panel PV output.



See also

2.2.2 Photovoltaic Panels (PV)
2.3.2 Solar DNI Resource

For more information

*The **HOMER Support Site** has a searchable knowledgebase and additional support options.*

***HOMER online** contains the latest information on model updates, as well as sample files, resource data, and contact information.*

Image source: RReDC Glossary of Solar Radiation Resource Terms, NREL Renewable Resource Data Center from http://rredc.nrel.gov/solar/pubs/shining/images/pg12.gif

7.46 Discount Factor

The discount factor is a ratio used to calculate the present value of a cash flow that occurs in any year of the project lifetime. HOMER calculates the discount factor using the following equation:

$$f_d = \frac{1}{(1+i)^N}$$

where
:

i = **real discount rate** [%]

N = number of years

Example: for i = 5% and N = 12 years, the discount factor equals 0.557. That means a $1000 nominal cash flow in year 12 has a present value of $557. In other words, a $1000 cash flow in year 12 is equivalent to a $557 cash flow in year zero. This is a demonstration of the time value of money: a dollar now is worth more than a dollar twelve years in the future.

See also
7.120 Present Value

7.47 Dispatch Strategy

A *dispatch strategy* is a set of rules used to control the operation of the generator(s) and the storage bank whenever there is insufficient renewable energy to supply the load. See **Barley and Winn, 1996** for a complete discussion of hybrid system dispatch strategies.

See also
2.4.2 System Control

7.48 Diurnal Pattern Strength

Type: Input Variable

Units: none

Symbol: δ

Typical Range: 0.0 - 0.4

The diurnal pattern strength is a number between 0 and 1 that reflects how strongly the wind speed tends to depend on the time of day. When you generate synthetic wind speed data, HOMER assumes a cosinusoidal diurnal pattern, with the diurnal pattern strength defined as the ratio of the amplitude to the mean.

The following equation describes the average diurnal profile of the synthesized wind speed data:

$$U_i = \overline{U}\left\{1 + \delta \cos\left[\left(\frac{2\pi}{24}\right)(i - \phi)\right]\right\} \quad for\ i = 1,2,\ldots 24$$

where
:

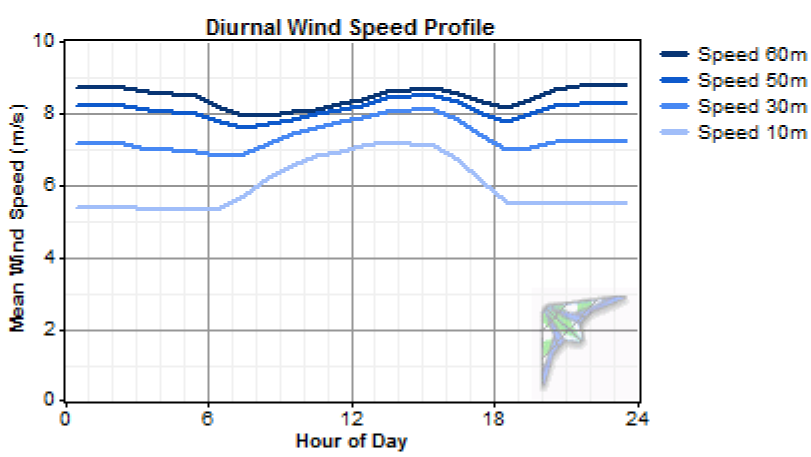
U_i = the mean wind speed in hour i [m/s]

U = the overall mean wind speed [m/s]

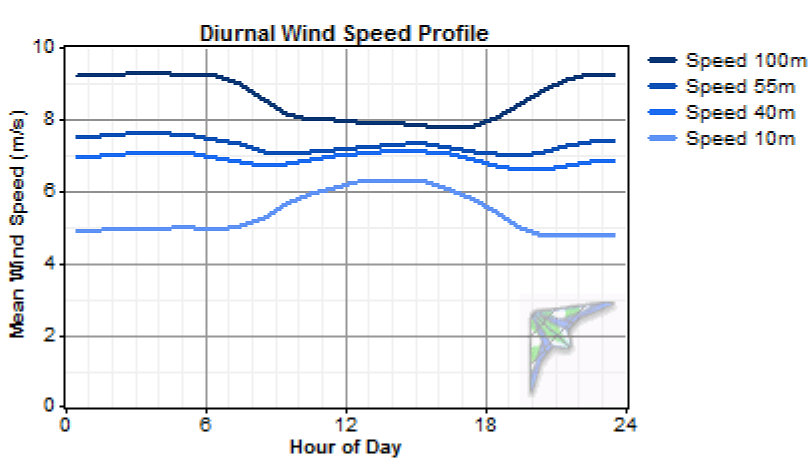
δ = diurnal pattern strength (a number between 0 and 1)

ϕ = **hour of peak windspeed** (an integer between 1 and 24)

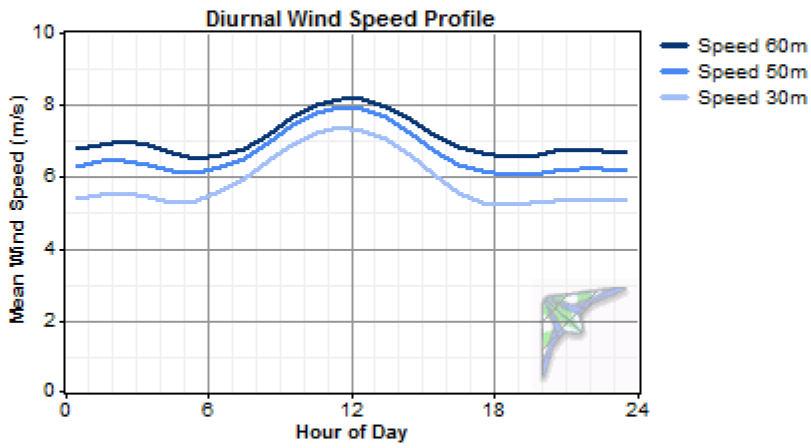
Note that the character of the diurnal pattern tends to vary significantly with height above ground. The following graph shows a typical example, where at 10m above ground the wind speed tends to peak in the afternoon, whereas at 60m above ground, the wind speed tends to peak overnight. This graph shows data measured at a site in the Midwest region of the US:



This pattern can be very pronounced, such as in the following graph, which shows mean diurnal profiles at heights from 10m to 100m above ground, at a location in the Great Plains region of the US. In this example, the diurnal pattern at 100m is almost the mirror image of that at 10m above ground:

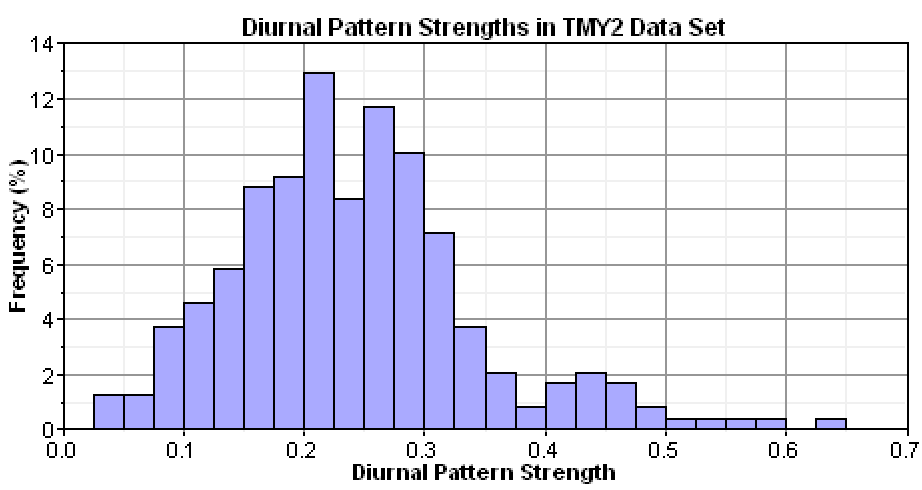


In other cases, the diurnal pattern changes much less with height above ground, such as in the following graph:



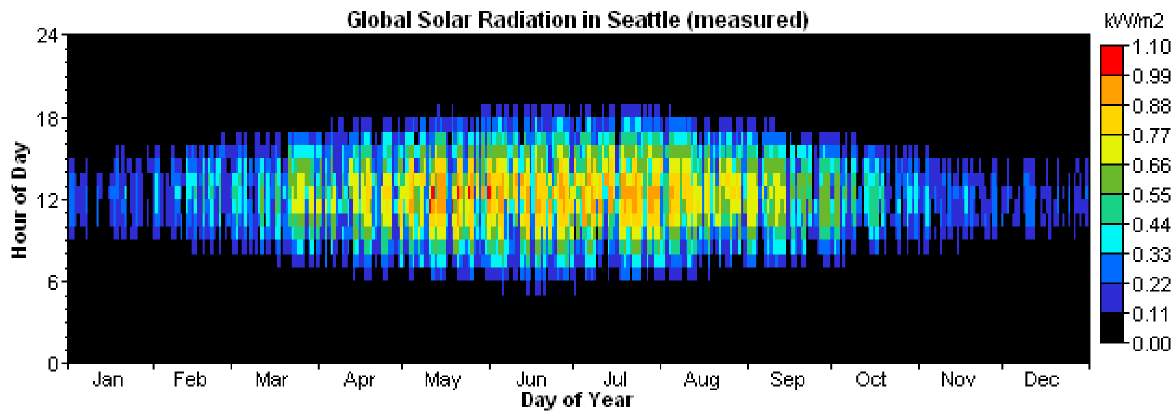
Since HOMER will use the wind speeds to estimate wind turbine power output, you want the wind speed data to reflect, as closely as possible, the conditions at the hub height of the wind turbine. So consider the height above ground when you specify the diurnal pattern strength and the hour of peak wind speed.

To measure the diurnal pattern strength from time series wind speed data, one can calculate the average diurnal profile and perform a curve fit operation to find the best-fit value of the hour of peak wind speed and the diurnal pattern strength. We performed that process for the 239 weather stations in the U.S. National Solar Radiation Data Base, which record wind speeds at 10m above ground. The histogram below shows the distribution of the diurnal pattern strength values that we measured. The measured values themselves appear in the **table of measured wind parameters**.



7.49 DMap

A DMap (data map) is a type of graph showing one year of time series data. With time of day on one axis and day of the year on the other, each time step of the year is represented by a rectangle which is colored according to the data value for that hour. The DMap format often allows you to see daily and seasonal patterns more easily than you could with a simple time series plot. An example of a DMap appears below:



7.50 Effective Head

Type: Intermediate Variable

Units: m

Symbol: h_{net}

One can model the friction pressure loss in the pipeline between the intake and the turbine as a loss in head. The effective head is the actual vertical drop minus this head loss. HOMER calculates the effective head (or net head) using the following equation:

$$h_{net} = h \cdot (1 - f_h)$$

where
:

h = **available head** [m]

f_h = **pipe head loss** [%]

HOMER uses the effective head to calculate the power output of the hydro turbine in each time step.

See also

7.8 Available Head

5.4 How HOMER Calculates the Hydro Power Output

7.51 Electrolyzer Efficiency

Type: Input Variable

Units: %

Symbol: $\eta_{electrolyzer}$

The efficiency with which the electrolyzer converts electricity into hydrogen. This is equal to the energy content (based on higher heating value) of the hydrogen produced divided by the amount of electricity consumed.

Example: The higher heating value of hydrogen is 142 MJ/kg, which is equal to 39.4 kWh/kg. So an electrolyzer that consumes 50 kWh of electricity to produce one kilogram of hydrogen has an efficiency of 39.4 kWh/kg divided by 50 kWh/kg, which is 79%.

7.52 Excess Electricity

Excess electricity is surplus electrical energy that must be dumped (or curtailed) because it cannot be used to serve a load or charge the batteries. Excess electricity occurs when there is a surplus of power being produced (either by a renewable source or by the generator when its minimum output exceeds the load) and the batteries are unable to absorb it all.

> **Note:** It is possible to have a capacity shortage on one bus and excess electricity on the other in the same time step. An undersized converter, or one with the "Parallel with AC generator?" option **not** selected, can cause this to happen.

A resistive heater (often called an electric boiler) can convert excess electricity into thermal energy that can meet the thermal load. In HOMER, this component is called the **Thermal Load Controller**, available from the Components menu.

If it cannot be put to use, excess electricity may need to be dissipated in a *dump load*, which is usually a simple resistive heater or a bank of light bulbs. In some cases, excess energy represents energy that could be curtailed rather than dissipated.

HOMER tabulates the excess electricity experienced by the system in each time step. You can see the time series and the annual total in the **Simulation Results** window, which appears when you double click on a system in the Optimization Results tab of HOMER's main window.

7.53 Excess Electricity Fraction

Type: Output Variable

Units: none

Symbol: f_{excess}

The excess electricity fraction is the ratio of **total excess electricity** to the **total electrical production**. HOMER calculates this value at the end of each simulation using the following equation:

$$f_{excess} = \frac{E_{excess}}{E_{prod}}$$

where
:

E_{excess} = **total excess electricity** [kWh/yr]

E_{prod} = **total electrical production** [kWh/yr]

See also

7.168 Total Excess Electricity

7.54 Feasible and Infeasible Systems

A feasible system is one that satisfies the constraints. An infeasible system is one that does not satisfy the constraints.

HOMER discards infeasible systems and does not display them in the optimization results or sensitivity results.

See also:

The Definition of a **7.158 System**
3.2 Optimization Results
3.3 Sensitivity Results
2.4.3 Constraints

7.55 Flow Rate Available To Hydro Turbine

Type: Intermediate Variable

Units: m^3/s

Symbol: $\dot{Q}_{available}$

The flow rate available to the hydro turbine is the maximum flow rate that could be diverted into the hydro turbine. In each time step, HOMER calculates the available flow rate using the following equation:

$$\dot{Q}_{available} = \dot{Q}_{stream} - \dot{Q}_{residual}$$

where:

$\dot{Q}_{stream}$ = the total stream flow [m^3/s]

$\dot{Q}_{residual}$ = **residual flow** [m^3/s]

HOMER uses the available stream flow to calculate the actual stream flow through the hydro turbine in each time step.

See also

7.88 Hydro Turbine Flow Rate
5.4 How HOMER Calculates the Hydro Power Output

7.56 Fossil Fraction

A co-fired generator can operate on a mixture of fossil fuel and **biogas**. The *fossil fraction* (x_{fossil}) is the ratio of fossil fuel used by the generator in dual-fuel mode to that required to produce the same output power in pure fossil mode. With compression-ignition (diesel) engines, it is necessary to maintain a minimum fossil fraction to ensure proper ignition.

For a more complete explanation of the fossil fraction and the operation of a co-fired generator, please see the article **Operation of a Co-fired Generator**.

See also

7.73 Generator Minimum Fossil Fraction

5.11 Operation of a Co-fired Generator

7.57 Fuel Carbon Content

Type: Input Variable

Units: % (by mass)

Symbol: k_{fuel}

The carbon content of the fuel as a percent of its mass. This value is used to calculate the annual emissions of carbon dioxide, carbon monoxide, and unburned hydrocarbons resulting from the consumption of this fuel in a generator, boiler, or reformer.

See also:

5.3 How HOMER Calculates Emissions

7.35 CO2 Emissions Penalty

7.34 CO Emissions Penalty

2.2.10.1 Simple Rates

7.58 Fuel Cell

A fuel cell converts chemical fuel to electricity through a chemical reaction in which the fuel is oxidized and electricity is generated. You can model a fuel cell with the generator component in HOMER. For example, to model a hydrogen fuel cell, add a generator, set the fuel to stored hydrogen, and adjust the fuel curve to match the fuel cell's specifications.

7.59 Fuel Price

Type: Input Variable

Units: $/L

Symbol: c_{fuel}

The price of fuel in dollars per liter. It is very common to do a sensitivity analysis on this variable for two reasons: it is difficult to accurately predict the future fuel price, and the optimal architecture of the power system can vary widely depending on the fuel price.

This input is used to calculate the **generator fuel cost**.

7.60 Fuel Sulfur Content

Type: Input Variable

Units: % (by mass)

The sulfur content of the fuel as a percent of its mass. This value is used to calculate the annual emissions of particulate matter and sulfur dioxide resulting from the consumption of this fuel in a generator, boiler, or reformer.

See also:

5.3 How HOMER Calculates Emissions
7.152 SO2 Emissions Penalty
7.119 PM Emissions Penalty
2.2.10.1 Simple Rates

7.61 Future Value

The future value is defined as the equivalent value at some designated future date of a sequence of cash flows, taking into account the time value of money.

See also

7.91 Real Discount Rate
7.151 Sinking Fund Factor
7.120 Present Value

7.62 Generator

In HOMER, a "generator" is a device that consumes fuel to produce electric (and sometimes thermal) energy. Generators can be dispatched, meaning the system can turn them on as necessary. Microturbines and fuel cells are generators, as are diesel- and gasoline-fueled reciprocating engine generators.

7.63 Generator Average Electrical Efficiency

Type: Output Variable

Units: %

Symbol: η_{gen}

This is the average electrical efficiency of the generator over the year, defined as the electrical energy out divided by fuel energy in. HOMER uses the following equation to calculate the average electrical efficiency:

$$\eta_{gen} = \frac{3.6 \cdot E_{gen}}{m_{fuel} \cdot \mathrm{LHV}_{fuel}}$$

where
:

E_{gen} = the generator's total annual electrical production [kWh/yr]

m_{fuel} = the generator's total annual fuel consumption [kg/yr]

LHV_{fuel} = the lower heating value of the fuel [MJ/kg]

The factor of 3.6 in the above equation arises because 1 kWh = 3.6 MJ.

See also:

7.64 Generator Average Total Efficiency

7.64 Generator Average Total Efficiency

Type: Output Variable

Units: %

Symbol: $\eta_{gen,tot}$

This is the average total efficiency of the generator over the year, defined as the electrical plus thermal energy out divided by fuel energy in. HOMER uses the following equation to calculate the average total efficiency:

$$\eta_{gen,tot} = \frac{3.6 \cdot \left(E_{gen} + H_{gen}\right)}{m_{fuel} \cdot \mathrm{LHV}_{fuel}}$$

where
:

E_{gen} = the generator's total annual electrical production [kWh/yr]

E_{gen} = the generator's total annual thermal production [kWh/yr]

m_{fuel} = the generator's total annual fuel consumption [kg/yr]

LHV_{fuel} = the lower heating value of the fuel [MJ/kg]

The factor of 3.6 in the above equation arises because 1 kWh = 3.6 MJ.

See also:

7.63 Generator Average Electrical Efficiency

7.65 Generator Carbon Monoxide Emissions Factor

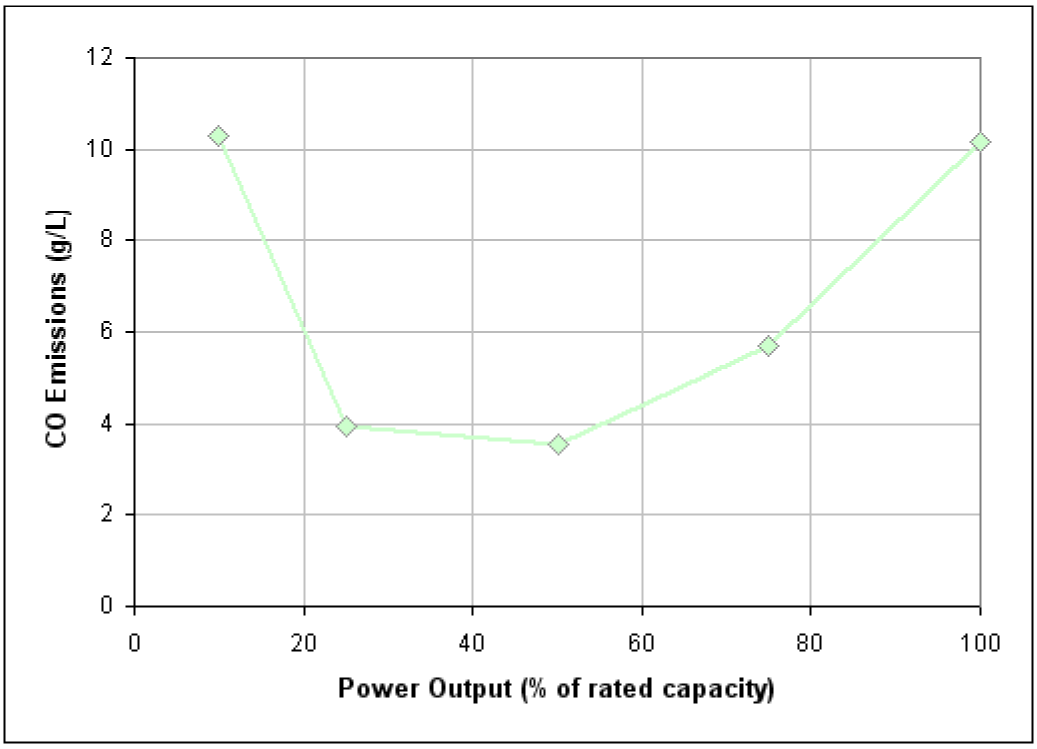
Type: Input Variable

Units: grams per unit fuel (fuel units can be L, m^3, or kg)

Symbol: $f_{gen,CO}$

The amount of carbon monoxide emitted per unit fuel consumed by the generator. Because carbon monoxide is a product of incomplete combustion, the quantity produced will depend on the fuel, engine design, and operating conditions, including the power output of the generator. But HOMER makes a simplifying assumption that this factor is constant.

The following graph shows the value of the carbon monoxide emissions factor for diesel generators in the size range 50 kW - 450 kW. The source of these data is an internal NREL report by Erin Kassoy entitled "Modeling diesel exhaust emissions in diesel retrofits". The default value for the generator CO emissions factor is equal to the average value between 50% and 100% load.



HOMER uses this value to calculate the emissions of carbon monoxide and carbon dioxide. For details, see the article on **How HOMER Calculates Emissions**.

7.66 Generator Derating Factor

Type: Input Variable

Units: %

Symbol: τ

The maximum output of a co-fired generator operating at the **minimum fossil fraction**, as a percentage of its rated output. For example, say a 20 kW diesel generator is modified to run on a mixture of diesel fuel and **biogas**, with a minimum diesel of 20%. If the output of the engine is limited to 15 kW when operating at 20% diesel fraction, the derating factor would be 15 kW divided by 20 kW, or 75%.

Note that HOMER assumes a co-fired generator can produce up to 100% of its rated output, provided the fossil fraction is high enough. In the above example, the generator could produce up to 20 kW, but the diesel fraction would have to exceed 20% for any output power above 15 kW.

For a more complete explanation of a cofired generator, please see **Operation of a Co-fired Generator**.

7.67 Generator Fuel Cost

Type: Output Variable

Units: $/yr

Symbol: $C_{fuel,gen}$

The annual cost of fueling the generator. HOMER calculates this value by multiplying the fuel price by the amount of fuel used by the generator in one year.

If the generator burns **biogas**, either as its primary fuel or co-fired with another fuel, HOMER includes the biomass cost in the generator fuel cost. The biomass cost is equal to the amount of biomass *feedstock* consumed over a year multiplied by the price of biomass.

7.68 Generator Fuel Curve Intercept Coefficient

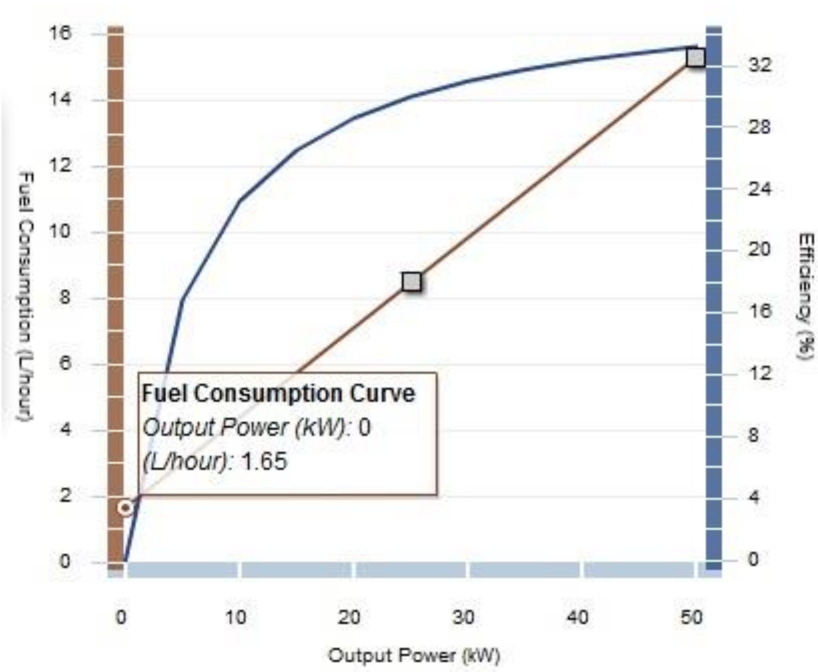
Type: Input Variable

Units: fuel units/hr/kW_{rated}

Symbol: F_0

The fuel curve intercept coefficient is the no-load fuel consumption of the generator divided by its rated capacity. If you were to plot a straight line of fuel consumption versus the power output of the generator, the y-intercept of that line divided by the generator size is equal to the fuel curve intercept coefficient.

For example, if a 50 kW generator consumes 8.48 L/hr at 25 kW output and 15.3 L/hr at rated output, the slope of the fuel curve would be (15.3-8.48)/(50-25) = 0.273 L/hr/kW_{output}. So the y-intercept would be 8.48 - (0.273*25) = 1.655 L/hr. Dividing by 50 kW (the size of the generator) gives the fuel curve intercept coefficient of 0.033 L/hr/kW_{rated}. This fuel curve is plotted below:



The **Fuel Curve Calculator** helps calculate the fuel curve slope and intercept coefficient.

If the generator is running in a particular time step, HOMER calculates the fuel consumption rate for that time step using the following equation:

$$F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}$$

where
:

F = fuel consumption rate [L/hr]

F_0 = generator fuel curve intercept coefficient [L/hr/kW_{rated}]

F_1 = **generator fuel curve slope** [L/hr/kW_{output}]

Y_{gen} = rated capacity of the generator [kW]

P_{gen} = output of the generator in this time step [kW]

If the generator is not running in a particular time step, then the fuel consumption for that time step is zero.

See also

7.69 Generator Fuel Curve Slope

7.69 Generator Fuel Curve Slope

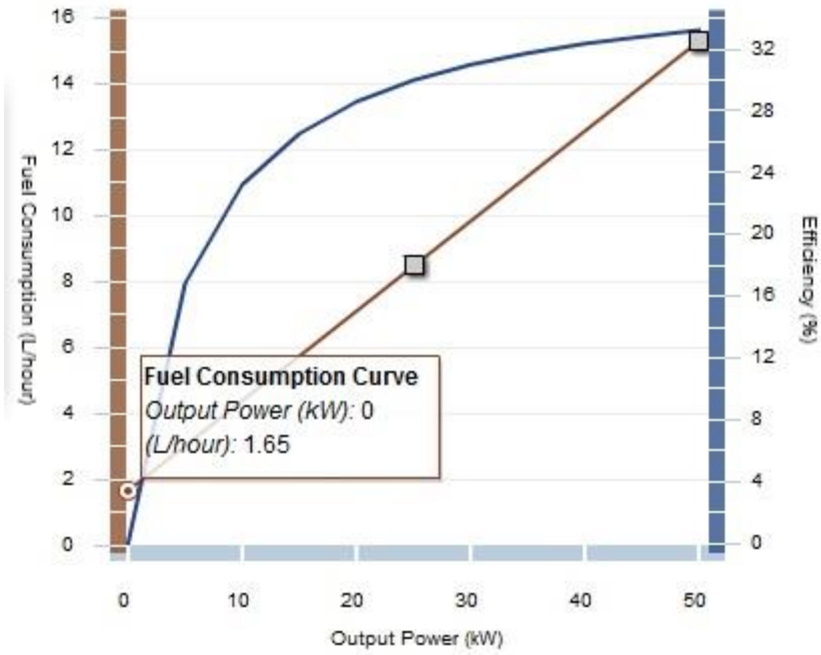
Type: Input Variable

Units: fuel units/hr/kW

Symbol: F_1

The fuel curve slope is the marginal fuel consumption of the generator, in units of fuel per hour per kW of output, or equivalently, units of fuel per kWh. If you were to plot a straight line of fuel consumption versus the power output of the generator, the slope of that line is the fuel curve slope.

For example, if a 50 kW generator consumes 8.48 L/hr at 25 kW output and 15.3 L/hr at rated output, the slope of the fuel curve would be (15.3-8.48)/(50-25) = 0.273 L/hr/kW_{output}. This fuel curve is plotted below:



The **Fuel Curve Calculator** helps calculate the fuel curve slope and intercept coefficient.

If the generator is running in a particular time step, HOMER calculates the fuel consumption rate for that time step using the following equation:

$$F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen}$$

where
:

F = fuel consumption rate this time step [L/hr]

F_0 = **generator fuel curve intercept coefficient** [L/hr/kW_{rated}]

F_1 = generator fuel curve slope [L/hr/kW_{output}]

Y_{gen} = rated capacity of the generator [kW]

P_{gen} = output of the generator in this time step [kW]

If the generator is not running in a particular time step, then the fuel consumption for that time step is zero.

See also
7.68 Generator Fuel Curve Intercept Coefficient

7.70 Generator Heat Recovery Ratio

Type: Input Variable

Units: %

Symbol: f_{hr}

This input is relevant only for cogeneration systems, also called combined-heat-and-power systems or CHP systems. Such systems serve both electric and thermal loads, with waste heat recovered from the generator meeting some or all of the thermal load. If you do not want to model a cogeneration system, leave this input at zero.

HOMER assumes that the generator converts all of the energy of the fuel into electricity and heat. The generator's fuel curve specifies how much electricity it produces for a given fuel input, and HOMER simply assumes the remaining fuel energy is converted to heat. The heat recovery ratio is the percentage of that heat that can be recovered to serve the thermal load.

7.71 Generator Hourly Replacement Cost

Type: Intermediate Variable

Units: $/hr

Symbol: $c_{rep,gen}$

The generator lifetime is specified in number of operating hours. So the hourly replacement cost of each generator can be calculated according to the following equation:

$$c_{rep,gen} = \frac{C_{rep,gen}}{R_{gen,h}}$$

where
:

$C_{rep,gen}$ = generator **replacement cost**

$R_{gen,h}$ = **generator lifetime**

7.72 Generator Lifetime

Type: Input Variable

Units: hr

Symbol: $R_{gen,h}$

Unlike the lifetime inputs for most other components, the generator lifetime is specified not in years but in hours of operation. This is because the lifetime of a generator depends strongly on the hours of operation, but not very strongly on its age.

It is not always easy to obtain lifetime data for a particular generator, as it can depend on operating conditions, maintenance frequency, fuel quality, and other factors. But it is possible to estimate longevity based on the engine type. Reciprocating internal combustion engines are the most common engine type. Of these, compression-ignition (diesel) engines tend to last several times longer than spark-ignition engines (gasoline, propane, or natural gas) engines. For longevity, low speed (1800 RPM) is superior to high speed (3600 RPM), liquid cooling is superior to air cooling, and pressurized oil lubrication is superior to splash lubrication. The following table serves as a rough guideline for estimating the lifetime of certain types of generators.

Generator Type	Size Range (kW)	Estimated Lifetime (hrs)
High speed (3600 RPM) air-cooled gasoline, natural gas, or propane generator	1-10	250 - 1,000
High speed (3600 RPM) air-cooled diesel	4 - 20	6,000 - 10,000
Low speed (1800 RPM) liquid-cooled natural gas or propane generator	15 - 50	6,000 - 10,000
Prime power liquid-cooled diesel	7 - 10,000	20,000 - 80,000
Natural gas microturbine	25 - 500	50,000 - 80,000

Because its lifetime is specified in operating hours, the more frequently the generator operates, the shorter its lifetime in years. This affects the economics of the system because more frequent replacements leads to higher annualized cost. HOMER takes this into consideration when deciding whether to operate a generator or to use an alternative dispatchable source such as a battery, the grid, or another generator.

Once it has simulated a system, HOMER calculates the generator's expected lifetime in years and reports it as the **generator operational life** on the **Simulation Results** window.

7.73 Generator Minimum Fossil Fraction

Type: Input Variable

Units: %

Symbol: x^{*}_{fossil}

The minimum allowable **fossil fraction** for a cofired generator operating on a mixture of fossil fuel and biogas. Diesel engines require a certain minimum amount of diesel fuel to ensure proper ignition. Spark-ignition engines may not have any such requirement, and may be able to operate on pure **biogas**.

7.74 Generator Minimum Percent Load

Type: Input Variable

Units: %

Symbol: $f_{gen,min}$

The minimum allowable load on the generator, as a percentage of its rated capacity. Specifying a minimum load will not prevent the generator from being shut off, it will simply prevent it from operating at too low a load. This input exists because some manufacturers recommend that their generators not be run below a certain load.

As an example, say this number is set to 30%. If the required power from the generator is 40% of its capacity, it will run at 40%. If the required power is 15%, it will run at 30%, with the excess power either serving the deferrable load, charging the batteries, or being dumped. If no power is required from the generator, it will be shut off.

7.75 Generator Nitrogen Oxides Emissions Factor

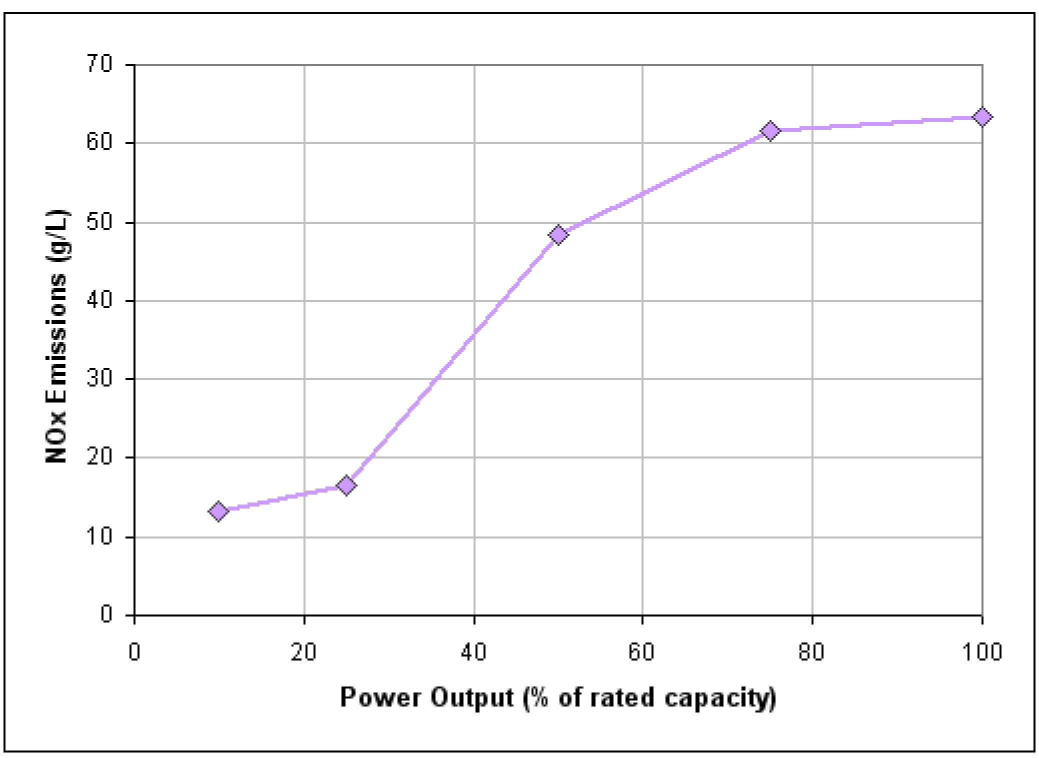
Type: Input Variable

Units: grams per unit fuel (fuel units can be L, m^3, or kg)

Symbol: $f_{gen,NOx}$

The amount of nitrogen oxides emitted per unit fuel consumed by the generator. The actual quantity of this pollutant produced by the generator will depend on engine design and operating conditions, principally the power output of the generator. But HOMER makes a simplifying assumption that this factor is constant.

The following graph shows the value of the nitrogen oxides emissions factor for diesel generators in the size range 50 kW - 450 kW. The source of these data is an unpublished NREL report by Erin Kassoy entitled "Modeling diesel exhaust emissions in diesel retrofits". HOMER's default value for the generator's nitrogen oxides emissions factor is equal to the average value between 50% and 100% load.



HOMER uses this value to calculate the emissions of nitrogen oxides. For details, see the article on **How HOMER Calculates Emissions**.

7.76 Generator Operational Life

Type: Output Variable

Units: yr

Symbol: R_{gen}

In HOMER, the lifetime of generators is specified in terms of operating hours. The number of years that a generator will last is therefore an output variable, which HOMER calculates according to the following equation:

$$R_{gen} = \frac{R_{gen,h}}{N_{gen}}$$

where
:

$R_{gen,h}$ = **generator lifetime** [hr]

N_{gen} = the number of hours the generator operates during one year [hr/yr]

For example, if the generator has a lifetime of 20,000 operating hours and HOMER determines that it will operate 4300 hours per year, then its expected lifetime in years would be 20,000 hours / 4300 hours per year = 4.65 years

7.77 Generator Particulate Matter Emissions Factor

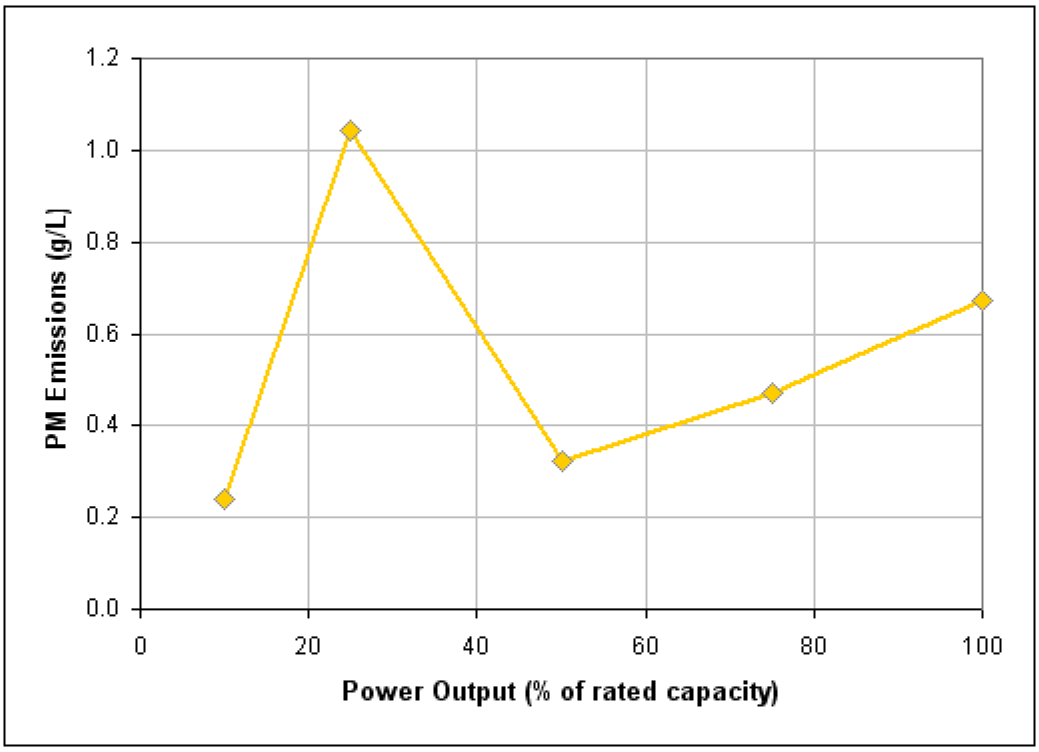
Type: Input Variable

Units: grams per unit fuel (fuel units can be L, m^3, or kg)

Symbol: $f_{gen,PM}$

The amount of particulate matter (smoke, soot, and liquid droplets)emitted per unit fuel consumed by the generator. The actual quantity of this pollutant produced by the generator will depend on the fuel, engine design, and operating conditions, including the power output of the generator. But HOMER makes a simplifying assumption that this factor is constant.

The following graph shows the value of the particulate matter emissions factor for diesel generators in the size range 50 kW - 450 kW. The source of these data is an internal NREL report by Erin Kassoy entitled "Modeling diesel exhaust emissions in diesel retrofits". HOMER's default value for the generator's particulate matter emissions factor is equal to the average value between 50% and 100% load.



HOMER uses this value to calculate the emissions of particulate matter. For details, see the article on **How HOMER Calculates Emissions**.

7.78 Generator Proportion of Sulfur Emitted as Particulate Matter

Type: Input Variable

Units: %

Symbol: x_{PM}

The fraction of the sulfur in the fuel that gets emitted as particulate matter. HOMER assumes that the rest gets emitted as sulfur dioxide. This value is 2.2% for diesel generators, according to the EPA document EPA420-P-02-016, dated November 2002, entitled "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling -- Compression-Ignition".

HOMER uses this value to calculate the emissions of sulfur dioxide. Note that HOMER does not use this value this value to calculate emissions of particulate matter. For that, it uses the **particulate matter emissions factor**. For details, see the article on **How HOMER Calculates Emissions**.

7.79 Generator Unburned Hydrocarbons Emissions Factor

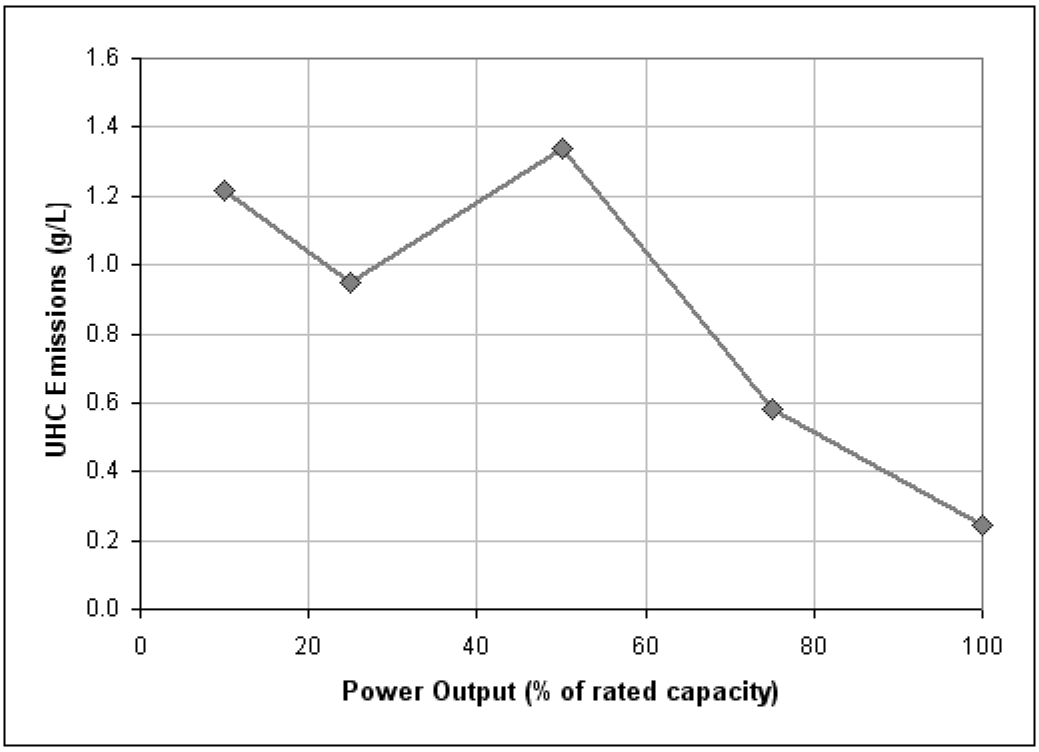
Type: Input Variable

Units: grams per unit fuel (fuel units can be L, m^3, or kg)

Symbol: $f_{gen,UHC}$

The amount of unburned hydrocarbons emitted per unit fuel consumed by the generator. The actual quantity of this pollutant produced by the generator will depend on the fuel, engine design, and operating conditions, including the power output of the generator. But HOMER makes a simplifying assumption that this factor is constant.

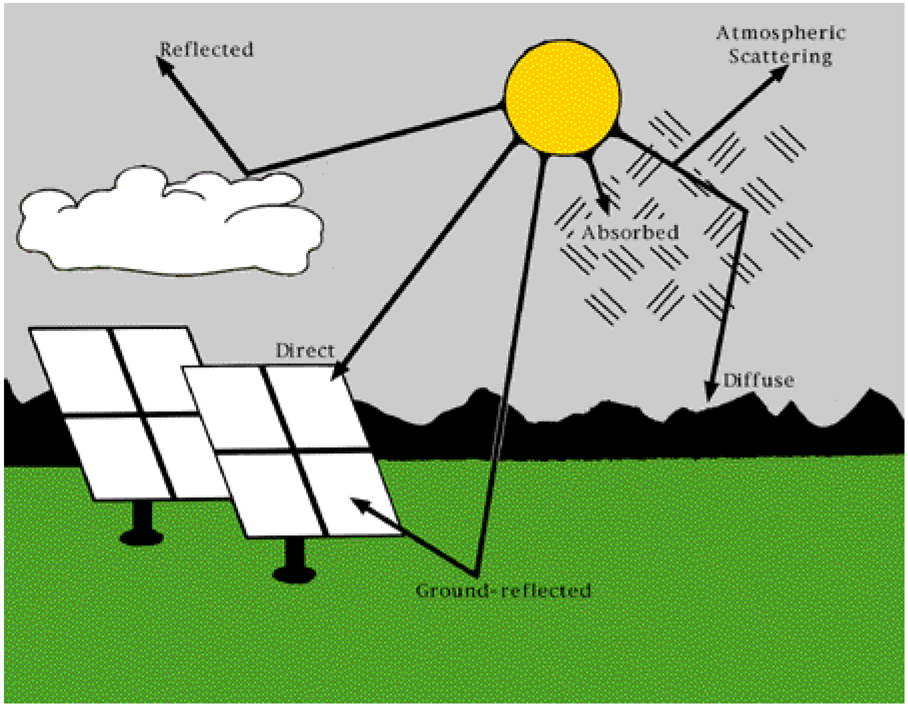
The following graph shows the value of the unburned hydrocarbons emissions factor for diesel generators in the size range 50 kW - 450 kW. The source of these data is an internal NREL report by Erin Kassoy entitled "Modeling diesel exhaust emissions in diesel retrofits". The default value for the generator's unburned hydrocarbon emissions factor is equal to the average value between 50% and 100% load.



HOMER uses this value to calculate the emissions of unburned hydrocarbons and carbon dioxide. For details, see the article on **How HOMER Calculates Emissions**.

7.80 Global Horizontal Irradiance (GHI)

Global Horizontal Irradiance is the total solar radiation incident on a horizontal surface. It is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and ground-reflected radiation. HOMER uses Solar GHI to compute flat-panel PV output.



See also

2.2.2 Photovoltaic Panels (PV)
2.3.1 Solar GHI Resource

For more information

*The **HOMER Support Site** has a searchable knowledgebase and additional support options.*

***HOMER online** contains the latest information on model updates, as well as sample files, resource data, and contact information.*

Image source: RReDC Glossary of Solar Radiation Resource Terms, NREL Renewable Resource Data Center from http://rredc.nrel.gov/solar/pubs/shining/images/pg12.gif

7.81 Grid Costs

The grid cost in HOMER Explorer is based on a levelized electricity cost in $/kWh. All grid electricity purchases will be at this rate.

-->

Since the grid is unlike any other component, HOMER calculates the costs associated with the grid in a unique way. This article explains how HOMER calculates each of the grid cost outputs.

Grid capital cost

If the system is connected to the grid and contains some other power producing device (such as a microturbine, a fuel cell, a PV array, or a wind turbine), the grid capital cost is equal to the interconnection charge. Otherwise, the grid capital cost is zero.

Grid replacement cost

The replacement cost of the grid is always zero.

Grid O&M cost

The grid O&M cost is equal to the annual cost of buying electricity from the grid (energy cost plus demand cost) minus any income from the sale of electricity to the grid. For grid-connected systems that contain some other power producing device (such as a microturbine, a fuel cell, a PV array, or a wind turbine), the grid O&M cost also includes the standby charge.

See also

7.31 Capital Recovery Factor
7.82 Grid Interconnection Charge
7.83 Grid Standby Charge
7.122 Project Lifetime

7.82 Grid Interconnection Charge

Type: Input Variable

Units: $

Symbol: $C_{grid,int}$

The interconnection charge is a one-time fee charged by the utility for allowing a power system to be connected to the grid. HOMER does not apply this fee to grid-only systems, but rather to grid-connected systems that include some other generation source. For such systems, the interconnection charge is added to the **grid capital cost**.

See also:

7.83 Grid Standby Charge
3.1.1.3 Grid Costs

7.83 Grid Standby Charge

Type: Input Variable

Units: $/yr

Symbol: $C_{grid,standby}$

The standby charge is an annual fee charged by the utility for providing backup grid power for a grid-connected power system. HOMER does not apply this fee to grid-only systems, but rather to grid-connected systems that include some other generation source (like a microturbine, a fuel cell, or a PV array). For such systems, the standby charge is added to the **grid costs**.

See also:

7.82 Grid Interconnection Charge
3.1.1.3 Grid Costs

7.84 Ground Reflectance

Type: Input Variable

Units: %

Symbol: ρ_g

The ground reflectance (also called albedo) is the fraction of solar radiation incident on the ground that is reflected. A typical value for grass-covered areas is 20%. Snow-covered areas may have a reflectance as high as 70%. This value is used in calculating the radiation incident on the tilted PV panels, but it has only a modest effect.

See also:

2.2.2 Photovoltaic Panels (PV)

7.85 Hydrocarbons Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{HC}

Use the HC emissions penalty to penalize systems for their production of unburned hydrocarbons. HOMER uses this input value when calculating the **Other O&M Cost**.

7.86 Hour of Peak Windspeed

Type: Input Variable

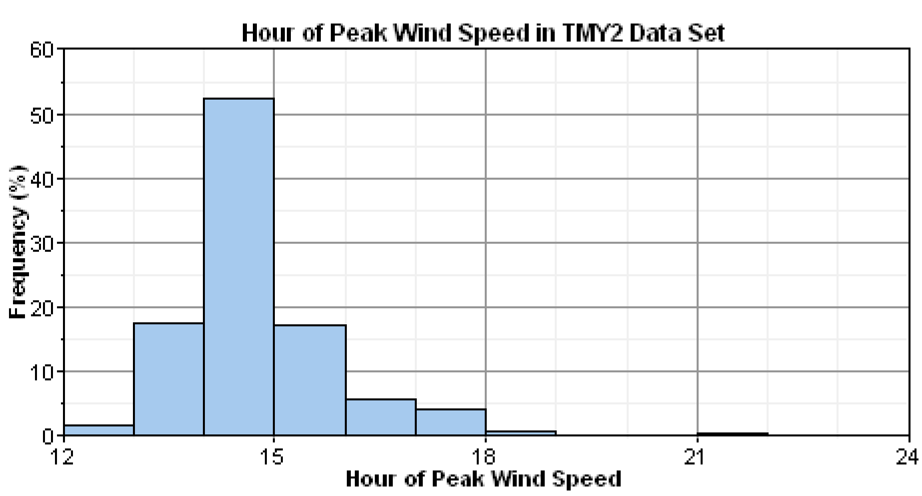
Units: none

Symbol: ϕ

Typical Range: 14 - 16

The hour of peak windspeed is the hour of the day that tends to be the windiest, on average. The article on diurnal pattern strength describes how HOMER calculates this value.

We calculated the hour of peak wind speed for each of the 239 weather stations in the TMY2 data set. The histogram below shows the resulting distribution. You can see the measured values themselves in the **table of measured wind parameters**.



See also

7.48 Diurnal Pattern Strength

7.112 One-Hour Autocorrelation Factor

7.175 Weibull k Value

7.87 Hydro Turbine Efficiency

Type: Input Variable

Units: %

Symbol: η_{hyd}

The efficiency with which the hydro turbine converts the mechanical power of the water into electrical power. HOMER uses this value to calculate the nominal hydro power and the actual output power of hydro turbine in each time step.

See also

7.107 Nominal Hydro Power

5.4 How HOMER Calculates the Hydro Power Output

7.88 Hydro Turbine Flow Rate

Type: Intermediate Variable

Units: m^3/s

Symbol: $\dot{Q}_{turbine}$

The hydro turbine flow rate is the amount of water flowing through the hydro turbine. HOMER calculates this value in each time step using the following equation:

$$\dot{Q}_{turbine} = \begin{cases} 0 & if\ \dot{Q}_{available} < \dot{Q}_{min} \\ \dot{Q}_{available} & if\ \dot{Q}_{min} \le \dot{Q}_{available} \le \dot{Q}_{max} \\ \dot{Q}_{max} & if\ \dot{Q}_{available} > \dot{Q}_{max} \end{cases}$$

where:

$\dot{Q}_{available}$ = the **flow rate available to the hydro turbine** [m^3/s]

$\dot{Q}_{min}$ = **minimum flow rate of the hydro turbine** [m^3/s]

$\dot{Q}_{max}$ = **maximum flow rate of the hydro turbine** [m^3/s]

Note: As this equation shows, HOMER assumes that unless the available stream exceeds the turbine's minimum flow rate, the turbine flow rate is zero, meaning the turbine does not operate and hence produces no power. If HOMER reports that your hydro turbine is not producing any power, this is probably the reason.

HOMER uses the hydro turbine flow rate to calculate the hydro power output in each time step.

See also

5.4 How HOMER Calculates the Hydro Power Output

7.89 Hydrogen Tank Autonomy

Type: Output Variable

Units: hr

Symbol: A_{htank}

The hydrogen tank autonomy is the ratio of the energy capacity of the hydrogen tank to the electric load. HOMER calculates the hydrogen tank autonomy using the following equation:

$$A_{htank} = \frac{Y_{htank} \mathrm{LHV}_{H_2} (24\, h/d)}{L_{prim,ave} (3.6\, MJ/kWh)}$$

where
:

Y_{htank} = capacity of the hydrogen tank [kg]

LHV_{H2} = energy content (lower heating value) of hydrogen [120 MJ/kg]

$L_{prim,ave}$ = average primary load [kWh/d]

7.90 Initial Capital Cost

The initial capital cost of a component is the total installed cost of that component at the beginning of the project.

See also

7.136 Replacement Cost

7.91 Real Discount Rate

Type: Input Variable

Units: %

Symbol: i

The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate (also called the *real interest rate* or just *interest rate*) from the "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and to calculate annualized costs from net present costs.

You can enter the nominal discount rate and the expected inflation rate in the Economic Inputs window. HOMER uses the following equation to calculate the real discount rate:

$$i = \frac{i' - f}{1 + f}$$

where
:

i = real discount rate

i' = nominal discount rate (the rate at which you could borrow money)

f = expected inflation rate

For example, if the nominal discount rate is 8% and the expected inflation rate is 3.5%, the annual real discount rate is 4.35%. If you want to enter the real annual interest rate directly, for example if you want to do a sensitivity analysis, you can set the expected inflation rate to zero and enter values for the real discount rate into the nominal discount rate input.

By defining the real discount rate in this way, **inflation** is factored out of the economic analysis. All costs therefore become *real costs*, meaning that they are in defined in terms of constant dollars. The assumption is that the rate of inflation is the same for all costs.

See also

Economic Inputs window
Annualized cost
Net present cost
Salvage value

7.92 Levelized Cost of Energy

Type: Output Variable

Units: $/kWh

Symbol: COE

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}}$$

where
:

$C_{ann,tot}$ = **total annualized cost** of the system [$/yr]

c_{boiler} = **boiler marginal cost** [$/kWh]

H_{served} = **total thermal load served** [kWh/yr]

E_{served} = **total electrical load served** [kWh/yr]

The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems that do not serve a thermal load ($H_{thermal}$=0) this term will equal zero.

The COE is a convenient metric with which to compare systems, but HOMER does not rank systems based on COE.

See also
7.6 Annualized Cost
7.163 Total Annualized Cost

7.93 LF

Abbreviation for the **Load Following** dispatch strategy.

See also
7.97 Load Following Strategy
7.39 Cycle Charging Strategy

7.94 Lifetime Throughput

Type: Input Variable

Units: kWh

Symbol: $Q_{lifetime}$

If the storage properties indicate that the storage life is limited by throughput, HOMER assumes that the storage will require replacement after a fixed amount of energy cycles through the storage, regardless of the depth of the individual charge-discharge cycles. HOMER uses this *lifetime storage throughput* to calculate the **life of the storage bank** and the **storage wear cost**.

See also
7.14 Battery Float Life

7.95 Load

A load consumes energy from the microgrid. A **primary load** can model anything that uses electricity, such as a light bulb or a motor. A **thermal load** can represent anything that uses heat energy, such as a heating system or an absorption chiller. A **deferrable load** consumes electricity on a flexible schedule and can model systems that need a certain amount of energy over a given period, but don't need power at specific times. A **hydrogen load** can model a consumer of hydrogen, such as a fuel cell or a chemical process.

See also
2.1 Loads Tab
2.1.3 Electric Load
2.1.4 Thermal Load

2.1.5 Deferrable Load
2.1.6 Hydrogen Load

7.96 Load Factor

The load factor is a dimensionless number equal to the average load divided by the peak load.

Example: If the average load is 66 kWh/d (or 2.75 kW) and the peak load is 10.5 kW, the load factor is 2.75 kW / 10.5 kW = 0.26.

7.97 Load Following Strategy

The load following strategy is a **dispatch strategy** whereby whenever a generator operates, it produces only enough power to meet the primary load. Lower-priority objectives such as charging the storage bank or serving the **deferrable load** are left to the renewable power sources. The generator may still ramp up and sell power to the grid if it is economically advantageous.

Under the load following strategy, HOMER dispatches the system's controllable power sources (generators, grid, storage bank) so as to serve the primary load and the thermal load at the least total cost each time step, while satisfying the **operating reserve requirement**. The total cost includes the cost of fuel, operation and maintenance, and replacement. To accomplish this, HOMER calculates the fixed and marginal cost of each dispatchable power source:

- A generator's fixed cost is equal to its hourly operation and maintenance cost plus its **hourly replacement cost** plus the cost of its no-load fuel consumption. Its marginal cost is equal to its fuel curve slope times the fuel price. If waste heat can be recovered from the generator **and** the waste heat is needed to serve the thermal load, the generator's marginal cost is reduced by the value of the thermal energy it produces (which is equal to the marginal cost of thermal energy from the **boiler**). If a cost is assigned to carbon emissions, the generator's marginal cost is increased accordingly.
- The storage bank's fixed cost is zero and its marginal cost is equal to the **storage wear cost**.
- The grid's fixed cost is zero and its marginal cost is equal to the grid power price. If a cost is assigned to carbon emissions, the grid's marginal cost is increased accordingly.

Once it characterizes each dispatchable source in this way, HOMER searches for the combination of generation sources that satisfies the primary load, required operating reserve, and thermal load at least cost.

See also
7.39 Cycle Charging Strategy

7.98 Maximum Annual Capacity Shortage

Type: Input Variable

Units: %

The maximum annual capacity shortage is the maximum allowable value of the **capacity shortage fraction**, which is the **total capacity**

shortage divided by the total electric load. HOMER considers infeasible (or unacceptable) any system with a higher value of the capacity shortage fraction.

Allowing some capacity shortage can change the results dramatically in some cases. This might happen if there were a very high peak for a very short time. If the maximum annual capacity shortage is set to zero, HOMER will size the system to meet even this very high peak load. This could mean that the system has to include large, expensive equipment that is not fully used most of the time. If you allow a small amount of capacity shortage, HOMER could choose to install smaller, less expensive equipment that would be able to supply all but that peak load.

> **Note:** If you set each of the four operating reserve inputs to zero, the capacity shortage fraction will be equal to the unmet load fraction.

See also:

7.138 Required Operating Reserve
7.164 Total Capacity Shortage
7.29 Capacity Shortage Fraction
7.173 Unmet Load Fraction

7.99 Maximum Battery Capacity

The maximum capacity (or theoretical capacity) of a storage is the total amount of energy it contains when fully charged. It is not possible to extract all this energy at any finite discharge current (it would take an infinite amount of time to extract it all), so storage sizes are not typically given in terms of maximum capacity. HOMER calculates the maximum capacity for use in the **kinetic storage model**.

7.100 Maximum Flow Rate

Type: Intermediate
Variable

Units: m^3/s

Symbol: $\dot{Q}_{max}$

The maximum flow rate is the maximum allowable flow rate through the hydro turbine. HOMER calculates the maximum flow rate of the hydro turbine using the following equation:

$$\dot{Q}_{max} = w_{max} \cdot \dot{Q}_{design}$$

where
:

w_{max} = the hydro turbine's **maximum flow ratio** [%]

$\dot{Q}_{design}$ = the hydro turbine's **design flow rate** [m^3/s]

HOMER uses this value to calculate the hydro turbine flow rate in each time step.

See also
7.103 Minimum Flow Rate
7.88 Hydro Turbine Flow Rate
5.4 How HOMER Calculates the Hydro Power Output

7.101 Maximum Flow Ratio

Type: Input Variable

Units: %

Symbol: w_{max}

The maximum acceptable flow rate through the hydro turbine, expressed as a percentage of the turbine's design flow rate. HOMER uses this input to calculate the maximum flow rate through the hydro turbine, and hence the actual flow rate through the hydro turbine.

See also
7.44 Design Flow Rate
7.100 Maximum Flow Rate
7.88 Hydro Turbine Flow Rate
7.104 Minimum Flow Ratio

7.102 Purchase Capacity

Type: Input Variable

Units: kW

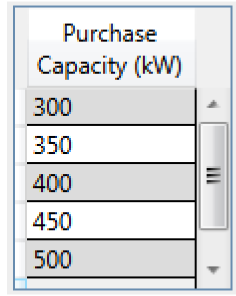
Symbol: T_{grid}

The purchase capacity is the maximum amount of power that can be drawn from the grid at any time. It is a **decision variable** because of the effect of demand charges. HOMER does not explicitly consider the demand rate in its time-step-by-time-step decisions as to how to control the power system; the demand charge is simply calculated at the end of each annual simulation. As a result, HOMER will not turn on a generator simply to save demand charges. But it will turn on a generator whenever the load exceeds the maximum grid demand.

If the demand rate is zero, you need only specify a single value for the maximum grid demand. Normally, the true capacity of the grid is much higher than the system peak load, and the maximum grid demand can be set to any value higher than the system peak load. In the rare case that the grid is unable to meet the system peak load, the maximum grid demand should be set to the actual capacity of the grid.

If the demand rate is not zero, specify a value equal to or greater than the peak load, plus at least one value smaller than the peak load. HOMER will find the optimal value.

The maximum grid demand appears in a table on the **Grid** window:



Purchase Capacity (kW)
300
350
400
450
500

7.103 Minimum Flow Rate

Type: Intermediate Variable

Units: m^3/s

Symbol: $\dot{Q}_{min}$

The minimum flow rate is the minimum allowable flow rate through the hydro turbine. HOMER assumes that the hydro turbine can operate only if the available stream flow is equal to or exceeds this minimum value. HOMER calculates the minimum flow rate of the hydro turbine using the following equation:

$$\dot{Q}_{min} = w_{min} \cdot \dot{Q}_{design}$$

where
:

w_{min} = the hydro turbine's **minimum flow ratio** [%]

$\dot{Q}_{design}$ = the hydro turbine's **design flow rate** [m^3/s]

HOMER uses this value to calculate the hydro turbine flow rate in each time step.

See also

7.100 Maximum Flow Rate
7.88 Hydro Turbine Flow Rate
5.4 How HOMER Calculates the Hydro Power Output

7.104 Minimum Flow Ratio

Type: Input Variable

Units: %

Symbol: w_{min}

The minimum acceptable flow rate through the hydro turbine, expressed as a percentage of the turbine's design flow rate. HOMER uses this input to calculate the minimum flow rate through the hydro turbine, and hence the actual flow rate through the hydro turbine.

See also

7.44 Design Flow Rate

7.103 Minimum Flow Rate
7.88 Hydro Turbine Flow Rate
7.101 Maximum Flow Ratio

7.105 Net Present Cost

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each component of the system, and of the system as a whole.

Example: A diesel generator has an initial capital cost of $96,000, a replacement cost of $48,000, and a lifetime of 3.52 years. Its cost of operation and maintenance (O&M) is $2,471/yr, and its fuel cost is $34,969/yr. What is the net present cost of this generator over a 25-year project lifetime at an annual real discount rate of 6%?

To perform this calculation, HOMER produces a cash flow table such as the one that appears below. Except for the salvage value that occurs at the end of the 25th year, all of these cash flows are costs, so they appear as negative numbers in the table.

The first column shows the time at which each cash flow occurs, in years since the start of the project. The capital cost occurs at the start of the project, meaning year zero. The annual O&M and fuel costs occur at the end of each year, and the replacement costs happen every 3.52 years.

The second column, highlighted in yellow, contains the discount factor. The columns highlighted in green contain the nominal cash flows, and the columns highlighted in purple contain the same cash flow discounted to year zero. HOMER calculates the discounted costs by multiplying the nominal costs by the discount factor.

The bottom row below the purple discounted cash flow columns contains the net present value of each category of cash flow, as well as the total net present value, shown in red, with a value of -$725,240. The net present value and the net present cost differ only in sign, so the net present cost of this generator over the 25-year project lifetime is $725,240.

HOMER does a similar analysis for each component of the system, and for the system as a whole.

Year	Discount	Nominal Cash Flows						Discounted Cash Flows					
	Factor	Capital	Replacement	Salvage	O&M	Fuel	Total	Capital	Replacement	Salvage	O&M	Fuel	Total
0	1.000	-96,000					-96,000	-96,000					**-96,000**
1	0.94				-2,4	-34,9	-37,44				-2,3	-32,9	**-35,3**

	3				71	69	1				31	90	**21**
2	0.890				-2,471	-34,969	-37,441				-2,200	-31,123	**-33,322**
3	0.840				-2,471	-34,969	-37,441				-2,075	-29,361	**-31,436**
3.52	0.815		-48,000				-48,000		-39,098				**-39,098**
4	0.792				-2,471	-34,969	-37,441				-1,958	-27,699	**-29,657**
5	0.747				-2,471	-34,969	-37,441				-1,847	-26,131	**-27,978**
6	0.705				-2,471	-34,969	-37,441				-1,742	-24,652	**-26,394**
7	0.665				-2,471	-34,969	-37,441				-1,644	-23,257	**-24,900**
7.04	0.663		-48,000				-48,000		-31,847				**-31,847**
8	0.627				-2,471	-34,969	-37,441				-1,551	-21,940	**-23,491**
9	0.592				-2,471	-34,969	-37,441				-1,463	-20,698	**-22,161**
10	0.558				-2,471	-34,969	-37,441				-1,380	-19,527	**-20,907**
10.56	0.540		-48,000				-48,000		-25,941				**-25,941**
11	0.527				-2,471	-34,969	-37,441				-1,302	-18,421	**-19,723**
12	0.497				-2,471	-34,969	-37,441				-1,228	-17,379	**-18,607**
13	0.469				-2,471	-34,969	-37,441				-1,159	-16,395	**-17,554**
14	0.442				-2,471	-34,969	-37,441				-1,093	-15,467	**-16,560**
14.0	0.44		-48,000				-48,00		-21,130				**-21,1**

8	0						0						**30**
15	0.417				-2,471	-34,969	-37,441				-1,031	-14,592	**-15,623**
16	0.394				-2,471	-34,969	-37,441				-973	-13,766	**-14,738**
17	0.371				-2,471	-34,969	-37,441				-918	-12,986	**-13,904**
17.60	0.359		-48,000				-48,000		-17,212				**-17,212**
18	0.350				-2,471	-34,969	-37,441				-866	-12,251	**-13,117**
19	0.331				-2,471	-34,969	-37,441				-817	-11,558	**-12,375**
20	0.312				-2,471	-34,969	-37,441				-771	-10,904	**-11,674**
21	0.294				-2,471	-34,969	-37,441				-727	-10,286	**-11,013**
21.12	0.292		-48,000				-48,000		-14,020				**-14,020**
22	0.278				-2,471	-34,969	-37,441				-686	-9,704	**-10,390**
23	0.262				-2,471	-34,969	-37,441				-647	-9,155	**-9,802**
24	0.247				-2,471	-34,969	-37,441				-610	-8,637	**-9,247**
24.64	0.238		-48,000				-48,000		-11,420				**-11,420**
25	0.233			43,120	-2,471	-34,969	5,679			10,047	-576	-8,148	**1,323**
Total		**-96,000**	**-336,000**	**43,120**	**-61,784**	**-874,234**	**-1,324,899**	**-96,000**	**-160,668**	**10,047**	**-31,593**	**-447,026**	**-725,239**

Note that HOMER uses the discount factor to account not for inflation, but for the time value of money. Inflation is factored out of the analysis by the use of the real discount rate instead of the nominal discount rate. All costs in the table above are in year-zero dollars. This explains why the fuel and O&M costs remain the same for each year of the project lifetime.

But even when we factor inflation out of the analysis, the time value of money dictates that a future cash flow is worth less than a present cash flow of the same amount. The discount factor accounts for this effect; its value decreases with increasing number of years from the start of the project.

See also

Total net present cost
Annualized cost
Present value
Future value
Salvage value
Project lifetime
Real Discount rate
Discount factor
Cash Flow Details table

7.106 Nominal Battery Capacity

The nominal capacity (or rated capacity) of a storage is the amount of energy that could be withdrawn from it at a particular constant current, starting from a fully charged state. The current used to rate batteries varies from one manufacturer to another, but it is typically either the 10-hour, 20-hour, or 100-hour rate. The 10-hour rate (C_{10}) is the current that causes the storage to be drained after 10 hours.

7.107 Nominal Hydro Power

Type: Output Variable

Units: kW

Symbol: $P_{hyd,nom}$

The nominal power of the hydro system. This would be the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine. The calculation of the nominal hydro power includes the **efficiency** of the hydro turbine, but not the **pipe head loss**.

> **Note:** HOMER uses this value only to identify the size of the hydro system, to allow easy comparison to the sizes of other components of the power system.

HOMER calculates the nominal hydro power using the following equation:

$$P_{hyd,nom} = \frac{\eta_{hyd} \cdot \rho_{water} \cdot g \cdot h \cdot \dot{Q}_{design}}{1000\ W/kW}$$

where

:

$P_{hyd,nom}$ = nominal power output of the hydro turbine [kW]

η_{hyd} = **hydro turbine efficiency** [%]

ρ_{water} = density of water [1000 kg/m^3]

g = acceleration due to gravity [9.81 m/s^2]

h = **available head** [m]

$\dot{Q}_{design}$ = the **design flow rate** of the hydro turbine [m^3/s]

See also

5.4 How HOMER Calculates the Hydro Power Output

7.108 Nonrenewable Electrical Production

Type: Intermediate Variable

Units: kWh/yr

Symbol: E_{nonren}

The nonrenewable electrical production is the total amount of electrical energy produced annually by the nonrenewable components of the power system. HOMER uses the following equation to calculate the nonrenewable electrical production:

$$E_{nonren} = E_{prod} - E_{ren}$$

where

:

E_{prod} = **total electrical production** [kWh]

E_{ren} = **renewable electrical production** [kWh]

HOMER uses this variable to calculate the renewable fraction.

See also

7.133 Renewable Fraction

7.135 Renewable Thermal Production

7.166 Total Electrical Production

7.109 Nonrenewable Thermal Production

Type: Intermediate Variable

Units: kWh/yr

Symbol: H_{nonren}

The nonrenewable thermal production is the total amount of thermal energy produced annually by non-renewable thermal energy sources.

HOMER uses the following equation to calculate the nonrenewable thermal production:

$$H_{nonren} = H_{prod} - H_{ren}$$

where
:

H_{prod} = **total thermal production** [kWh]

H_{ren} = **renewable thermal production** [kWh]

HOMER uses this value to calculate the renewable fraction.

See also

7.133 Renewable Fraction
7.132 Renewable Electrical Production
7.167 Total Thermal Production

7.110 NOx Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{NOx}

Use the NO_x emissions penalty to penalize systems for their production of nitrogen oxides. HOMER uses this input value when calculating the **Other O&M cost**.

7.111 Operation and Maintenance Cost

The O&M cost of a component is the cost associated with operating and maintaining that component. The total O&M cost of the system is the sum of the O&M costs of each system component.

For most components, you enter the O&M cost as an annual amount. In the case of the generator, you enter the O&M cost as an hourly value, and HOMER multiplies that by the operating hours per year to calculate the annual O&M cost.

The grid O&M cost is the annual cost of buying power from the grid minus any revenue earned from selling power to the grid.

HOMER classifies miscellaneous annual costs, such as the system fixed O&M cost, and penalties such as emissions penalties and the capacity shortage penalty, as other O&M cost.

HOMER displays the O&M costs on the Cost Summary and Cash Flow tabs of the Simulation Results window.

See also

3.1.1.3 Grid Costs
7.117 Other Operation and Maintenance Cost
7.160 System Fixed Operations and Maintenance (O&M) Cost
7.30 Capacity Shortage Penalty

2.4.4 Emissions

7.112 One-Hour Autocorrelation Factor

Type: Input Variable

Units: none

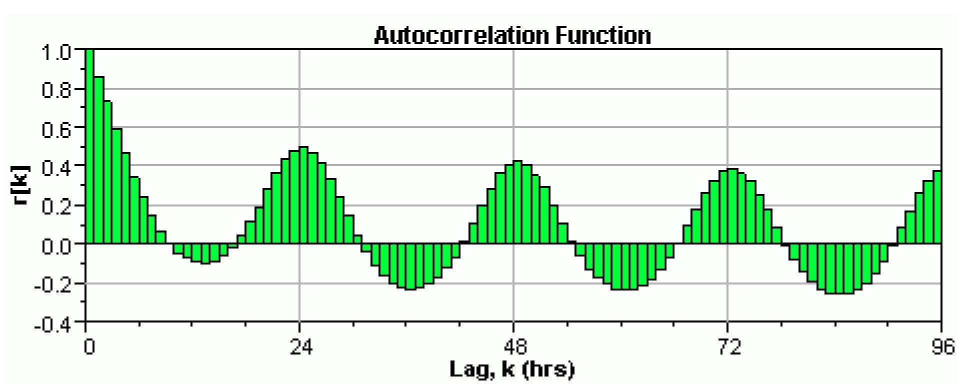
Symbol: r_1

Typical Range: 0.80 - 0.95

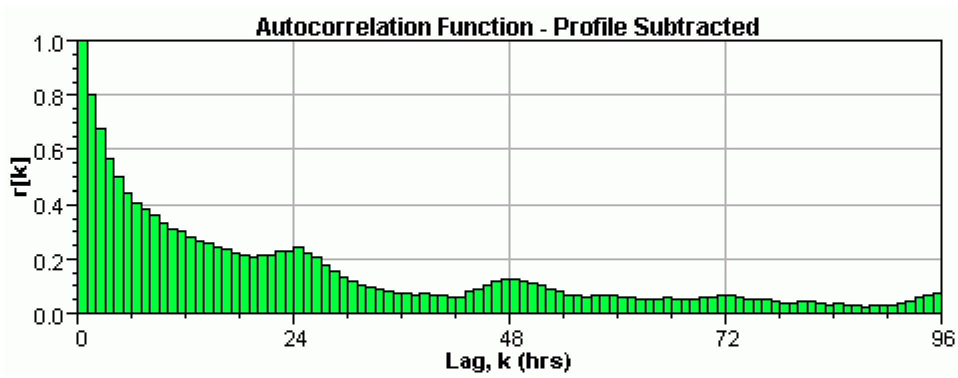
The autocorrelation factor reflects how strongly the wind speed in one time step depends on the wind speeds in previous time steps. A high autocorrelation factor indicates that the wind speed tends to depend strongly on the wind speed in the previous time step. Lower values indicate that the wind speed tends to fluctuate in a more random fashion from one time step to the next. Among other factors, local topography can influence this parameter. Autocorrelation factors tend to be lower (0.70 - 0.80) in areas of complex topography and higher (0.90 - 0.97) in areas of more uniform topography.

To define the autocorrelation factor we first need to look at the typical autocorrelation characteristics of measured wind speed data.

As explained in the discussion of **autocorrelation**, the daily patterns in the wind data tend to complicate its autocorrelation function. The graph below shows the autocorrelation function for the hourly wind speed data measured at San Diego, California:



To simplify the autocorrelation characteristics of wind data, we can factor out the diurnal pattern. HOMER does this by calculating the average diurnal profile, and then subtracting that profile from the wind speed data. For example, if the diurnal profile showed an average wind speed of 3.2 m/s at 1 a.m., then HOMER would subtract 3.2 m/s from all 365 values of wind speed at 1 a.m. It does the same for all 24 hours of the day, resulting in a time series that has an average of 0 m/s and no daily pattern. The autocorrelation function of this new time series typically displays almost no oscillation. The graph below shows the autocorrelation function for the San Diego data after subtracting out the diurnal profile:

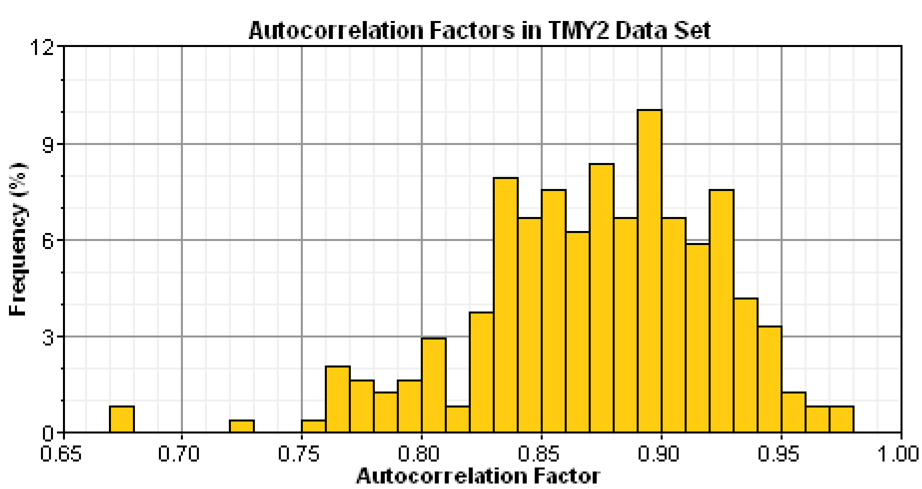


The autocorrelation function shown above dies down roughly in damped exponential fashion, so that to a good approximation,

$$r_k = r_1^k$$

We can therefore describe the degree of correlation with a single parameter. In HOMER we call this the *one-hour autocorrelation factor*, which is r_k where k is the number of time steps in one hour. If the time step is 60 minutes, the one-hour autocorrelation factor is r_1. If the time step is 20 minutes, the one-hour autocorrelation factor is r_3. If the time step is 10 minutes, the one-hour autocorrelation factor is r_6.

To help HOMER users estimate the one-hour autocorrelation factor in the absence of measured data, we calculated the autocorrelation factor for each of the 239 weather stations in the TMY2 data set. The histogram below shows the resulting distribution. You can see the measured values themselves in the table of TMY2 wind parameters.



The complexity of local topography has a significant effect on the autocorrelation factor. Areas surrounded by a variety of different types of topography tend to have low (0.70 - 0.80) autocorrelation factors. For example, the stations with the lowest autocorrelation factors in the **table of measured wind parameters** are Los Angeles CA, Denver CO, Phoenix AZ, Lander WY, Seattle WA, and Salt Lake City UT. Each of these cities is surrounded by complex topography: mountains or hills on one side, and plains or open water on another. In such surroundings, shifts in wind direction can result in the wind having a very different character. So there is less persistence of wind speeds, and therefore lower autocorrelation [**Brett and Tuller, 1991**].

Areas surrounded by more uniform topography tend to have high (0.90 - 0.97) autocorrelation factors. The stations with the highest autocorrelation factors in the **table of measured wind parameters** include Cut Bank MT, St. Paul Island AK, and the island of Guam. Each of these sites is surrounded by relatively featureless topography: either plains or open water.

> **Note**: the autocorrelation factor is independent of the Weibull k value. Whereas the Weibull k value reflects the breadth of the annual distribution of wind speeds, the autocorrelation factor reflects how randomly the wind speeds vary from hour to hour. The data contained in the table of measured wind parameters shows no correlation between these two parameters.

See also

7.7 Autocorrelation
5.17 Generating Synthetic Wind Data
7.175 Weibull k Value
7.48 Diurnal Pattern Strength
7.86 Hour of Peak Windspeed
6.4 Wind Data Parameters

7.113 Operating Capacity

The operating capacity is the total amount of electrical generation capacity that is operating (and ready to produce electricity) at any one time. It is therefore the maximum amount of electrical load that the system could serve at a moment's notice.

To ensure reliable supply, the operating capacity should be greater than the electric load. The difference between the operating capacity and the electric load is the **operating reserve**. As it simulates the power system, HOMER attempts to keep the operating reserve equal to or greater than the **required operating reserve**.

In HOMER, both dispatchable power sources (generators, grid, storage bank) and renewable power sources (wind, solar, hydro) provide operating capacity. The operating capacity of a dispatchable source is equal to the maximum amount of power it could produce at a moment's notice. For example:

- A generator that is not currently operating provides no operating capacity because it cannot be counted on to provide power at a moment's notice. It must first be started, allowed to warm up, and synchronized.
- A 50 kW generator that is operating provides 50 kW of operating capacity, regardless of the actual amount of power it is producing at any time.
- The operating capacity provided by the grid is equal to the **maximum grid demand**.
- The operating capacity provided by the storage bank is equal to the maximum amount of power it could discharge at a particular time. It therefore depends on the storage bank's state of charge and its recent charge and discharge history. For more information please see the article on the **kinetic storage model**.

The operating capacity provided by a non-dispatchable renewable source (like a PV array or a wind turbine) is equal to the amount of power the source is currently producing, not the maximum amount of power it could produce. Since a renewable power source cannot be controlled like a dispatchable source can, its maximum capacity is not relevant in this context. So a wind turbine with a rated capacity of 50 kW that is only producing 13 kW provides only 13 kW of operating capacity.

HOMER keeps track operating capacity and operating reserve separately for the AC and DC buses. For more information please see **operating reserve**.

7.114 Operating Cost

Type: Output Variable

Units: $/yr

Symbol: $C_{oper,tot}$

The operating cost is the annualized value of all costs and revenues other than initial capital costs. HOMER uses the following equation to calculate the operating cost:

$$C_{operating} = C_{ann,tot} - C_{ann,cap}$$

where
:

$C_{ann,tot}$ is the **total annualized cost** [$/yr]

$C_{ann,cap}$ is the total annualized capital cost [$/yr]

The total annualized capital cost is equal to the total initial capital cost multiplied by the capital recovery factor.

HOMER displays the operating cost in the optimization results list, and at the top of the Simulation Results window. You can see the total annualized cost and the total annualized capital cost by going to the Cost Summary tab of the Simulation Results window and choosing to display annualized costs.

See also

7.163 Total Annualized Cost
3.1 Simulation Results
3.1.1 Cost Summary Outputs

7.115 Operating Reserve

Operating reserve is surplus operating capacity that can instantly respond to a sudden increase in the electric load or a sudden decrease in the renewable power output. Operating reserve provides a safety margin that helps ensure reliable electricity supply despite variability in the electric load and the renewable power supply.

Tip: "Spinning reserve" is a more common term that means exactly the same thing as operating reserve. We call it operating reserve simply because batteries, fuel cells, and the grid can provide it, but they do not spin.

Power systems must always provide some amount of operating reserve because the electric load tends to jump around randomly. Without operating reserve, the load would sometimes exceed the operating capacity of the system and the lights would go out. Systems that include wind and solar power sources require additional operating reserve to guard against random decreases in the renewable power supply.

The operating reserve is equal to the **operating capacity** minus the electric load. HOMER keeps track of the operating capacity (and hence operating reserve) separately for the AC and DC buses. It accounts for the efficiency and the capacity of the converter when operating reserve on one bus is needed to cover load on the other bus. For example, consider a diesel-storage-inverter system serving an AC load. If the storage is discharging 2 kW but is capable of discharging 10 kW, it is providing 8 kW of DC operating reserve. If the inverter efficiency is 90% and the inverter capacity is not a limiting factor, that 8 kW of DC operating reserve corresponds to 7.2 kW of AC operating reserve. In other words, the storage bank could supply the AC load even if the load suddenly increased by as much as 7.2 kW. But the inverter capacity can be a limiting factor. If the inverter capacity (the maximum amount of AC power it can provide) is 5 kW, then the storage bank provides only 3.2 kW of AC operating reserve, since the inverter is providing 1.8 kW of AC power to serve the load and therefore has 3.2 kW of excess capacity.

When simulating systems, HOMER attempts to keep the operating reserve equal to or greater than the **required operating reserve**. That may necessitate operating a generator that is not needed to meet the average load (or a larger generator than is needed to meet the average load) just to satisfy the operating reserve requirement.

See also

7.138 Required Operating Reserve
7.98 Maximum Annual Capacity Shortage
7.164 Total Capacity Shortage
7.29 Capacity Shortage Fraction

7.116 Other Capital Cost

Type: Output Variable

Units: $

Symbol: $C_{cap,other}$

HOMER uses the 'other capital cost' to account for the system fixed capital cost and, if any primary load efficiency measures are in effect for the current system configuration, the capital cost associated with those efficiency measures.

The 'other capital cost' appears in the Cash Flow Details Table.

HOMER uses the following equation to calculate the other capital cost:

$$C_{cap,other} = C_{cap,fixed} + C_{eff,1} + C_{eff,2}$$

where
:

$C_{cap,fixed}$ = **system fixed capital cost** [$]

$C_{eff,1}$ = cost of efficiency measures (if any) for primary load 1 [$]

$C_{eff,2}$ = cost of efficiency measures (if any) for primary load 2 [$]

See also
7.159 System Fixed Capital Cost
7.117 Other Operation and Maintenance Cost

7.117 Other Operation and Maintenance Cost

Type: Output Variable

Units: $/yr

Symbol: $C_{om,other}$

The other O&M cost is the sum of:

- the system fixed O&M cost
- the penalty for capacity shortage
- the penalties for emissions of pollutants

HOMER uses the following equation to calculate the other O&M cost:

$$C_{om,other} = C_{om,fixed} + C_{cs} + C_{emissions}$$

where
:

$C_{om,fixed}$ = **system fixed O&M cost** [$/yr]

C_{cs} = the penalty for capacity shortage [$/yr]

$C_{emissions}$ = the penalty for emissions [$/yr]

HOMER uses the following equation to calculate the penalty for capacity shortage:

$$C_{cs} = c_{cs} \cdot E_{cs}$$

where

:

c_{cs} = **capacity shortage penalty** [$/kWh]

E_{cs} = **total capacity shortage** [kWh/yr]

HOMER uses the following equation to calculate the penalty for emissions:

$$C_{emissions} = \frac{c_{CO_2} M_{CO_2} + c_{CO} M_{CO} + c_{UHC} M_{UHC} + c_{PM} M_{PM} + c_{SO_2} M_{SO_2} + c_{NO_x} M_{NO_x}}{1000}$$

where
:

c_{CO2} = penalty for emissions of CO_2 [$/t]

c_{CO} = penalty for emissions of CO [$/t]

c_{UHC} = penalty for emissions of unburned hydrocarbons (UHC) [$/t]

c_{PM} = penalty for emissions of particulate matter (PM) [$/t]

c_{SO2} = penalty for emissions of SO_2 [$/t]

c_{NOx} = penalty for emissions of NO_x [$/t]

M_{CO2} = annual emissions of CO_2 [kg/yr]

M_{CO} = annual emissions of CO [kg/yr]

M_{UHC} = annual emissions of unburned hydrocarbons (UHC) [kg/yr]

M_{PM} = annual emissions of particulate matter (PM) [kg/yr]

M_{SO2} = annual emissions of SO_2 [kg/yr]

M_{NOx} = annual emissions of NO_x [kg/yr]

You can specify the penalties for each pollutant on the **Emissions** window. For information on how HOMER calculates emissions of each pollutant, please see the article on **how HOMER calculates emissions**.

7.118 Pipe Head Loss

Type: Input Variable

Units: %

Symbol: f_h

The frictional loss in the hydro pipeline, expressed as a fraction of the **available head**.

Water (like any viscous fluid) flowing through a pipe experiences a loss in pressure due to friction. We can express this pressure loss in terms of a loss of head, where head is the vertical drop through which the fluid flows. In HOMER, you specify the pipe head loss as a percentage of the available head.

Small high-head, low-flow hydro systems typically experience pipe head losses of between 10% and 20%. With low-head systems, pipe head losses are typically only a few percent.

The head loss percentage is defined in terms of the absolute head loss h_l and the **total available head** *h*:

$$f_h = 100\frac{h_l}{h}$$

The Darcy?-Weisbach equation can be used to predict frictional losses in a circular pipe:

$$h_l = f_D\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

- h_l = Absolute head loss due to friction, given in units of length
- f_D = Darcy friction factor
- *L* = Pipe length
- *D* = Pipe diameter
- *V* = Flow velocity (where Q-dot is volumetric flow rate):

$$V = \frac{\dot{Q}}{A}, \quad A = \frac{\pi D^2}{4}$$

- *g* = Gravitational acceleration (i.e. 9.81 m/s^2)

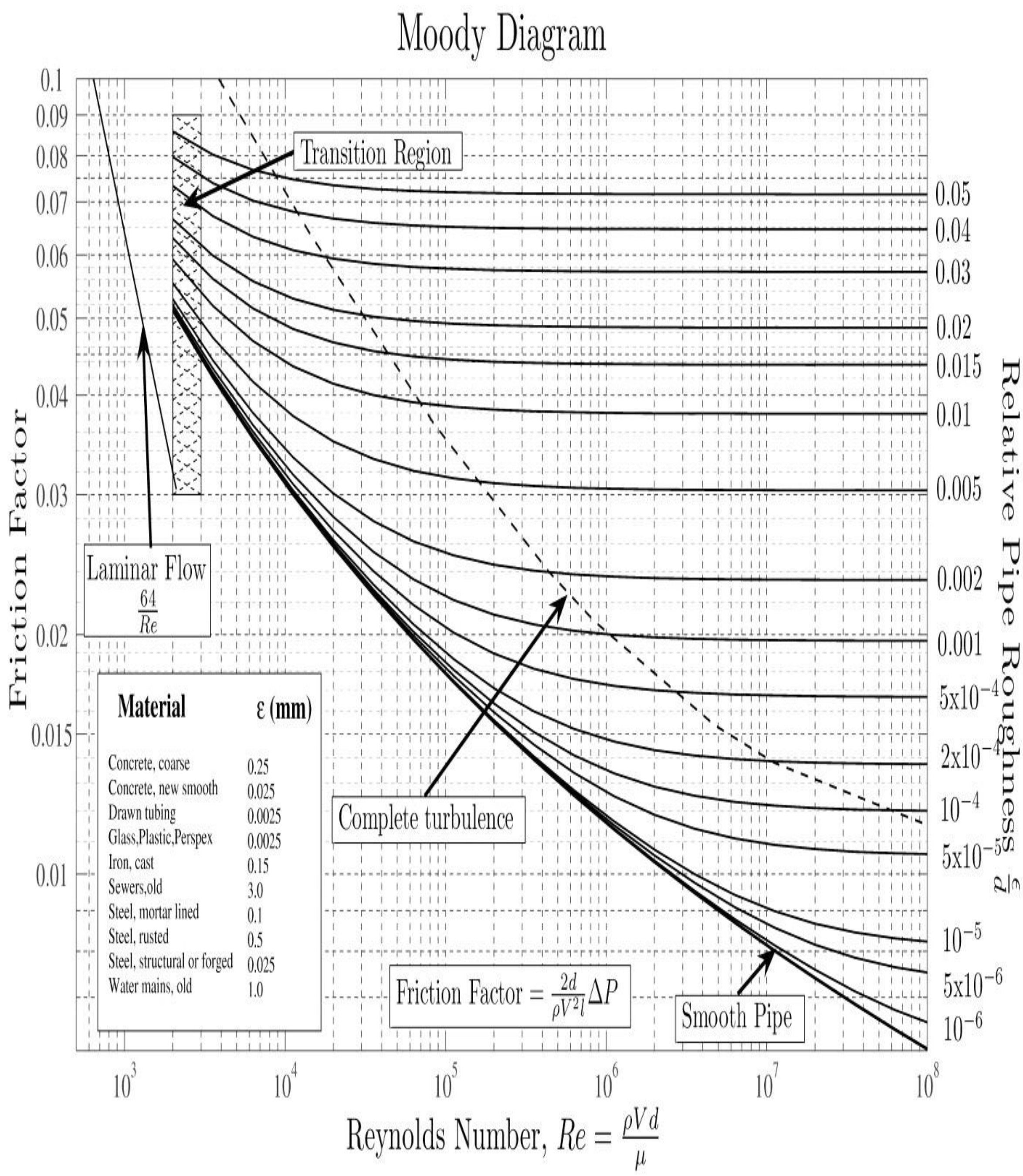
The Darcy friction factor f_D can be calculated several different ways, including the well-known Moody diagram (below) or one of many on-line calculators. For laminar flows (Reynolds number, Re, less than 2300), a simple relationship can be used:

f_D = 64/Re

The friction factor can vary for transition flows (2300 < Re < 4000), and a number of correlations have been proposed. The Moody diagram can provide a good estimate in this regime. For turbulent flows, the Moody diagram is a good reference, or f_D can be computed by numerical solution of the Colebrook-White equation:

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7D_\mathrm{h}} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

- ? = Roughness height
- D_h = Hydraulic diameter (inside diameter for circular tubes)



7.119 PM Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{PM}

Use the PM emissions penalty to penalize systems for their production of particulate. HOMER uses this input value when calculating the **Other O&M cost**.

7.120 Present Value

The present value is the equivalent value at the present of a set of future cash flows, taking into account the time value of money.

For example, if the real interest rate is 6%, the present value of a $1000 payment twelve years in the future is $1000 / ((1.06)^12) = $497.

See also

Real discount rate

Capital recovery factor
Future value

7.121 Probability Transformation

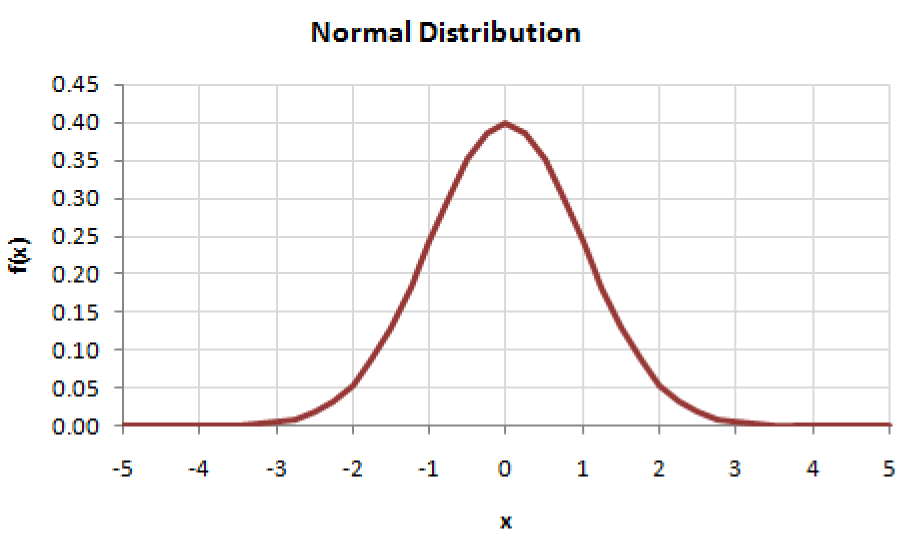
A probability transformation is a statistical procedure by which one modifies a set of numbers to conform to a desired probability distribution function.

To perform a probability transformation, HOMER first calculates the cumulative distribution function of the original set of data -- we will refer to this as the 'original CDF'. Then for each original data point, it performs the following steps:

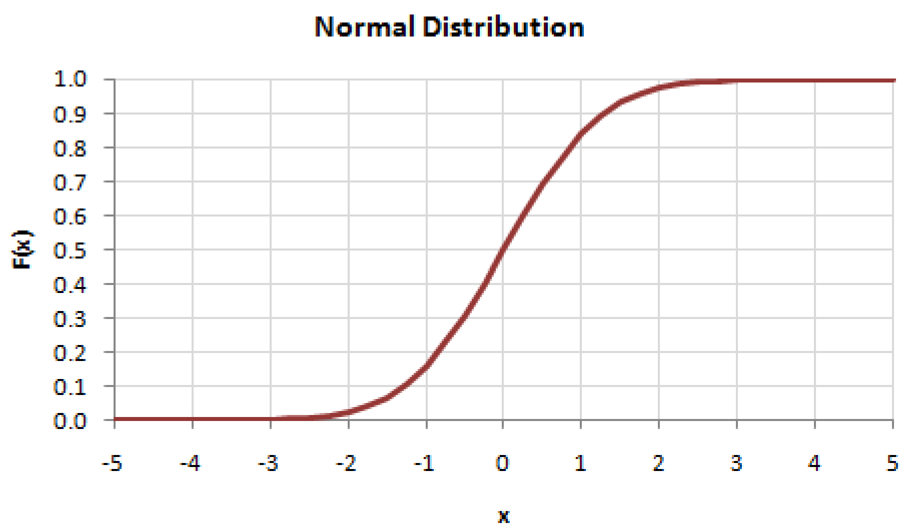
1. It refers to the original CDF to calculate the percentile value corresponding to that original data point
2. It refers to the desired CDF to calculate the transformed value corresponding to that same percentile value

Let's look at an example to illustrate this process. Imagine that we have a set of data that conform to a normal distribution, and we want to transform it so that it conforms to a Weibull distribution. (HOMER does exactly this when synthesizing wind speed data.)

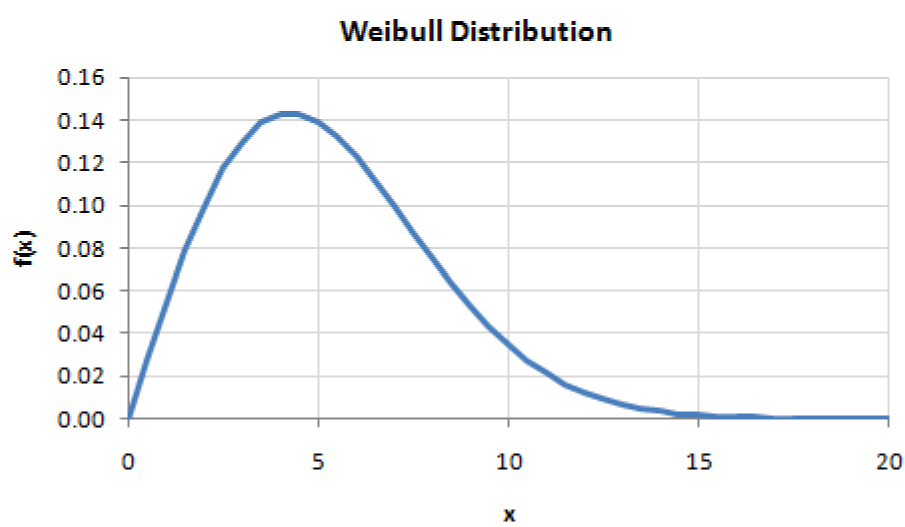
If our normally-distributed data had a mean of zero and a standard deviation of 1, its probability distribution function would look like so:



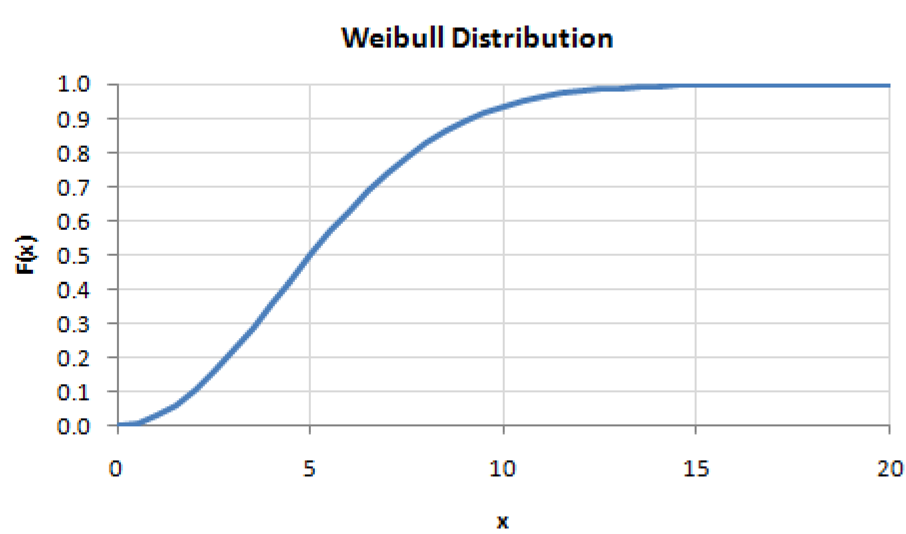
And its cumulative distribution function -- the original CDF -- would look like so:



Imagine that we wish to transform this data to fit a Weibull distribution with a mean value of 6 and a Weibull k value of 2. Our desired probability distribution function would therefore look like so:



And our desired cumulative distribution function -- the desired CDF -- would look like so:



To transform each value in the original data set, we would refer to the original CDF to find its corresponding *y*-value, then we would take that same *y*-value to the desired CDF and find its corresponding *x*-value.

An original value of zero, for example, corresponds to a CDF value of 0.5 on the original CDF. Looking at the desired CDF, we find that the value corresponding to a CDF value of 0.5 is approximately 5. That means that any zero value in the original data set gets transformed into a value of 5 in the transformed data set. Similarly, an original value of -1 would be transformed to value of approximately 2.5, and an original value of 1.5 would be transformed to a value of approximately 10.

This example looks at transforming data from a normal distribution to a Weibull distribution, but with this same probability transformation approach, we could transform from any distribution to any other distribution.

7.122 Project Lifetime

Type: Input Variable

Units: yr

Symbol: R_{proj}

The project lifetime is the length of time over which the costs of the system occur. HOMER uses the project lifetime to calculate annualized costs from net present costs. HOMER assumes that salvage values occur at the end of the project lifetime.

You enter the project lifetime in the Economics window.

See also

Economic Inputs window
Annualized cost
Net present cost
Salvage value
Real discount rate

7.123 PV Azimuth

Type: Input Variable

Units: °

Symbol: γ

The azimuth is the direction towards which the PV panels face. Due south is 0°, due east is -90°, due west is 90°, and due north is 180°. With fixed-azimuth systems, the panels are almost always oriented towards the equator (0° azimuth in the northern hemisphere, 180° azimuth in the southern hemisphere).

The azimuth is insignificant if the panels are mounted horizontally (zero slope). If you choose vertical-axis or two-axis tracking, HOMER does not let you enter the azimuth, but rather calculates it in each time step as the tracking system moves the PV array.

See also

7.129 PV Tracking System
7.127 PV Slope
2.2.2 Photovoltaic Panels (PV)

7.124 PV Derating Factor

Type: Input Variable

Units: %

Symbol: f_{PV}

The PV derating factor is a scaling factor that HOMER applies to the PV array power output to account for reduced output in real-world operating conditions compared to the conditions under which the PV panel was rated.

Use the derating factor to account for such factors as soiling of the panels, wiring losses, shading, snow cover, aging, and so on. If you choose not to explicitly model the effect of temperature on the PV array, then you should also include temperature-related effects in the derating factor.

See also:

5.1 How HOMER Calculates the PV Array Power Output
2.2.2 Photovoltaic Panels (PV)

7.125 PV Efficiency at Standard Test Conditions

Type: Input Variable

Units: %

Symbol: $\eta_{mp,STC}$

The efficiency with which the PV array converts sunlight into electricity at its maximum power point under standard test conditions. HOMER uses the efficiency to calculate the PV cell temperature.

PV manufacturers rarely report this efficiency in their product brochures, but one can calculate it for any PV module using the following equation:

$$\eta_{mp,STC} = \frac{Y_{PV}}{A_{PV} G_{T,STC}}$$

where
:

$\eta_{mp,STC}$ is the efficiency of the PV module under standard test conditions [%]

Y_{PV} is the rated power output of the PV module under standard test conditions [kW]

A_{PV} is the surface area of the PV module [m^2]

$G_{T,STC}$ is the radiation at standard test conditions [1 kW/m^2]

In November 2007 we performed a non-exhaustive, non-scientific survey of the product brochures available for some of the commonly available PV modules. The following table contains the average values of the efficiency under standard test conditions for various types of PV modules in our survey.

PV Module Type	Modules In Survey	Average Value of Efficiency at STC [%]
Polycrystalline silicon	10	13.0
Monocrystalline silicon	8	13.5
Monocrystalline/amorphous silicon hybrid	1	16.4
Thin film amorphous silicon	4	5.5
Thin film CIS	1	8.2

Tip: HOMER assumes the PV array always operates at its maximum power point, as it would if it were controlled by a maximum power point tracker.

See also:

5.8 How HOMER Calculates the PV Cell Temperature
7.156 Standard Test Conditions
2.2.2 Photovoltaic Panels (PV)

7.126 PV Nominal Operating Cell Temperature

Type: Input Variable

Units: °C

Symbol: $T_{c,NOCT}$

The nominal operating cell temperature is the surface temperature that the PV array would reach if it were exposed to 0.8 kW/m^2 of solar radiation, an ambient temperature of 20°C, and a wind speed of 1 m/s. Sometimes called the "normal operating cell temperature" and frequently abbreviated NOCT, the nominal operating cell temperature provides a measure of how the PV cell temperature (the surface temperature of the PV array) varies with the ambient temperature and the solar radiation. HOMER uses the NOCT to calculate the PV cell temperature.

PV manufacturers typically report the nominal operating cell temperature as part of their product data. In our non-exhaustive survey of commercially-available PV modules in November 2007, about 60% of the product data sheets specified the NOCT, with the values varying over a narrow range from 45°C to 48°C.

See also:

5.8 How HOMER Calculates the PV Cell Temperature
2.2.2 Photovoltaic Panels (PV)

7.127 PV Slope

Type: Input Variable

Units: °

Symbol: β

The slope is the angle at which the panels are mounted relative to the horizontal. A slope of 0° corresponds to horizontal, and 90° corresponds to vertical. With fixed-slope systems, a slope roughly equal to the latitude will typically maximize the annual PV energy production. The azimuth specifies the direction towards which the panels slope.

If you choose a horizontal-axis or two-axis tracking system, HOMER does not let you enter the slope, but rather calculates it in each time step.

See also
7.129 PV Tracking System
7.123 PV Azimuth
2.2.2 Photovoltaic Panels (PV)

7.128 PV Temperature Coefficient of Power

Type: Input Variable

Units: %/°C

Symbol: α_P

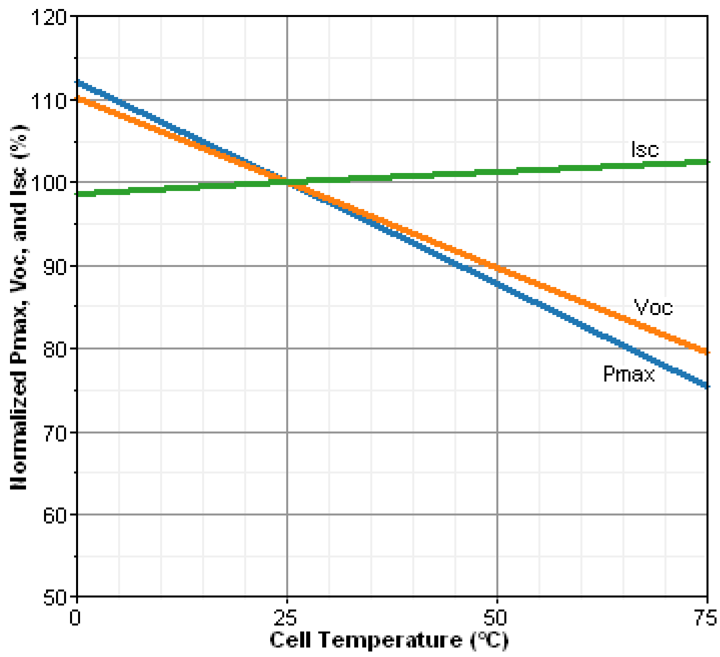
The temperature coefficient of power indicates how strongly the PV array power output depends on the cell temperature, meaning the surface temperature of the PV array. It is a negative number because power output decreases with increasing cell temperature. Manufacturers of PV modules usually provide this coefficient in their product brochures, often labeled either as "temperature coefficient of power", "power temperature coefficient", or "max. power temperature coefficient".

In November 2007 we performed a non-exhaustive, non-scientific survey of the product brochures available for some of the commonly available PV modules. The following table contains the average values of the temperature coefficient of power for various types of PV modules in our survey.

PV Module Type	Modules In Survey	Modules Reporting α_P	Average Value of α_P [%/°C]
Polycrystalline silicon	10	7	-0.48

Monocrystalline silicon	8	4	-0.46
Monocrystalline/amorphous silicon hybrid	1	1	-0.30
Thin film amorphous silicon	4	4	-0.20
Thin film CIS	1	1	-0.60

If the product brochure does not specify the value of the temperature coefficient of power, it may contain a graph showing the normalized performance versus cell temperature, like the sample shown below. In such a graph, the slope of the power line (labeled Pmax in this sample) is the temperature coefficient of power. The normalized open-circuit voltage and short-circuit current also appear in this sample.



Some product brochures do not specify the temperature coefficient of power, but do specify the temperature coefficient of the open-circuit voltage. In that case, you can calculate the temperature coefficient of power using the approximation suggested by **Duffie and Beckman (1991)**:

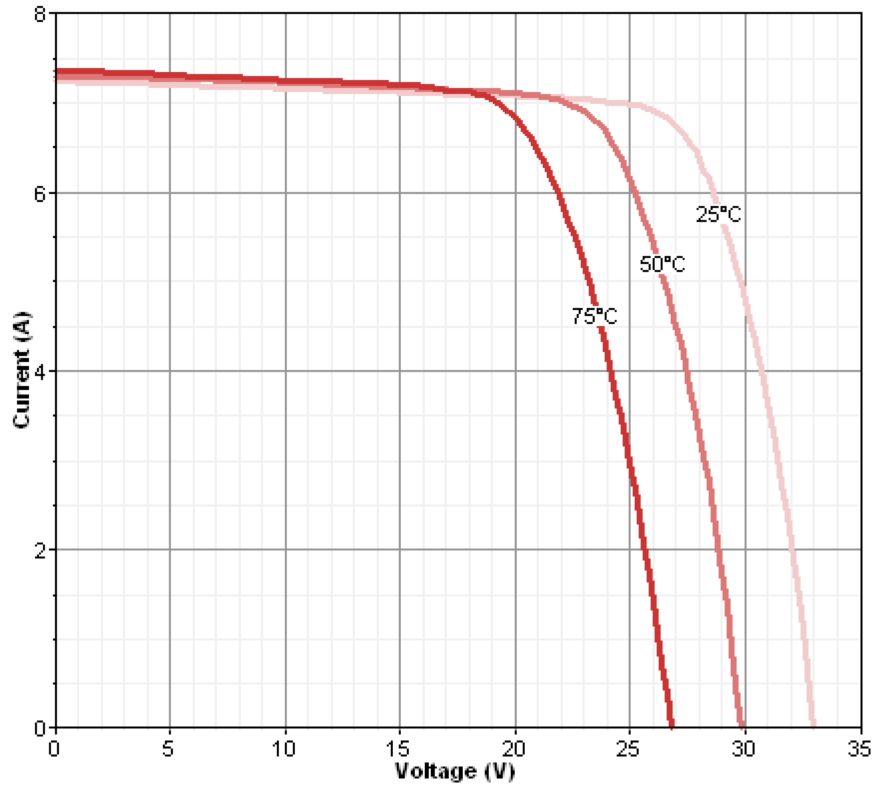
$$\alpha_p \approx \frac{\mu_{Voc}}{V_{mp}}$$

where
:

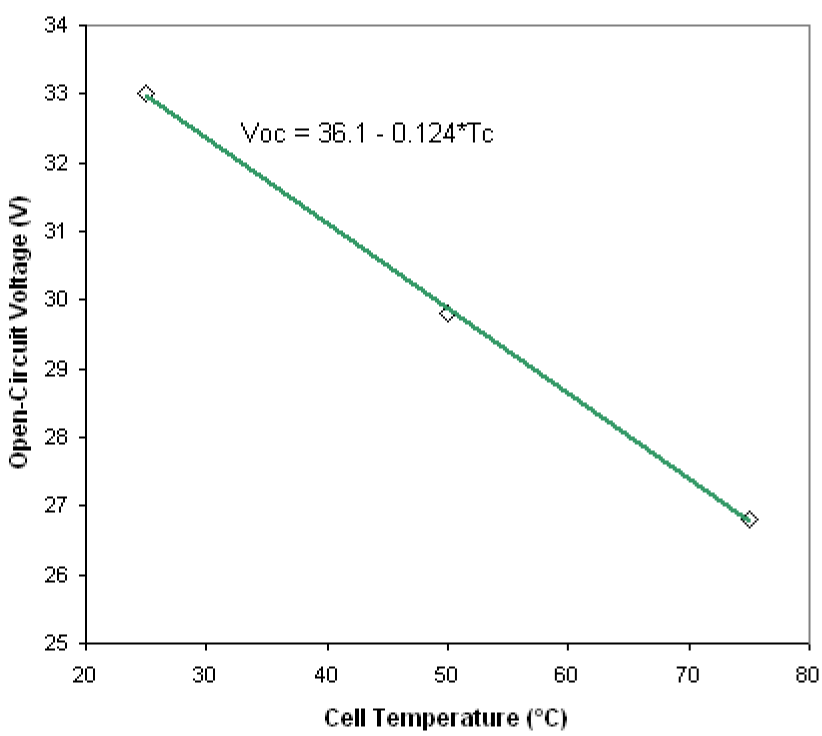
μ_{Voc} is the temperature coefficient of the open-circuit voltage [V/°C]

V_{mp} is the voltage at the maximum power point under **standard test conditions** [V]

If the brochure does not specify the temperature coefficient of the open-circuit voltage but it contains a graph showing the IV curve at different cell temperatures, such as the sample shown below, you can use the graph to calculate the temperature coefficient of the open-circuit voltage.



To do so, plot the open-circuit voltage (the voltage at the bottom of the IV curve) versus cell temperature, and find the slope of that line, as shown below. The slope of that line is the temperature coefficient of the open-circuit voltage. In this example, the slope of the line is -0.124 V/°C.



See also:

5.8 How HOMER Calculates the PV Cell Temperature

5.1 How HOMER Calculates the PV Array Power Output

2.2.2 Photovoltaic Panels (PV)

7.129 PV Tracking System

Type: Input Variable

Units: none

Photovoltaic panels are typically mounted at a fixed orientation. They can, however, be made to "track" the sun in order to maximize the incident solar radiation. Tracking systems are classified according to the number of axes of rotation and the frequency with which the adjustments are made. HOMER can consider the following tracking systems:

- **No Tracking**: Panels are mounted at a fixed slope and azimuth. This is the simplest and most common case.
- **Horizontal Axis, monthly adjustment**: Rotation is about a horizontal east-west axis. The slope is adjusted on the first day of every month so that the sun's rays are perpendicular to the surface at noon of that day.
- **Horizontal Axis, weekly adjustment**: Rotation is about a horizontal east-west axis. The slope is adjusted on the first day of every week so that the sun's rays are perpendicular to the surface at noon of that day.
- **Horizontal Axis, daily adjustment**: Rotation is about a horizontal east-west axis. The slope is adjusted each day so that the sun's rays are perpendicular to the surface at noon.
- **Horizontal Axis, continuous adjustment**: Rotation is about a horizontal east-west axis. The slope is adjusted continually in order to minimize the angle on incidence.
- **Vertical Axis, continuous adjustment**: Rotation is about a vertical axis. The slope is fixed, but the azimuth is continually adjusted to minimize the angle of incidence.
- **Two Axis**: The panels are rotated about both horizontal and vertical axes so that the sun's rays are always perpendicular to the surface. This type of tracking system maximizes the power production of the PV panels, but it is the most expensive.

See also

7.127 PV Slope
7.123 PV Azimuth
2.2.2 Photovoltaic Panels (PV)

7.130 Reformer Efficiency

Type: Input Variable

Units: %

Symbol: η_{ref}

The efficiency with which the reformer converts the fuel to hydrogen. This is equal to the energy content (based on LHV) of the hydrogen out divided by the energy content (based on LHV) of the fuel in. HOMER uses this value to determine how much fuel the reformer uses to produce a certain amount of hydrogen.

7.131 Relative State of Charge

The relative state of charge is the ratio of the current **absolute state of charge** to the maximum capacity of the storage bank. When the batteries are fully charged, the relative state of charge is 100%. Wherever HOMER reports the amount of energy stored in the storage bank, it reports the relative state of charge.

State of charge is often abbreviated as SOC.

See also

7.2 Absolute State of Charge

7.132 Renewable Electrical Production

Type: Intermediate Variable

Units: kWh/yr

Symbol: E_{ren}

The renewable electrical production is the total amount of electrical energy produced annually by the renewable components of the power system. It is the sum of the electrical energy produced by the PV array, the wind turbines, and the hydro system, plus that portion of the electrical energy produced by each generator which originates from biomass.

HOMER uses this variable to calculate the renewable fraction.

See also

7.133 Renewable Fraction
7.135 Renewable Thermal Production
7.166 Total Electrical Production

7.133 Renewable Fraction

Type: Output Variable

Units: none

Symbol: f_{ren}

The renewable fraction is the fraction of the energy delivered to the load that originated from renewable power sources. HOMER calculates the renewable fraction using the following equation:

$$f_{ren} = 1 - \frac{E_{nonren} + H_{nonren}}{E_{served} + H_{served}}$$

where
:

E_{nonren} = **nonrenewable electrical production** [kWh/yr]

$E_{grid,sales}$ = energy sold to the grid [kWh/yr] (included in E_{served})

H_{nonren} = **nonrenewable thermal production** [kWh/yr]

E_{served} = **total electrical load served** [kWh/yr]

H_{served} = **total thermal load served** [kWh/yr]

HOMER abbreviates the renewable fraction as "Ren. Frac." in the sensitivity and optimization results tables.

7.134 Renewable Penetration

Type: Output Variable

Units: none

Symbol: p_{ren}

In every time step, HOMER calculates the renewable penetration using the following equation:

$$p_{ren} = \frac{P_{ren}}{L_{served}}$$

where
:

P_{ren} = total renewable electrical power output in this time step [kW]

L_{served} = total electrical load served in this time step [kW]

On the **Electrical** tab of the Simulation Results window, HOMER reports the maximum value of renewable penetration that occurs during the year.

7.135 Renewable Thermal Production

Type: Intermediate Variable

Units: kWh/yr

Symbol: H_{ren}

The renewable thermal production is the total amount of thermal energy produced annually by renewable-fueled generators. The renewable thermal output of each generator is equal to that portion of its total thermal output originating from biomass (as opposed to fossil fuel, if the generator is co-fired).

HOMER uses this value to calculate the renewable fraction.

See also

7.133 Renewable Fraction
7.132 Renewable Electrical Production
7.167 Total Thermal Production

7.136 Replacement Cost

The replacement cost is the cost of replacing a component at the end of its lifetime, as specified by lifetime parameter in the component model. This may be different from the initial capital cost for several reasons:

- Not all of the component may require replacement at the end of its life. For example, the wind turbine nacelle may need replacement but the tower may not.
- The initial capital cost may be reduced or eliminated by a donor organization, but the replacement cost may not.

- You may want to account for the fixed costs (e.g. travel cost) of a visit to the site. At initial construction, these costs are shared by all components, but at replacement time they may not.
- You may want to account for a reduction over time in the purchase cost of a particular technology.

Important: the replacement cost is not meant to account for **inflation**. All costs in HOMER are *real costs*, defined in terms of constant dollars. For more information, please see that article on the real interest rate.

Replacement cost is abbreviated as Repl. in HOMER's cost input tables.

See also

7.90 Initial Capital Cost
7.91 Real Discount Rate

7.137 Required Operating Capacity

HOMER calculates the required operating capacity each time step by adding the **required operating reserve** to the electric load. When simulating the operation of a power system, HOMER attempts to keep the operating capacity equal to or greater than the required operating capacity. HOMER records any shortfall as a **capacity shortage**.

See also

7.138 Required Operating Reserve
7.98 Maximum Annual Capacity Shortage
7.164 Total Capacity Shortage
7.29 Capacity Shortage Fraction

7.138 Required Operating Reserve

Required operating reserve is the minimum amount of **operating reserve** that the system must be capable of providing. HOMER calculates the required operating reserve for each time step based on the values that you enter on the **Constraints** window. Whenever possible, HOMER ensures that enough dispatchable capacity is available to keep the operating reserve equal to or greater than the required operating reserve. HOMER records any shortfall as a **capacity shortage**.

Because operating reserve guards against increases in the load or decreases in the renewable power output, the required operating reserve is a function of both the load and the renewable power output (specifically, the solar and wind power output, since the hydro power output typically experiences little short-term variability). The amount of required operating reserve therefore typically changes from one time step to the next. In each time step, HOMER calculates the required operating reserve on the AC and DC buses using the following equations:

$$L_{res,AC} = r_{load} \cdot L_{prim,AC} + r_{peakload} \cdot \hat{L}_{prim,AC} + r_{wind} \cdot P_{wind,AC}$$

$$L_{res,DC} = r_{load} \cdot L_{prim,DC} + r_{peakload} \cdot \hat{L}_{prim,DC} + r_{wind} \cdot P_{wind,DC} + r_{solar} \cdot P_{PV}$$

where
:

$L_{res,AC}$	is the required operating reserve on the AC bus
$L_{res,DC}$	is the required operating reserve on the DC bus
r_{load}	is the input 'operating reserve as a percent of load in the current time step'
$L_{prim,AC}$	is the average AC primary load in the current time step
$L_{prim,DC}$	is the average DC primary load in the current time step
$r_{peakload}$	is the input 'operating reserve as a percent of annual peak load'
$\hat{L}_{prim,AC}$	is the highest AC primary load experienced by the system during the year
$\hat{L}_{prim,DC}$	is the highest DC primary load experienced by the system during the year
r_{wind}	is the input 'operating reserve as a percent of wind power output'
$P_{wind,AC}$	is the average AC wind power output in the current time step
$P_{wind,DC}$	is the average DC wind power output in the current time step
r_{solar}	is the input 'operating reserve as a percent of solar power output'
P_{PV}	is the average PV array output in the current time step

See also

7.98 Maximum Annual Capacity Shortage
7.164 Total Capacity Shortage
7.29 Capacity Shortage Fraction

7.139 Residual Flow

Type: Input Variable

Units: L/s

Symbol: $\dot{Q}_{residual}$

The residual flow is the quantity of water that must remain undisturbed in the waterway for ecological reasons, such as to support fish populations. It is the quantity of water that cannot be diverted to flow though the hydro turbine.

HOMER uses the residual flow to calculate the flow rate available to the hydro turbine.

See also

7.88 Hydro Turbine Flow Rate

7.140 Resource

In HOMER, a "resource" is anything coming from outside the system that is used by a **component** to generate electric or thermal energy. Wind, solar radiation, and diesel fuel are examples of resources. Electrolyzed hydrogen is not, because it is produced by the system.

7.141 Return On Investment

Type: Output Variable

Units: %

Symbol: ROI

The *Return on Investment* (ROI) is the yearly cost savings relative to the initial investment. HOMER calculates the return on investment with the following equation:

$$ROI = \frac{\sum_{i=0}^{R_{proj}} C_{i,ref} - C_i}{R_{proj}\left(C_{cap-}C_{cap,ref}\right)}$$

where
:

$C_{i,ref}$ = nominal annual cash flow for base (reference) system

C_i = nominal annual cash flow for current system

R_{proj} = **project lifetime** in years

C_{cap} = capital cost of the current system

$C_{cap,ref}$ = capital cost of the base (reference) system

In words, the ROI is the average yearly difference in nominal cash flows over the project lifetime divided by the difference in capital cost.

> **Note:** The year nominal cash flows are available in the cash flow tab of the detailed results window. You can export the cashflow data by switching to "Table" with the radio buttons in the top left of the cash flow screen, and then use the "Export To:" drop down menu on the right to export the data.

7.142 Salvage Value

Salvage value is the value remaining in a component of the power system at the end of the project lifetime. HOMER assumes *linear depreciation* of components, meaning that the salvage value of a component is directly proportional to its remaining life. It also assumes that the salvage value depends on the replacement cost rather than the initial capital cost. HOMER calculates salvage value using the following equation:

$$S = C_{rep} \cdot \frac{R_{rem}}{R_{comp}}$$

R_{rem}, the remaining life of the component at the end of the project lifetime, is given by:

$$R_{rem} = R_{comp} - \left(R_{proj} - R_{rep}\right)$$

R_{rep}, the replacement cost duration, is given by:

$$R_{rep} = R_{comp} \cdot \mathrm{INT}\left(\frac{R_{proj}}{R_{comp}}\right)$$

other definitions:

C_{rep}	= replacement cost [$]
R_{comp}	= component lifetime [yr]
R_{proj}	= project lifetime [yr]
INT()	= a function that returns the integer amount of a real number. For example, INT(6.843) = 6

HOMER assumes that salvage value accrues at the end of the project lifetime.

Example 1: A wind turbine has a capital cost of $1 million, a replacement cost of $750,000, and a 25-year lifetime. At the end of a 20-year project lifetime, what is its salvage value? Solution: the replacement cost duration, R_{rep}, is zero, the remaining life, R_{rem}, is 5 years, so the salvage value is $750,000 * 5/25 = $150,000. Note that the capital cost does not affect the calculation of salvage value.

Example 2: A diesel generator has a capital cost of $400,000, a replacement cost of $350,000, and a lifetime of 7.85 years. At the end of a 30-year project lifetime, what is its salvage value? Solution: the replacement cost duration, R_{rep}, is 23.55 years, the remaining life, R_{rem}, is 1.40 years, so the salvage value is $350,000 * 1.40/7.85 = $62,420.

See also

7.122 Project Lifetime
7.136 Replacement Cost

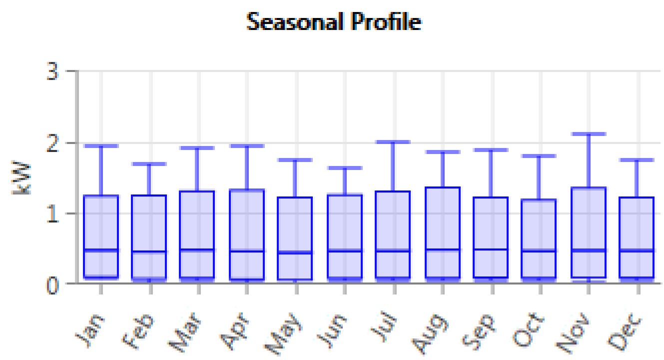
7.143 Search Space

The Search Space is the set of **decision variable** values that HOMER searches to locate the optimal system.

If you are specifying your own search space, you define the search space by specifying the sizes and quantities of the different system components in the **Search Space** for a particular **component** or in the Design Values window.

7.144 Seasonal Profile Plot

The seasonal profile is a box and whisker plot of the monthly minima, maxima, and averages.



For each month, the top line corresponds to that month's overall maximum. The bottom line corresponds to the overall minimum. The top of the blue box is the average of the daily maxima of all of the days in the month, and the bottom of the box is the average daily minimum. The middle line is the overall average for the whole month.

See also:
2.1.2 Load Profile Menu

7.145 Sensitivity Analysis

You can perform a sensitivity analysis by entering multiple values for a particular input variable. HOMER repeats its optimization process for each value of that variable and lets you see how the results are affected. An input variable for which you have specified multiple values is called a **sensitivity variable**, and you can define as many sensitivity variables as you want.

A sensitivity analysis can be referred to as *one-dimensional* if there is a single sensitivity variable. If there are two sensitivity variables, it is a *two-dimensional* sensitivity analysis, and so on. HOMER's most powerful graphical capabilities were developed to help examine the results of sensitivity analyses of two or more dimensions.

For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also
7.148 Sensitivity Variable
7.146 Sensitivity Case
7.147 Sensitivity Link

7.146 Sensitivity Case

A sensitivity case is a specific combination of **sensitivity variable** values. For example, say you have specified four values for the average annual wind speed (3 m/s, 4 m/s, 5 m/s, and 6 m/s) and three values for the fuel price ($0.40/L, $0.50/L, and $0.60/L). Then you have specified twelve different sensitivity cases because there are twelve different combinations of sensitivity values. HOMER performs a separate optimization for each sensitivity case.

If there are no sensitivity variables, then there is only one sensitivity case.

For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

7.145 Sensitivity Analysis
7.148 Sensitivity Variable
7.147 Sensitivity Link

7.147 Sensitivity Link

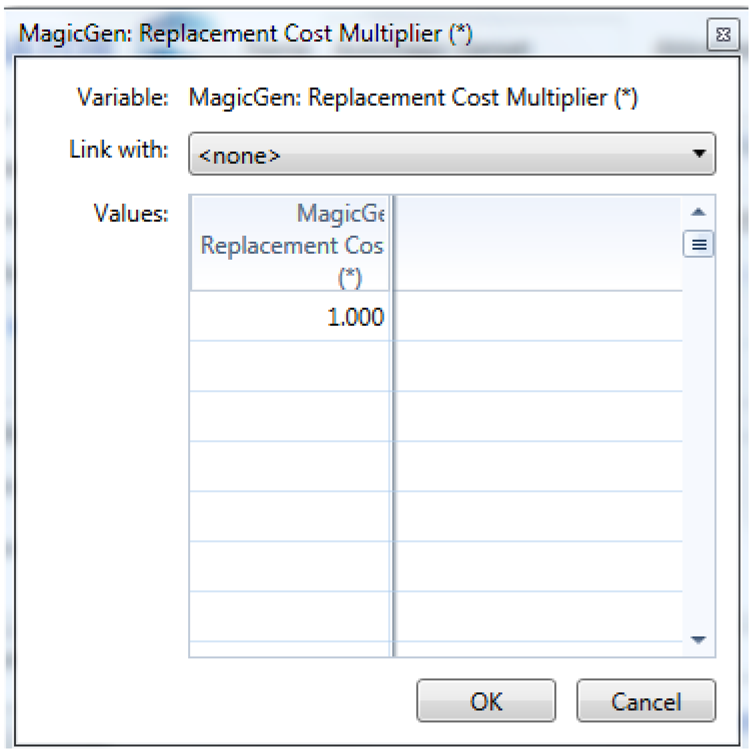
A sensitivity variable is an input variable for which multiple values have been specified. HOMER performs a separate optimization procedure for each possible combination of sensitivity variable values. The total number of **sensitivity cases** is the product of the number of variable values specified for each sensitivity variable. With several sensitivity variables, each with several values, the number of sensitivity cases can be very large, and result in a long computation time.

In some cases you may not be interested in all combinations of sensitivity variable values. Some sensitivity variables tend to vary together, and so it makes sense to vary them together for the sensitivity analysis. In this case, a linked sensitivity may be appropriate. Linked sensitivities can greatly reduce the number of optimizations HOMER runs.

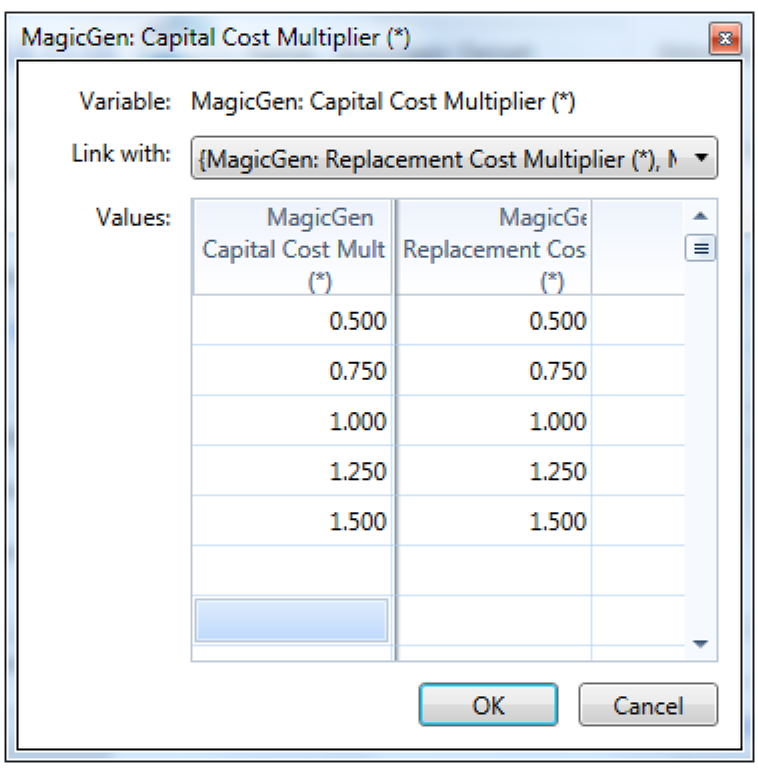
When you link two sensitivity variables, HOMER optimizes the system with each pair of values. You must specify the same quantity of values for all variables in a sensitivity link. **Capital cost** and **replacement cost** are good candidates for a sensitivity link. If the capital cost is higher than expected, it is likely that the replacement cost will be higher too.

You can specify a sensitivity link from the **sensitivity variable** editor.

Click on the {...} sensitivity button to open the sensitivity variable editor. Enter values for the sensitivity variable. Then click ok. Now, if you open the editor for any other sensitivity variable, you can set a link using the drop-down menu labeled "Link with:" shown in the image below.



Once you select the variable with which to link, HOMER will create a "link group" for these sensitivity variables. HOMER will display a warning until the member variables of the link group all have the same number of entries. You can add another variable by opening its sensitivity variable editor and using the drop-down menu to select the desired link group. You can have many link groups, and you can have any number of variables linked together in each group.



In the example above, HOMER will optimize with pairs from each row in the table: (0.5, 0.5), (0.75, 0.75), (1.0, 1.0), and so on. In this example, HOMER will run 5 optimizations for the 5 sensitivity cases. Without the sensitivity link here, HOMER would run 25 optimizations instead of 5: (0.5, 0.5), (0.5, 0.75), (0.5, 1.0), and so on.

For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

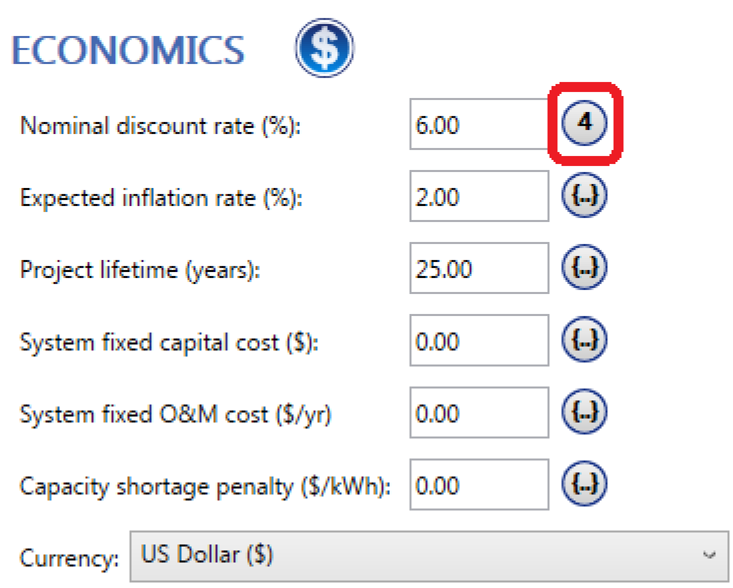
7.145 Sensitivity Analysis
7.148 Sensitivity Variable
7.146 Sensitivity Case

7.148 Sensitivity Variable

A sensitivity variable is an input variable for which multiple values have been specified. HOMER performs a separate optimization procedure for each specified value. For an explanation of why you would do this, please see **Why Would I Do a Sensitivity Analysis?**

It is easy to specify multiple values for an input variable. All variables for which multiple values can be specified have a sensitivity button beside them. The sensitivity button for the **Annual Real Discount Rate** can be seen below next to the input field:

To specify multiple values, click on the sensitivity button and enter any number of values on the **sensitivity values dialog box**:



The values do not have to be evenly spaced, and you can enter them in any order you want. If there are other sensitivity variables, they will be listed in the drop-down box labeled "Link with". By selecting one of these variables, you can perform a linked sensitivity.

When you click OK, the sensitivity button will display the number of values that have been specified for the Annual Real Discount Rate:

For capital, replacement and O&M cost variables, rather than performing a sensitivity analysis directly on these costs, there is a *multiplier variable* which scales these values. If, for example, you entered a PV Capital of $1000/kW, then Capital Cost Multipliers of 3, 4, and 5 would correspond to effective PV Capital Costs of $3000/kW, $4000/kW, and $5000/kW.

For variables specified in the component cost tables, the sensitivity concept is slightly different. Inputs like the initial capital cost are not defined by a single value, but by a column in the component cost table. There may be just one value in that column, but there may be more. For each such variable, there is a *multiplier variable* which is accessed by clicking on the sensitivity button below the appropriate table column. Pictured below is the wind turbine cost table and the sensitivity buttons for the initial capital cost, replacement cost, and O&M cost.

Costs

Size (kW)	Capital ($)	Replace ($)	O&M ($/yr)
1	5500	3000	80
2	10500	5700	120

Multiplier:

Because you can enter several values for these multiplier variables, they allow you to do a sensitivity on any column. The multiplier simply scales the whole column up or down. You can edit the first value in the sensitivity table for a multiplier variable. That's not the case with normal sensitivity values, where the first value in the sensitivity table is the value entered in the corresponding edit box.

HOMER designs an optimal hybrid system for each **sensitivity case**.

For more information, please see **Why Would I Do a Sensitivity Analysis?**

See also

7.145 Sensitivity Analysis
7.146 Sensitivity Case
7.147 Sensitivity Link

7.149 Setpoint State of Charge

The setpoint state of charge is a parameter that can be applied to the **cycle charging strategy**. If a setpoint state of charge is applied, once the system starts to charge the battery bank it will not stop until the battery bank reaches the setpoint state of charge.

The setpoint state of charge tends to reduce the amount of time the battery bank spends at a low state of charge. It also tends to reduce the number of generator starts and the number of battery charge-discharge cycles that occur throughout the year.

The setpoint state of charge appears on the **System Control** window.

See also

7.39 Cycle Charging Strategy

7.150 Simulation Time Step

The default simulation time step in HOMER is 1 hour (60 minutes).

HOMER Pro can simulate system operation with any time step from as long as several hours to as short as one minute. You specify the simulation time step on the **Optimization menu**.

The shorter the time step, the more time steps HOMER must simulate to cover one year, so the longer each simulation takes.

The simulation time step does not have to match the time step of any time series data you may have imported. For example, if you import 10-minute wind data and 60-minute load data, and you simulate on a 10-minute time step, HOMER will divide each 60-minute load value into six identical 10-minute values. If you simulate on a 60-minute time step, HOMER will aggregate six 10-minute wind speed values together into a single 60-minute value for each time step. Or you could choose to simulate using a 30-minute time step, in which case it would aggregate the wind values and disaggregate the load values.

7.151 Sinking Fund Factor

The sinking fund factor is a ratio used to calculate the **future value** of a series of equal annual cash flows. The equation for the sinking fund factor is:

$$\mathrm{SFF}(i,N) = \frac{i}{(1+i)^N - 1}$$

where
:

i = **real discount rate**

N = number of years

Example: for i = 7% and N = 5 years, the sinking fund factor is equal to 0.1739. Therefore, five annual payments of $173.90 earning 7% interest would be worth $1000.00 at the end of the fifth year.

See also
7.31 Capital Recovery Factor

7.152 SO2 Emissions Penalty

Type: Input Variable

Units: $/t

Symbol: c_{SO2}

Use the SO_2 emissions penalty to penalize systems for their production of sulfur dioxide. HOMER uses this input value when calculating the **Other O&M cost**.

7.153 Solar Absorptance

The solar absorptance of a surface is the fraction of the sun's radiation that the surface absorbs.

The solar absorptance is a factor in the calculation of the PV array temperature. But it is a relatively unimportant one, so rather than making you enter it, HOMER uses the assumption suggested by **Duffie**

and Beckman (1991) that the product of the solar absorptance and the solar transmittance is 0.9 or 90%.

See also
7.154 Solar Transmittance
5.8 How HOMER Calculates the PV Cell Temperature

7.154 Solar Transmittance

The solar transmittance of a surface is the fraction of the sun's radiation that are transmitted through the surface.

The solar transmittance is a factor in the calculation of the PV array temperature. But it is a relatively unimportant one, so rather than making you enter it, HOMER uses the assumption suggested by **Duffie and Beckman (1991)** that the product of the solar absorptance and the solar transmittance is 0.9 or 90%.

See also
7.153 Solar Absorptance
5.8 How HOMER Calculates the PV Cell Temperature

7.155 Specific Fuel Consumption

Type: Output Variable

Units: L/kWh, m^3/kWh, or kg/kWh, depending on the units of the fuel

Symbol: F_{spec}

The specific fuel consumption is the average amount of fuel consumed by the generator per kWh of electricity it generates. HOMER calculates the specific fuel consumption using the following equation:

$$F_{spec} = \frac{F_{tot}}{E_{gen}}$$

where
:

F_{tot} = total annual generator fuel consumption [L/yr, m^3/yr, or kg/yr]

E_{gen} = total annual electrical production of the generator [kWh/yr]

7.156 Standard Test Conditions

PV manufacturers rate the power output of their PV modules at standard test conditions (STC), meaning a radiation of 1 kW/m^2, a cell temperature of 25°C, and no wind. Standard test conditions do not reflect typical operating conditions, since full-sun cell temperatures tend to be much higher than 25°C.

See also
5.8 How HOMER Calculates the PV Cell Temperature

7.157 Suggested Lifetime Throughput

HOMER calculates a suggested value of lifetime throughput for a storage based on the information entered in the lifetime curve. The suggested value is equal to the average value of the lifetime throughput values that fall within the allowable range of depth of discharge. (This allowable range is determined by the minimum state of charge -- if the minimum state of charge is 40%, then the storage will only experience depths of discharge between 0% and 60%.) You can accept the suggested value or modify it according to your judgement.

7.158 System

In HOMER documentation, the word *system* refers to the combinations of technologies and components of a power generation system. The terms *system type* and *system configuration* have different meanings that are described below.

System type

A system type is a combination of technologies. For example, wind/diesel/battery describes a system type that includes wind turbines, diesel generators, and batteries.

System configuration

A system configuration is a combination of particular numbers and sizes of components. For example, a system with a generic 10 kW wind turbine, 15 kW diesel generator, 32 batteries and a 6 kW inverter describes a configuration of the wind/diesel/battery system type. The same system type with 48 batteries is a different system configuration.

HOMER simulates system configurations. As it searches for the optimal system type, HOMER typically evaluates hundreds or thousands of system configurations. HOMER displays a list of system configurations in the **overall optimization results** table, and the most cost effective configuration of each system type in the **categorized optimization results** table.

A system configuration can also be defined by dispatch strategy. For example, a system consisting of a generic 10 kW wind turbine, 15 kW diesel, 32 batteries, and an inverter could have two configurations: one with a load following dispatch strategy, and another with a cycle charging dispatch strategy.

7.159 System Fixed Capital Cost

Type: Input Variable

Units: $

Symbol: $C_{cap,fixed}$

The system fixed capital cost is the capital cost that occurs at the start of the project regardless of the size or architecture of the power system.

The system fixed capital cost adds to the total initial capital cost of the system, and therefore to the total net present cost. But since it affects the NPC of all system configurations in the search space by the same amount, it has no effect on the system rankings.

See also

7.160 System Fixed Operations and Maintenance (O&M) Cost
7.170 Total Net Present Cost

7.160 System Fixed Operations and Maintenace (O&M) Cost

Type: Input Variable

Units: $/yr

Symbol: $C_{om,fixed}$

The system fixed operation and maintenance (O&M) cost is the recurring annual cost that occurs regardless of the size or architecture of the power system.

The system fixed O&M cost affects the total net present cost of each system configuration equally, so it has no effect on the system rankings.

See also

7.159 System Fixed Capital Cost
7.170 Total Net Present Cost

7.161 System Roundtrip Efficiency

Type: Intermediate Variable

Units: none

Symbol: η

The system roundtrip efficiency is the overall efficiency of the system in converting AC energy to DC, putting that energy into storage in the battery bank, removing it from the battery bank, and converting it back to AC. HOMER calculates the system roundtrip efficiency using the following equation:

$$\eta = \eta_{inv}\ \eta_{rt}\ \eta_{rect}$$

where
:

η_{inv} = inverter efficiency

η_{rt} = **battery roundtrip efficiency**

η_{rect} = rectifier efficiency

7.162 Thermal Load Served

Type: Output Variable

Units: kWh/yr

Symbol: H_{served}

The thermal load served is the total amount of thermal energy that went towards serving the thermal load during the year.

7.163 Total Annualized Cost

Type: Output Variable

Units: $/year

Symbol: $C_{ann,tot}$

The total annualized cost is the annualized value of the total net present cost. HOMER calculates the total annualized cost using the following equation:

$$C_{ann,tot} = \mathrm{CRF}(i, R_{proj}) \cdot C_{NPC,tot}$$

where
:

$C_{NPC,tot}$ = the **total net present cost** [$]

i = the **annual real discount rate** [%]

R_{proj} = the **project lifetime** [yr]

CRF() = a function returning the **capital recovery factor**

HOMER uses the total annualized cost to calculate the levelized cost of energy.

See also

7.6 Annualized Cost
7.170 Total Net Present Cost
7.92 Levelized Cost of Energy

7.164 Total Capacity Shortage

Type: Output Variable

Units: kWh/yr

Symbol: E_{cs}

The total capacity shortage (or annual capacity shortage) is the total amount of **capacity shortage** that occurs throughout the year. At the end of the year, this value is used to calculate the **capacity shortage fraction**.

Note that if each of the four operating reserve inputs (specified on the **Constraints** window) are set to zero, the total capacity shortage will be equal to the **total unmet load**.

See also

7.138 Required Operating Reserve
7.98 Maximum Annual Capacity Shortage
7.29 Capacity Shortage Fraction
7.171 Total Unmet Load

7.165 Total Electrical Load Served

Type: Output Variable

Units: kWh/yr

Symbol: E_{served}

The total electrical load served is the total amount of energy that went towards serving the primary and deferrable loads during the year, plus the amount of energy sold to the grid. HOMER calculates the total electrical load served using the following equation:

$$E_{served} = E_{served,ACprim} + E_{served,DCprim} + E_{served,def} + E_{grid,sales}$$

where
:

$E_{served,primAC}$ = **AC primary load served** [kWh/yr]

$E_{served,primDC}$ = **DC primary load served** [kWh/yr]

$E_{served,def}$ = **deferrable load served** [kWh/yr]

$E_{grid,sales}$ = energy sold to the grid [kWh/yr]

HOMER uses this value to calculate the renewable fraction and the levelized cost of energy.

See also

7.133 Renewable Fraction
7.92 Levelized Cost of Energy
7.162 Thermal Load Served

7.166 Total Electrical Production

Type: Output Variable

Units: kWh/yr

Symbol: E_{prod}

The total electrical production is the total amount of electrical energy produced by the power system in one year. It is the sum of the electrical energy produced by all components of the system.

See also

7.167 Total Thermal Production
7.132 Renewable Electrical Production

7.167 Total Thermal Production

Type: Output Variable

Units: kWh/yr

Symbol: H_{prod}

The total thermal production is the total amount of thermal energy produced by the power system in one year. It is the sum of the thermal energy produced by all components of the system.

See also
7.166 Total Electrical Production
7.135 Renewable Thermal Production

7.168 Total Excess Electricity

Type: Output Variable

Units: kWh/yr

Symbol: E_{excess}

The total excess electricity is the total amount of **excess electricity** that occurs throughout the year.

See also
7.53 Excess Electricity Fraction

7.169 Total Fuel Cost

Type: Output Variable

Units: $/yr

Symbol: $C_{fuel,tot}$

The total fuel cost is the sum of the fuel costs of each generator and the boiler.

7.170 Total Net Present Cost

Type: Output Variable

Units: $

Symbol: C_{NPC}

The total net present cost (NPC) of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

HOMER calculates the total NPC by summing up the total discounted cash flows in each year of the project lifetime.

The total NPC is HOMER's main economic output, the value by which it ranks all system configurations in the optimization results, and the basis from which it calculates the total annualized cost and the levelized cost of energy.

See also

7.105 Net Present Cost
7.163 Total Annualized Cost
7.92 Levelized Cost of Energy

7.171 Total Unmet Load

Type: Output Variable

Units: kWh/yr

Symbol: E_{unmet}

The total unmet load is the total amount of **unmet load** that occurs throughout the year.

7.172 Unmet Load

Unmet load is electrical load that the power system is unable to serve. It occurs when the electrical demand exceeds the supply. For each **system**, HOMER calculates the **total unmet load** that occurs over the year, as well as the **unmet load fraction**. By default, HOMER considers any system that experiences unmet load infeasible, but you can change that by entering a non-zero value for the **maximum annual capacity shortage**.

7.173 Unmet Load Fraction

Type: Output Variable

Units: none

Symbol: f_{unmet}

The unmet load fraction is the proportion of the total annual electrical load that went unserved because of insufficient generation. The equation for the unmet load fraction is given below:

$$f_{unmet} = \frac{E_{unmet}}{E_{demand}}$$

where
:

E_{unmet} = **total unmet load** [kWh/yr]

E_{demand} = total annual electrical demand (primary plus deferrable) [kWh/yr]

7.174 Weibull Distribution

The two-parameter Weibull distribution is often used to characterize wind regimes because it has been found to provide a good fit with measured wind data. The probability density function is given by the following equation:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \cdot \exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$

where
:

v is the wind speed [m/s]

k is the Weibull shape factor [unitless]

c is the Weibull scale parameter [m/s]

The cumulative distribution function is given by the following equation:

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$

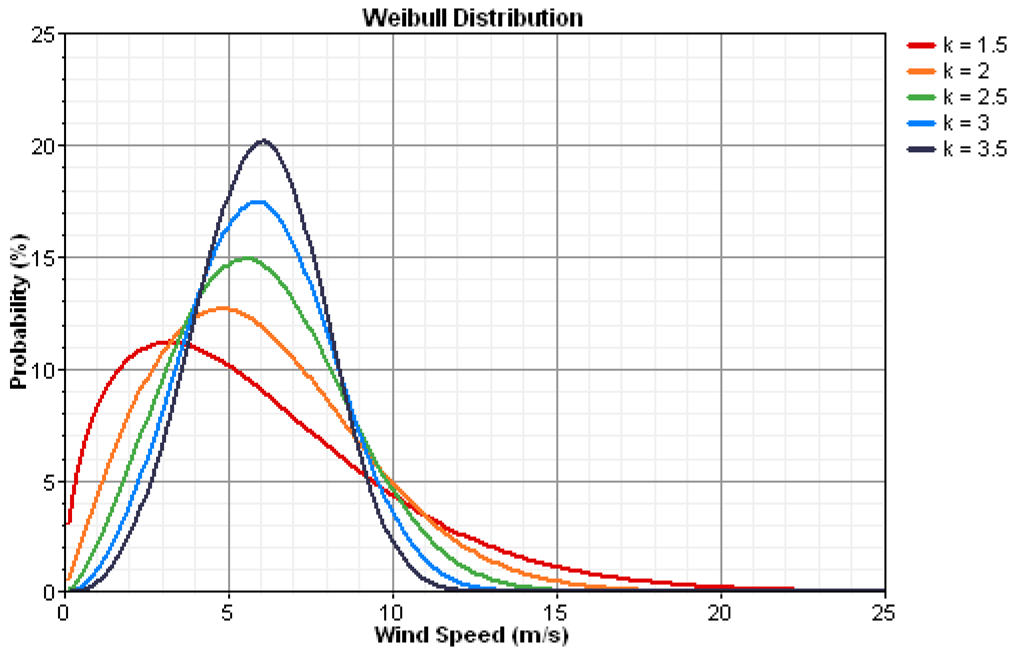
The following equation relates the two Weibull parameters and the average wind speed:

$$\bar{v} = c\Gamma\left(\frac{1}{k} + 1\right)$$

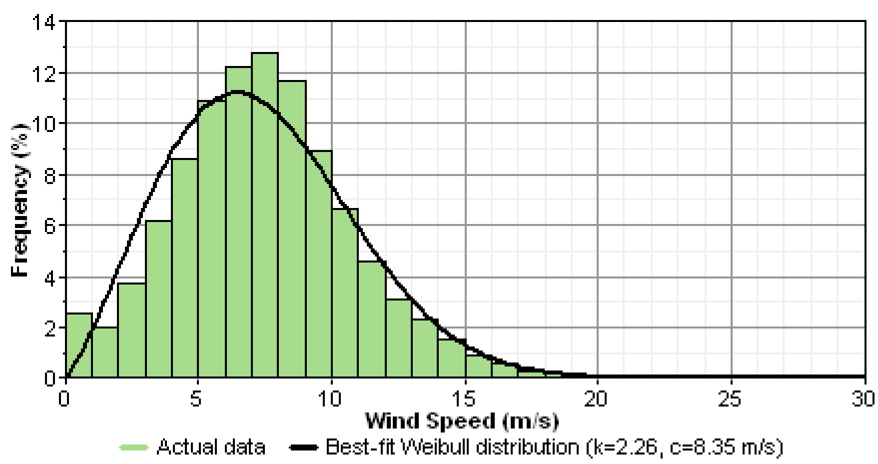
where
:

Γ is the gamma function

One can describe a Weibull distribution by an average wind speed and a Weibull k value. The graph below shows five Weibull distributions, all with the same average wind speed of 6 m/s, but each with a different Weibull k value. As the graph shows, lower k values correspond to broader distributions.



To fit a Weibull distribution to measured wind data, HOMER uses the maximum likelihood method given by **Stevens and Smulders, 1979**. The graph below shows a typical distribution of wind speeds and the best-fit Weibull distribution.



See also

7.175 Weibull k Value

7.175 Weibull k Value

Type: Input Variable

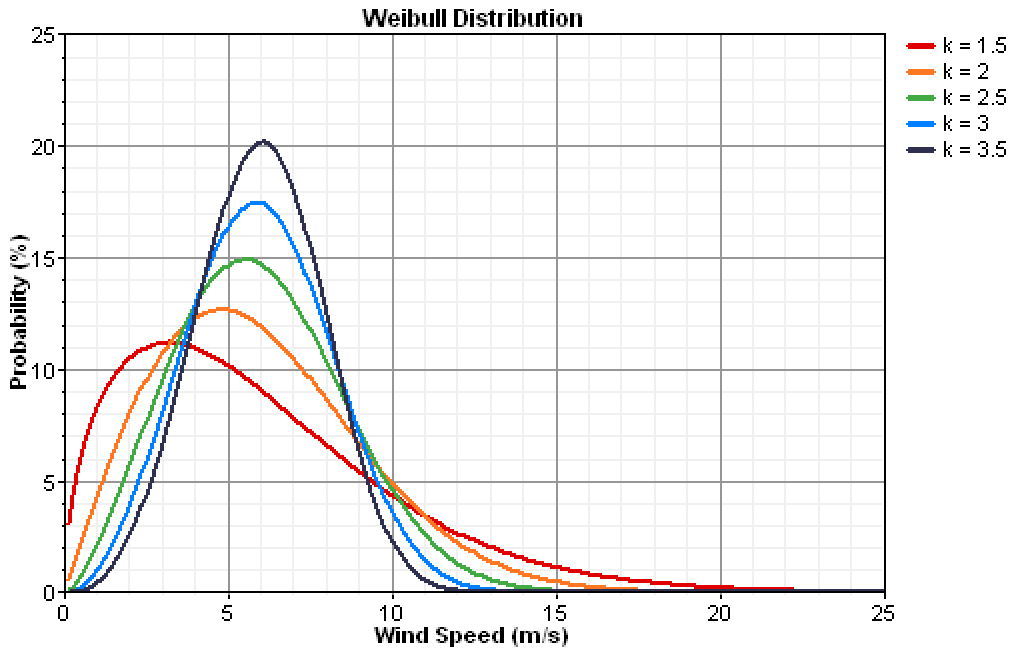
Units: none

Symbol: k

Typical Range: 1.5 - 2.5

The Weibull k value, or Weibull shape factor, is a parameter that reflects the breadth of a distribution of wind speeds. HOMER fits a Weibull distribution to the wind speed data, and the k value refers to the shape of that distribution.

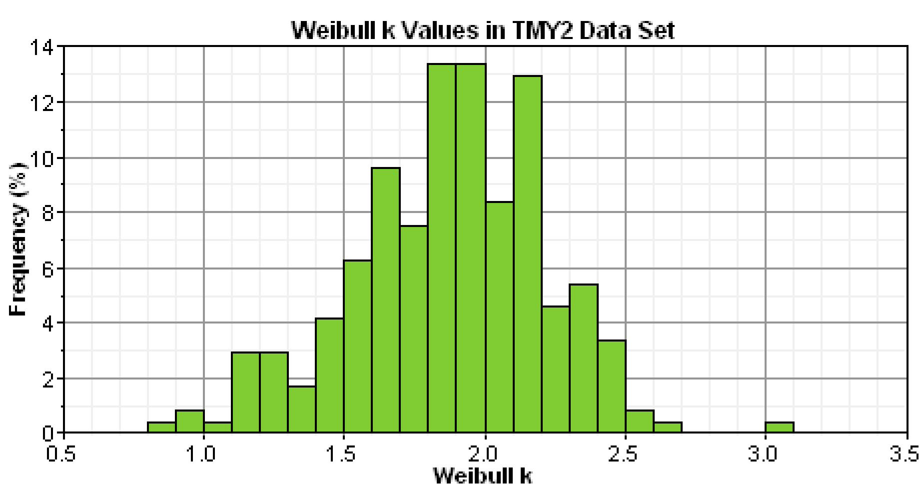
The graph below shows five Weibull distributions, all with the same average wind speed of 6 m/s, but each with a different Weibull k value. As the graph shows, lower k values correspond to broader distributions of wind speed, meaning that winds tend to vary over a large range of speeds. Higher k values correspond to narrower wind speed distributions, meaning that wind speeds tend to stay within a narrow range.



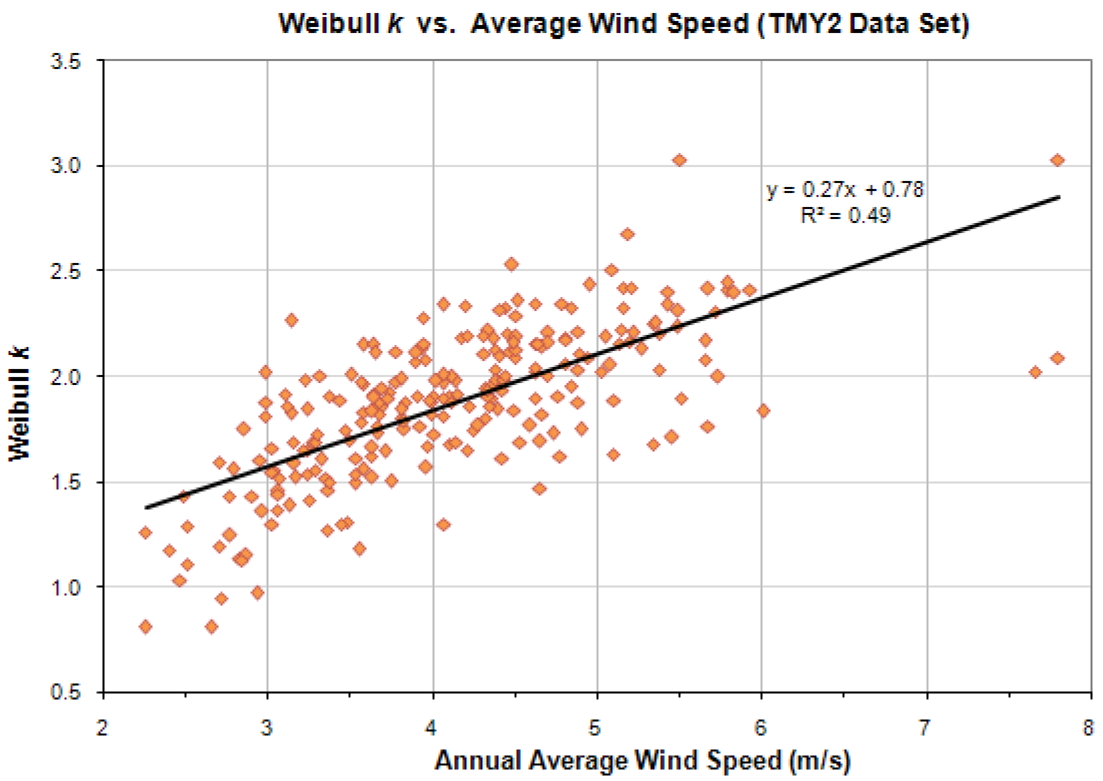
Lower *k* values correspond to broader wind speed distributions. So a very gusty location may have a Weibull *k* value as low as 1.5 or so, whereas a location characterized by very steady winds (like tropical trade wind environments) may have a *k* value as high as 3 or 4. When you synthesize wind speed data, HOMER uses a default Weibull *k* value of 2, which is typical of many wind regimes.

When fitting a Weibull distribution to measured wind data, HOMER uses the maximum likelihood method given by **Stevens and Smulders, 1979**.

To help HOMER users estimate Weibull *k* values in the absence of measured data, we calculated the best-fit Weibull *k* value for each of the 239 weather stations in the TMY2 data set. The histogram below shows the resulting distribution of Weibull *k* values. The measured values themselves appear in the **table of measured wind parameters**.



In the TMY2 data set, we observed a correlation between the Weibull *k* value and the average wind speed, with higher annual average wind speeds tending to correspond to lower Weibull *k* values. The graph below displays this correlation:



See also

7.174 Weibull Distribution
7.112 One-Hour Autocorrelation Factor
7.48 Diurnal Pattern Strength
7.86 Hour of Peak Windspeed
6.4 Wind Data Parameters

7.176 Wind Turbine Hub Height

Type: Input Variable

Units: m

Symbol: z_{hub}

The wind turbine hub height is the height above ground at which the rotor sits. Hub heights typically range between 25m (for smaller wind turbines, 50 kW or less) and 100m (for large, multi-megawatt wind turbines). Wind speeds tend to increase with height above ground, so if the hub turbine is not the same as the anemometer height, HOMER adjusts the wind speed data accordingly.

For details on how HOMER calculates the wind speed at the hub height of the wind turbine, see **Wind Resource Variation with Height**.

See also:

2.3.4.2 Wind Resource Variation with Height
7.5 Anemometer Height

2.4.2 System Control

The System Control menu in the **Project** tab allows you to modify how HOMER simulates your systems.

Dispatch Strategy

A **dispatch strategy** is a set or rules that govern the operation of the generator(s) and the battery bank. HOMER can model two dispatch strategies, cycle charging and load following. Which is optimal depends on many factors, including the sizes of the generators and battery bank, the price of fuel, the O&M cost of the generators, the amount of renewable power in the system, and the character of the renewable resources. If you choose to model both, HOMER will simulate each system using both dispatch strategies and you will be able to see which is optimal.

Under the **load following** strategy, whenever a generator is needed it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power, when the renewable power output sometimes exceeds the load.

Under the **cycle charging** strategy, whenever a generator has to operate, it operates at full capacity with surplus power going to charge the battery bank. Cycle charging tends to be optimal in systems with little or no renewable power.

If you can apply a **setpoint state of charge** to the cycle charging strategy, the generator(s) will not stop charging the battery bank until it reaches the specified state of charge. The sensitivity button to the right allows you to do a **sensitivity analysis** on this setpoint.

> Note that the dispatch strategy is abbreviated "Dispatch" in the sensitivity and optimization results tables. The rows contain "CC" for cycle charging or "LF" for load following.

Select the option "Allow diesel-off operation" if the system can maintain stability without the generator running. This option only has an effect if there is a generator in the system which can sometimes be turned off. Some systems require a generator to maintain bus voltage and frequency. If the system includes a "grid-forming" component other than the generator, you can deselect this option, and HOMER will turn the generator off if the load can be supplied with other sources.

The check box "Multiple generators can operate simultaneously" only affects the operation of systems that include two or more generators on the same bus. If you check this box, HOMER will allow multiple generators on the same bus to operate at once whenever necessary. Otherwise, multiple generators on the same bus must take turns operating.

Note: To the right of each numerical input is a sensitivity button ()which allows you to do a **sensitivity analysis** on that variable. For more information, please see **Why Would I Do a Sensitivity Analysis?**