

# **Running on Renewables (Lesson Plan)**

## *(Utilizing HOMER: Modeling Software for Hybrid Electric Power Systems)*

**Suggested Grade Level**     9-12

### **Overview**

Students utilize software developed by the National Renewable Energy Laboratory (NREL) called HOMER to find out what costs and benefits are associated with converting or combining sustainable technology to their school's power production portfolio. Their mission will be to best utilize a "Clean Energy Grant" to assist the school in the purchase of renewable energy sources such as wind turbines and photovoltaic arrays (solar panels). Two separate courses or tracks of study based on experience are presented. In Track 1 students use a pre-existing data file and in Track 2 students create a data file to make decisions about what renewable energy sources are best utilized and most cost-effective in their region. Suggested time frame for implementing this lesson is three (3) 50-minute class periods.

Please note: the HOMER software works only on PCs. You will need extra time to download and learn how to use the software, prior to implementing this lesson. If you would like to learn more about HOMER and how it works, visit these sites:

<http://www.nrel.gov/homer>

<http://www.mistaya.ca/homer>

### **Standard Statements**

#### **3.2 Inquiry and Design**

3.2.10 B Apply process knowledge and organize scientific and technological phenomena in varied ways.

3.2.10 C Apply the elements of scientific inquiry to solve problems.

3.2.10 D Identify and apply the technological design process to solve problems.

#### **3.4 Physical Science, Chemistry and Physics**

3.4.10 B Analyze energy sources and transfers of heat.

#### **3.7 Technological Devices**

3.7.10 C Apply basic computer operations and concepts.

3.7.10 D Utilize computer software to solve specific problems.

#### **4.2 Renewable and Nonrenewable Resources**

4.2.10 A Explain that renewable and nonrenewable resources supply energy and materials.

4.2.10 B Evaluate factors affecting availability of natural resources.

4.2.10 C Analyze how man-made systems have impacted the management and distribution of natural resources.

#### **4.8 Humans and the Environment**

4.8.10 A Analyze how society's needs relate to the sustainability of natural resources.

4.8.10 B Analyze the relationship between the use of natural resources and sustaining our society.

4.8.10 C Analyze how human activities may cause changes in an ecosystem.

## Content Objectives

*Students will know that*

1. Renewable and nonrenewable resources supply energy and materials.
2. Examples of alternative sources of renewable energy are solar photo voltaic (PV) cells, wind turbines, biomass and fuel cells.
3. The sun is a major source of energy that emits wavelengths of visible light, infrared and ultraviolet radiation. Light is captured by solar photo voltaic (PV) cells and converted into electricity.
4. A wind turbine uses the wind which turns the propeller like blades. The blades turn a shaft that spins a generator to make electricity.
5. Alternative sources of renewable energy can supply supplemental energy or can be utilized as an independent energy source.

## Process Objectives

*Students will be able to*

1. Devise and carry out a procedure in HOMER to make decisions about what renewable energy sources are best utilized, and most cost-effective, in their region using a regionally-specific sample data set.
2. Evaluate and analyze design options for different micropower systems that model an on-grid power source to determine if the renewable resources are an adequate power source.
3. Change the renewable energy parameters within HOMER - including PV, wind turbines, fuel cells, etc.
4. Analyze factors affecting the availability of renewable and nonrenewable resources.
5. Evaluate the advantages of reusing our natural resources and renewable energy sources.
6. Describe how technology has changed the use of natural resources and how newer technologies are allowing us to create renewable energy sources.

## Assessment Strategies

1. Evaluation of completed student handout utilizing HOMER to assess the best renewable energy sources for their school.
2. Group discussion of key ideas about renewable energy sources.
3. Evaluation of the inquiry based worksheet, which evaluates how HOMER was utilized to solve an individually devised sustainable problem, and what results were interpreted from HOMER's analysis data.

## Materials

*Per student:*

### Track 1:

- Computer with HOMER software and PA Energy File
  - Download the free HOMER software (version 2.19) by accessing <http://www.nrel.gov/homer/>
  - Download the free PA Energy File for HOMER from the E21 Web site
- Student Handout (Track 1): A Guide to Using the PA Energy File and HOMER (5 pages)
- Student Worksheet Tracks 1 & 2, one copy per student or show on projector for entire class to view.
- Extension Worksheet Tracks 1 and 2: Running on Renewables (3 pages)
- Calculator

### Track 2:

- Computer with HOMER software
  - Download the free software (version 2.19) by accessing <http://www.nrel.gov/homer/>
- Student Handout Track 2: A Step-by-Step Guide (9 pages)
- Student Worksheet Tracks 1 & 2, one copy per student or show on projector for entire class to view.
- Extension Worksheet Tracks 1 and 2: Running on Renewables (3 pages)
- Calculator

### Multimedia Resources

- Simulations
  - Wind Story
- Videos
  - Wind (6:36)
  - Photovoltaics (pv4) (1:11)
  - Power Systems (1:58)
  - PA Energy's Energy from the Sun (4:15)

### Procedures

#### *Part 1: Review on Renewable Energy Sources*

*(30 min)*

1. Facilitate a small discussion about the importance of renewable energy sources. Provide an overview of the activities that the class is going to embark upon.
2. As a class have the students watch the Wind movie and go through the Wind Story interactive simulation.
3. Have the students also watch a movie clip on solar panels called Photovoltaics (pv4).
4. Follow with a look at the Power Systems movie.
5. If time permits, also watch the movie clip called PA Energy's Energy from the Sun.
6. Review and discuss how wind and solar energy are renewable resources.

#### *Part 2: Introduction to HOMER*

*(1-50 min Class Period)*

##### Track 1

1. Introduce the basis of the HOMER lesson.
2. Have students complete the Running on Renewables Student Worksheet for Tracks 1 & 2.
3. Allow students to work alone or in pairs at the computer to become familiar with HOMER.
4. Allow the students to follow the instructions on using HOMER using the Student Handout Track 1: A Guide to Using the PA Energy File and HOMER. They will input data from the PA Energy File.hmr into the HOMER program.
5. After students have gone through the exercise allow them to discuss their results and thoughts on renewable energy.

## Track 2

1. Introduce the basis of the HOMER lesson.
2. Have students complete the Running on Renewables Student Worksheet for Tracks 1 & 2.
3. Allow students to work alone or in pairs at the computer to become familiar with HOMER.
4. Allow the students to follow the instructions on using HOMER using the Student Handout Track 2: A Step-by-Step Guide to Using HOMER. They will input data from the Student Worksheet for Tracks 1 & 2 into the computer program.
5. After students have gone through the exercise allow them to discuss their results and thoughts on renewable energy.

## Extension

### *Part 3: Inquiry Based Investigation Using HOMER*

*(1-50 min Class Period)*

1. Give students Running on Renewables Extension Worksheet Tracks 1 and 2.
2. Explain that they want to come up with a scheme that allows HOMER to simulate their school running solely on renewable energy.
3. Have the students work at the computer following the instructions on the Extension Worksheet Tracks 1 and 2.
4. Students will first remove the Diesel generator.
5. Students will need to adjust specific parameters and add a battery to the system. (Hint: Students may need to use an excessive amount of batteries (300 or more), about 300 or more wind turbines and at least a 25kW PV array.)
6. Students can alter as many parameters as needed so that HOMER will be able to calculate the data.
7. Discuss with the class if their renewable sources were effective and feasible to run a school.

## Running on Renewables (Teacher Notes)

(Utilizing *HOMER: Modeling Software for Hybrid Electric Power Systems*)

### General Lesson Notes for Part 1: Review on Renewable Energy Sources

- **HOMER.** HOMER is a free computer program developed by the National Renewable Energy Laboratory (NREL) that models on and off-grid power sources. Typically this simulation is used world-wide to simulate real-world energy issues. By utilizing this computer based tool in the classrooms students will experience ways to evaluate and analyze different design options for micropower systems. The students will input parameters specifying single or multiple power sources including PV, wind turbines, etc. It will allow students to explore what renewable technologies are most cost-effective and also determine if the renewable resources used are an adequate power source. Troubleshooting tips for using HOMER can be found at <http://nrel.gov/homer>.
- **“Track” Layout.** There are two tracks that can be used to bring HOMER into the classroom.
  - **Track 1.** Track one was created for teachers and students that may not be as proficient with computers and software. This track utilizes a PA Energy file that can be loaded directly into HOMER so that the students would not have to manually set up the energy system within the program. The Student Handout (Track 1): A Guide to Using the PA Energy File and HOMER explains how to load the PA Energy file and then instructs the student to change the PA specific parameters found in Student Worksheet Tracks 1 & 2. The students then continue with the inquiry based lesson in the Extension Worksheet Track 1 and 2.
  - **Track 2.** Track two includes a Student Handout (Track 2): A Step-by-Step Guide to Using HOMER is an instruction manual that allows the student to manually create a power grid using a generator, array, wind turbine, a primary load and a converter. The students will use Student Worksheet Tracks 1 & 2 to input PA Specific data into HOMER such as wind speed in meters per second, and clearness index data. The Student Worksheet for Tracks 1 & 2 also includes questions on how HOMER was utilized. The second part of this lesson (Extension Part 3: Inquiry Based Investigation Using HOMER) includes an Extension Worksheet for Tracks 1 and 2: Running on Renewables, is an inquiry based lesson, which allows the students to delete a generator that is powering a school, and attempt to manipulate parameters within the program so that the school can run on renewables alone.
- **Renewable Energy.** Fossil fuels including coal, oil and natural gas are relied upon heavily in the United States. These resources are *nonrenewable*, and eventually the available supply of these resources will be depleted. In comparison, *renewable energy* resources such as wind and solar energy are replenishable. Beyond that, they have less of an impact upon the environment.
- **Energy efficiency.** Renewable energy sources are found in many different forms such as biomass, geothermal energy, hydropower, , solar energy, and wind energy. If our country begins to utilize these renewable energy sources less money will be spent on energy as a whole and these technologies also cut down on pollution. For more information on this topic visit <http://www.nrel.gov/learning/>

General Lesson Notes for Part 2: Introduction to HOMER

**STUDENT HANDOUT TRACK 1: A Step-by-Step Guide to Using the PA Energy File and HOMER**

Part 1 Notes

- **Wind Speed.** *(This explanation pertains to Questions 1-3 in Student Worksheet Tracks 1 & 2).* Wind speed is presented in a chart and is reported in meters per second (m/s). Notice that the Pennsylvania cities that were chosen have an average wind speed of approximately 4m/s. When choosing a wind turbine this average will be of importance since most turbines are efficient at wind speeds greater than 10 m/s. Students will pick a PA city nearest to their hometown and calculate the average wind speed using a calculator.

Part 2 Notes

- **Latitude and Longitude.** *(This explanation pertains to Questions 4-5 in Student Worksheet Tracks 1 & 2).* Latitude and Longitude are numbers which describe location on Earth. For example on the chart Latitude for Allentown is 40°, 39' N meaning Allentown's position is at an angle of 40 degrees, 39 minutes and to the North of the equator. Homer does not ask for seconds. Also the (') should not be confused for feet when using this notation. Longitude lines are also called meridians and extend from pole to pole. The prime meridian is at *zero degrees longitude* and the longitude lines going towards the east, are numbered from 1 to 180 degrees; those lines going to the west, are also numbered from 1 to 180 degrees, but going the other way. The location of the students PA city is important when HOMER takes into account the position of a solar panel.

Part 3 Notes

- **Clearness Index.** *(This explanation pertains to Question 6 in the Student Worksheet Tracks 1 & 2).* The Clearness Index is the measure of the radiation that is transmitted through the atmosphere. This important radiation parameter (written as  $K_T$ ) is defined under the daily time scale in Table 3. It is principally a measure of the radiation that is transmitted through the atmosphere. HOMER can determine the amount of electricity produced by a PV cell by calculating the average daily solar radiation that hits the PV cells.

Part 4 Notes

- **Fuel Cost.** *(This explanation pertains to Questions 7-8 in the Student Worksheet Tracks 1 & 2).* The fuel chart is used to assign resource data for the diesel generator. Due to the current rise in fuel costs, students are asked to look up what the current cost of fuel is in their hometown. They can then approximately convert the cost per gallon into cost per liter. Students can use the internet to look up the current cost of gas at <http://www.pennsylvaniagasprices.com/>

Part 5 Notes

- **Energy Flow Diagram.** *(This explanation pertains to Question 9 in the Student Worksheet Tracks 1 & 2).* Electricity flows in two ways: alternating current (AC) or direct current (DC). The current is caused by electrons moving along a conductor. Typical households and commercial building are powered by AC voltage. AC voltage is more efficient because it can travel over long distances and the voltage can also be changed readily. AC voltage can also be converted to DC voltage using an adaptor which is found in many of the appliances found in

your home. DC voltage is supplied by batteries, but it can not travel far before it starts to lose energy. In looking at the energy flow diagram the Generator produces AC voltage into the system. The Wind Turbine and the Solar Panel create DC voltage which is then converted by the converter into AC voltage so that it can be used on the power grid. The system load (Primary Load 1) is the amount of energy that is required to efficiently run the school for one day.

### Part 6 Notes

- **Analyzing the System in HOMER.** *(This explanation pertains to Questions 10-14 in the Student Worksheet Tracks 1 & 2).* After HOMER calculates the inputted data, the students are able to draw conclusions about how successful incorporating renewables will be for their school's energy system.
  - The students will be able to see the percentage of electrical energy production utilized by each energy input. Typically the generator will be the bulk source of energy for the system at approximately 80%; the PV array will typically produce 16% of the energy and the wind turbines only 1% due to the low average of the wind speed in conjunction with the wind turbines lack of efficiency at those speeds.
  - After analyzing the energy system of the school, it is clear that renewable energy sources that were picked are typically a supplemental energy source for a building. These sources do assist in reducing pollution, are efficient and thus they are a "clean energy" alternative. There are also other renewable energy sources such as biomass or fuel cells that would adequately produce power for a building. These renewable energy sources co- generate heat and power and may be more sufficient to balance out the energy demand for buildings in our geographic region.

## **STUDENT HANDOUT TRACK 2: A Step-by-Step Guide to Using Homer**

The students will use the Student Handout Track 2 and the Student Worksheet Tracks 1 & 2 to complete this lesson. Students will begin by filling in the Student Worksheet Tracks 1 & 2 for Parts 1-5 which include questions 1-9 on the worksheet. On Part 6 the students will use their student handout track 2 to complete the student worksheet questions 10-14.

### Part 1 Notes

- **Wind Speed.** *(This explanation pertains to Questions 1-3 in the Student Worksheet Tracks 1 & 2.)* Wind speed is presented in a chart and is reported in meters per second (m/s). Notice that the Pennsylvania cities that were chosen have an average wind speed of approximately 4m/s. When choosing a wind turbine this average will be of importance since most turbines are efficient at wind speeds greater than 10 m/s. Students will pick a PA city nearest to their hometown and calculate the average wind speed using a calculator.

### Part 2 Notes

- **Latitude and Longitude.** *(This explanation pertains to Questions 4-5 in the Student Worksheet Tracks 1 & 2.)* Latitude and Longitude are numbers which describe location on Earth. For example on the chart Latitude for Allentown is 40°, 39' N meaning Allentown's position is at an angle of 40 degrees, 39 minutes and to the North of the equator. Homer does not ask for



seconds. Also the (') should not be confused for feet when using this notation. Longitude lines are also called meridians and extend from pole to pole. The prime meridian is at *zero degrees longitude* and the longitude lines going towards the east, are numbered from 1 to 180 degrees; those lines going to the west, are also numbered from 1 to 180 degrees, but going the other way. The location of the students PA city is important when HOMER takes into account the position of a solar panel.

### Part 3 Notes

- **Clearness Index.** *(This explanation pertains to Question 6 in the Student Worksheet Tracks 1 & 2).* The Clearness Index is the measure of the radiation that is transmitted through the atmosphere. This important radiation parameter (written as  $K_T$ ) is defined under the daily time scale in Table 3. It is principally a measure of the radiation that is transmitted through the atmosphere. HOMER can determine the amount of electricity produced by a PV cell by calculating the average daily solar radiation that hits the PV cells.

### Part 4 Notes

- **Fuel Cost.** *(This explanation pertains to Questions 7-8 in Student Worksheet Tracks 1 & 2).* The fuel chart is used to assign resource data for the diesel generator. Due to the current rise in fuel costs, students are asked to look up what the current cost of fuel is in their hometown. They can then approximately convert the cost per gallon into cost per liter. Students can use the internet to look up the current cost of gas at <http://www.pennsylvaniagasprices.com/>

### Part 5 Notes

- **Energy Flow Diagram.** *(This explanation pertains to Question 9 in the Student Worksheet Tracks 1 & 2).* Electricity flows in two ways: alternating current (AC) or direct current (DC). The current is caused by electrons moving along a conductor. Typical households and commercial building are powered by AC voltage. AC voltage is more efficient because it can travel over long distances and the voltage can also be changed readily. AC voltage can also be converted to DC voltage using an adaptor which is found in many of the appliances found in your home. DC voltage is supplied by batteries, but it can not travel far before it starts to lose energy. In looking at the energy flow diagram the Generator produces AC voltage into the system. The Wind Turbine and the Solar Panel create DC voltage which is then converted by the converter into AC voltage so that it can be used on the power grid. The system load (Primary Load 1) is the amount of energy that is required to efficiently run the school for one day.

### Part 6 Notes

- **Analyzing the System in HOMER.** *(This explanation pertains to Questions 10-14 in the Student Worksheet Tracks 1 & 2).* After HOMER calculates the inputted data, the students are able to draw conclusions about how successful incorporating renewables will be for their school's energy system.
  - The students will be able to see the percentage of electrical energy production utilized by each energy input. Typically the generator will be the bulk source of energy for the system at approximately 80%; the PV array will typically produce 16% of the energy and the wind turbines only 1% due to the low average of the wind speed in conjunction with the wind turbines lack of efficiency at those speeds.



After analyzing the energy system of the school, it is clear that renewable energy sources that were picked are typically a supplemental energy source for a building. These sources do assist in reducing pollution, are efficient and thus they are a “clean energy” alternative. There are also other renewable energy sources such as biomass or fuel cells that would adequately produce power for a building. These renewable energy sources co- generate heat and power and may be more sufficient to balance out the energy demand for buildings in our geographic region.

### General Lesson Notes for Part 3: Inquiry Based Investigation Using HOMER

#### **Extension Worksheet for Tracks 1 and 2**

Running on Renewables Lesson 2 is an inquiry based lesson which allows the student to use what they have learned from Lesson 1 and apply it by changing parameters within HOMER. The students are asked to remove the diesel generator from the system so that the school would run solely on renewable energy sources such as the PV array and the wind turbine. Batteries are needed to store the energy produced by the renewables so this option must be added to the program.

#### Part 1 Notes

- **Adding Components to Homer:** *(This explanation pertains to Questions 1-12 of Extension Worksheet.)* First the students will completely remove the diesel generator. They will then add batteries to the system. Due to the inquiry based format of this lesson, it is important that students are informed that when they are inputting parameters into HOMER for Lesson 2 it would be best to cover all possibilities within the program. So exaggerating the numbers inputted for each component will be useful. For instance when assigning parameters for the number of batteries the students may want to go as high as 100. It will also be okay that the student receive an error during this lesson, this will force them to go back into the program to reassign parameter until the system works. The converter will also need to be ramped up due to the amount of batteries that will need to be added to the system. The converter is responsible for converting the DC voltage stored in the batteries to AC voltage. Students may want to start at 20 kW/h with the converter and increase the wattage by 20 increments until they reach 100. The students will probably need to adjust the quantity of wind turbines in their system, it is recommended that they start at a quantity of 50 and increase in increments of 25 until they reach 200. It is also recommended that the PV array wattage is increased, students may want to increase in increments of 5kW until they reach 50. When the students hit *calculate* they should be able to see a system which works solely on renewables. If any errors occur they will show up at the very bottom of HOMER screen.

#### Part 2 Notes

- **Analyzing Components in the System:** *(This explanation pertains to Questions 13-18 of the Extension Worksheet.)* After HOMER has calculated the results on the right side of the screen HOMER will rank the system by the net present cost (NPC). This is a calculation based on cost per year, capital recovery factor, interest rate and project lifetime. The students are asked to list how their energy is being generated in question 13. If they look at the first system in the results section they can list if they see a PV array, wind turbine, etc. In question 14 they are asked to compare the cost of this system to lesson one’s cost with a diesel generator. The initial capital in the diesel generator system will typically cost less since this is the total installed cost of that component at the beginning of the project, but the Total NPC will be higher due to fuel cost, etc. In lesson two the initial capital will be more due to the higher initial cost of a renewable system

but the Total NPC will be noticeably lower since renewable energy sources run more efficiently. In question 15 and 16 the student will be able to see how many wind turbines and batteries were needed to run their system. The number is listed under the name of the wind turbine and in the Batt. box on the right of the screen. Question 17 asks the size of the PV array in kW, the PV array is listed first on the right of the screen under PV (kW). Question 18 is an open ended question allowing students to analyze both systems, the teacher may want to discuss this question with the class.

Notes on Additional References

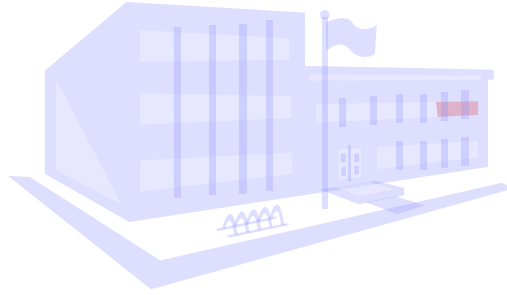
- <http://www.windpower.org/en/kids/index.htm>
- <http://www.nrel.gov>
- <http://www.eia.doe.gov/kids/>
- <http://www.eere.energy.gov/>
- <http://www.wppsef.org/>
- <http://www.consumerenergycenter.org/renewable/>

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Running on Renewables

### Student Worksheet: Tracks 1 & 2



**Mission:** Your school has recently received a “Clean Energy Grant.” The grant will assist your school in the purchase of renewable energy sources such as wind turbines and photovoltaic arrays (solar panels). Your mission is to figure out what renewable energy source/s would best suit your school. You will be using a computer program called HOMER to assist you in simulating the energy needs of your school building. You will then be able to determine what renewable source you would recommend your school to install. To help you complete the mission, you will need to gather some data.

**Directions:** Please fill in the blanks below and save this data for entering into your Student Handout: Track 1 or Track 2 after you have completed questions 1-9.

1. What Pennsylvania City is closest to your hometown in Table 1 (see page 4 of this worksheet): \_\_\_\_\_
2. Please fill in the chart below with your cities Wind Speed(m/s) from Table 1 (see page 4).

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec

3. Using a calculator, find the **Average Wind Speed** (m/s) from your chart: \_\_\_\_\_

Now take a look at Table 2: Latitude and Longitude Coordinates for Pennsylvania Cities (see page 4 of this worksheet) to answer questions 4 and 5.

4. What is the Latitude coordinate for your city? \_\_\_\_\_°, \_\_\_\_\_ North
  5. What is the Longitude coordinate for your city? \_\_\_\_\_°, \_\_\_\_\_ West
- After entering in your city’s location HOMER can determine the amount of electricity produced by a Photovoltaic (PV cell) by calculating the average daily solar radiation that hits the PV cells using the latitude and longitude data.

Now let’s take a look at Table 3: Clearness Index (Kt) for Pennsylvania Cities (see page 4 of this worksheet) to answer question 6. The Clearness Index is a measure of the clearness of the atmosphere.

6. Please fill in the chart below with your city’s **Clearness Index** from Table 3 (see page 4).

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec

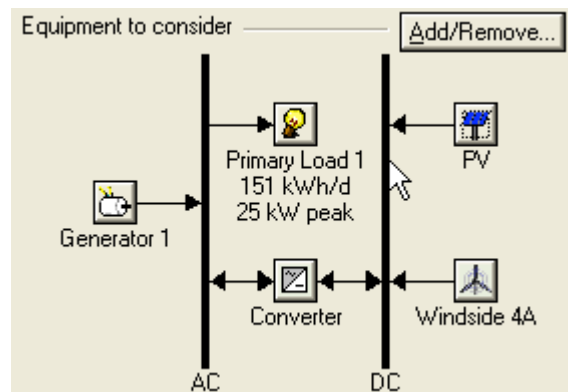
**Directions:** Complete the following questions and save the data for entering into your Student Handout: Track 2.

Let's take a look at the fuel chart converting cost per liter and cost per gallon.

Fuel Cost \$ Liter	Fuel Cost Per Gallon
\$0.30 Liter	\$1.14
\$0.40 Liter	\$1.52
\$0.50 Liter	\$1.90
\$0.60 Liter	\$2.27
\$0.70 Liter	\$2.65
\$0.80 Liter	\$3.03
\$0.90 Liter	\$3.40

7. From the chart above convert cost of fuel per gallon in the city where you live to Fuel Cost \$ Liter. You can check the prices at the local gas station or search on the internet for current gas prices. \$0.\_\_\_\_\_ Liter
8. How might an increase in the cost of Diesel fuel effect the budget of your school? (Please write your answer below.)

9. In looking at the schematic to the right, please write a brief explanation of the way the energy is flowing in the system in the space below. (Note: Arrows show the energy flow direction.)





**Table 1. Wind Speed in Meter Per Second (m/s) for Pennsylvania Cities**

Table 1. Wind Speed (m/s) Data for Pennsylvania								
Month	Allentown	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Wilkes-Barre	Williamsport
Jan	4.56	4.43	6.12	3.75	4.60	4.74	3.93	4.02
Feb	4.56	4.11	5.50	3.75	4.78	4.51	3.89	3.89
Mar	4.92	4.25	5.63	4.11	5.01	4.69	4.20	4.11
April	4.83	4.11	5.32	4.07	4.83	4.51	4.20	4.20
May	4.07	3.53	4.78	3.31	4.29	3.89	3.75	3.53
June	3.67	3.08	4.51	3.04	3.89	3.49	3.53	3.17
July	3.22	2.64	4.25	2.82	3.58	3.17	3.22	2.82
Aug	3.17	2.59	4.25	2.64	3.58	2.99	3.13	2.73
Sept	3.31	2.86	4.56	2.68	3.75	3.17	3.26	2.77
Oct	3.62	3.40	5.23	2.99	3.89	3.62	3.49	3.04
Nov	4.29	4.11	6.08	3.53	4.34	4.25	3.84	3.67
Dec	4.38	4.29	6.21	3.58	4.47	4.56	3.93	3.89

Source: [http://rredc.nrel.gov/solar/old\\_data/nsrdb/bluebook/state.html](http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/state.html)

**Table 2: Latitude and Longitude Coordinates for Pennsylvania Cities**

Pennsylvania City	Latitude	Longitude
ALLENTOWN	40°, 39 N	75°, 26 W
BRADFORD	41°, 48 N	78°, 38 W
ERIE	42°, 5 N	80°, 11 W
HARRISBURG	40°, 13 N	76°, 51 W
PHILADELPHIA	39°, 53 N	75°, 15 W
PITTSBURGH	40°, 30 N	80°, 13 W
WILKES-BARRE	41°, 20 N	75°, 44 W
WILLIAMSPORT	41°, 16 N	77°, 3 W

Source: <http://www.i4at.org/lib2/solarrad.htm>

**Table 3: Clearness Index (Kt) by Month of Pennsylvania Cities**

Month	Allentown	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Wilkes-Barre	Williamsport
Jan	0.45	0.44	0.4	0.46	0.45	0.41	0.43	0.43
Feb	0.47	0.48	0.44	0.48	0.48	0.44	0.46	0.46
Mar	0.48	0.48	0.45	0.48	0.49	0.45	0.47	0.47
April	0.49	0.48	0.48	0.49	0.49	0.47	0.48	0.48
May	0.49	0.49	0.51	0.5	0.5	0.49	0.49	0.49
June	0.51	0.51	0.54	0.52	0.52	0.52	0.51	0.51
July	0.52	0.51	0.55	0.52	0.53	0.52	0.52	0.52
Aug	0.51	0.5	0.52	0.51	0.53	0.51	0.51	0.5
Sept	0.49	0.47	0.49	0.5	0.51	0.5	0.48	0.48
Oct	0.48	0.45	0.44	0.49	0.49	0.47	0.46	0.45
Nov	0.42	0.38	0.36	0.43	0.45	0.39	0.39	0.39
Dec	0.41	0.39	0.36	0.42	0.43	0.37	0.38	0.39

Source: [http://rredc.nrel.gov/solar/old\\_data/nsrdb/bluebook/state.html](http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/state.html)

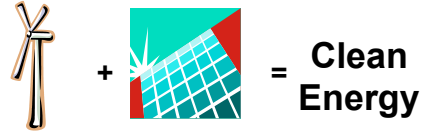


Name: \_\_\_\_\_

Date: \_\_\_\_\_

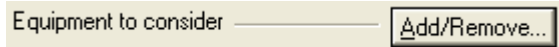
## Running on Renewables

### Extension Worksheet Tracks 1 and 2

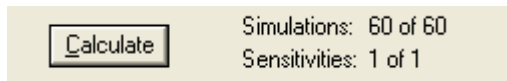


The components you had HOMER analyze included a diesel generator. What if the school wanted to run on only a PV array and wind turbines?

1. Remove the diesel generator from the list of equipment to consider by clicking on the Add/Remove button and deselecting the generator.



2. Click on the Calculate button. What does this do to the simulation?

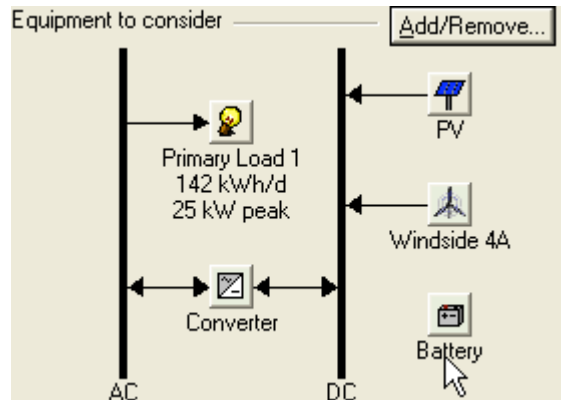


3. Your system can no longer supply the electrical needs for the school because the generator was removed. You must now store the energy that you create from your PV array and your wind turbines so that you can meet the energy needs. Let's first try and add a battery to your list of equipment.

4. Click on the Add/Remove button and check the battery box, click OK.



5. Next click on the battery icon as shown below.



6. Select the Trojan L16P battery from the drop down list, the battery cost is \$240.00 per 6 volts for both the initial capital investment and the replacement cost. You will need at least 5 batteries to run our 10kw PV. (Note: The higher the voltage the more efficient the system is.)
7. See if you can add enough batteries to meet your school's electrical demand. You may need to add many batteries at one time, for example you may want multiples of 10 or 20 instead of 1 or 5. Click OK.

8. Click Calculate. What happens? Did your system work or are you still receiving an error?
  
9. You may need to add more converter capacity because batteries produce DC. Let's try ramping up your converter; click on your converter icon and change the size of your converter to at least 40kw/h. Also increase the sizes to consider in the right column. (Hint: Think big!)
  
10. Click Calculate. What happens? Did your system work or are you still receiving an error?
  
11. If you received an error again you must adjust your system by changing the parameters of the Wind Turbine and PV array. Exaggerate your parameters this time until you find an all-renewable system that works.
  
12. Click Calculate. What happens? Did your system work or are you still receiving an error? Keep adjusting as needed until your systems works.
  
13. How is the electricity being generated now?
  
14. What has this done to the cost of the system?
  
15. How many Wind Turbines did it take to make your system work? \_\_\_\_\_
  
16. How many batteries did your final system need? \_\_\_\_\_
  
17. What size of PV array did you use? \_\_\_\_\_ kW




# Running on Renewables

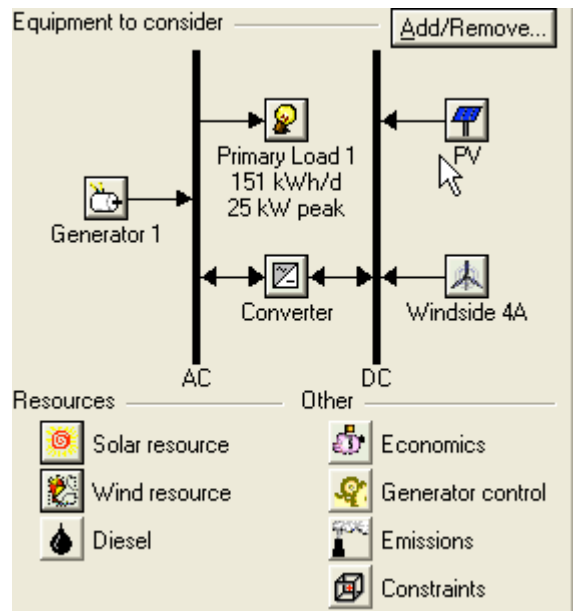
## Student Handout (Track 1): A Guide to Using the PA Energy File and HOMER

### Getting Started:






1. Open the HOMER program on your computer.
2. Select the File Icon  to open the PA Energy file. HOMER will open a popup box, go to your desktop and open the PA Energy File.hmr, click Open. HOMER will open the file and create a schematic window as shown below:

From the **Main Window** you will notice the HOMER displays buttons with your components and your load requirements. Also notice in the Resource section displays buttons for your solar, wind and diesel resource. You will also notice that the arrow now connects to the AC load and shows the direction of energy flow.

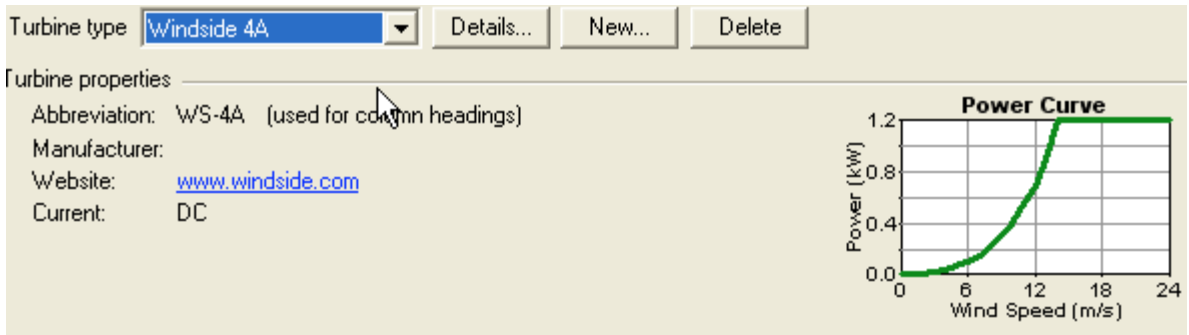


### ■ Looking at your System’s Load

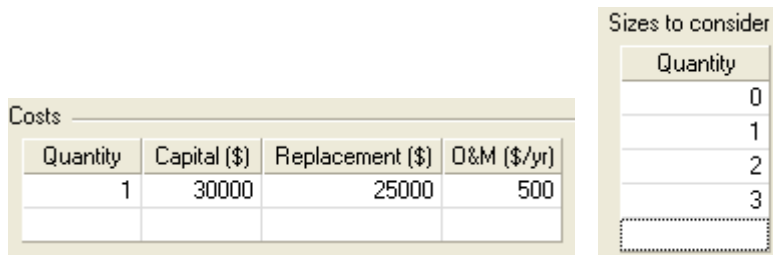
A key piece of information for the model is your school’s electricity load—the electricity demand of the system at any one time.


1. Click on the Primary Load 1 Icon 
2. You will see that your school uses the most energy from 7:00 a.m. to 4:00 p.m.  
(Note: Military time is used; i.e., 1:00 p.m. is 13:00)
3. Click “OK”, this will close the primary Load Window.
4. Click on the Generator 1 icon  to open up the “Generator Inputs” window.
5. You will see that the generator in your school produces 25KW’s and cost \$10,000.
6. Click “OK” to return to the Main Window.
7. Click on the Wind Turbine icon  to open the “Wind Turbine Inputs” window.
8. From the drop down list click through the wind turbines and look at the power curve that is shown on the right side of the screen. Try to find a Wind Turbine that would best maximize your Average Wind Speed (m/s) from your PA city found on your Student Worksheet Track 1 and 2, Question 3 and choose that Turbine.

- a. From the example below we can see that the Windside 4A turbine produces 1.2 kW of energy when the Wind speed is at 14m/s. Would this Turbine be a good choice for PA? Probably not since it maximizes its performance at 14m/s.



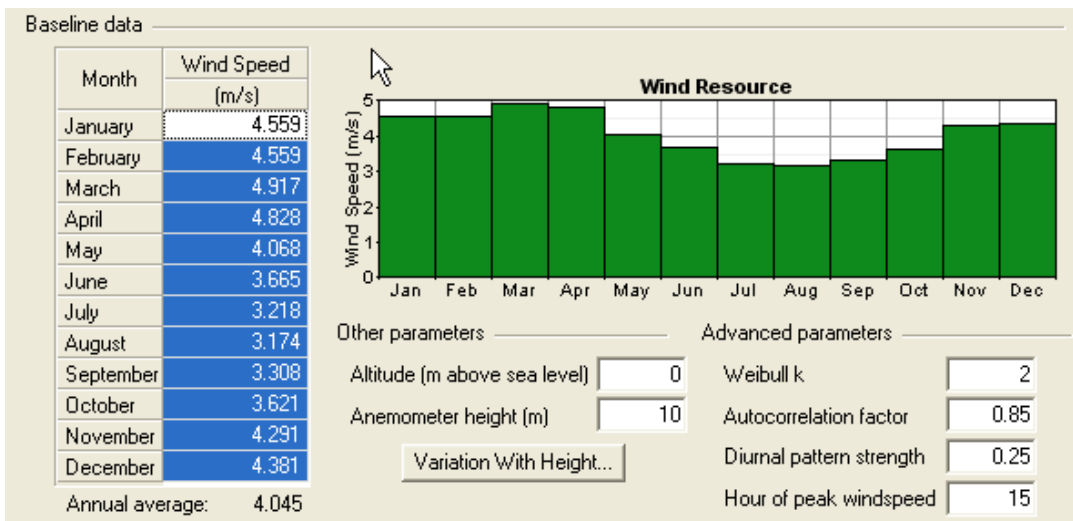
9. After choosing your Wind Turbine input the following values in for the Costs:




10. Click “OK” to return to the Main Window.  
 11. Click on the Wind Resource  to open the Wind Resource inputs window.  
 12. For Data Source choose to enter monthly averages

Data source:  Enter monthly averages  Import hourly data file


13. Next, type in your monthly data from your Student Worksheet Tracks 1 and 2 Question 2 for Wind Speed (m/s). Please refer to your chart for your cities Wind Speed (m/s). You will also notice that HOMER creates a Wind Resource graph on the right.



14. Click “OK” to return to the Main window.
15. Click on the Photovoltaic icon  to open up the “Photovoltaic Inputs” window.
16. You will see that your school will be using a 10 KW PV array and the cost for this solar cell is \$35,000.
17. Under the Properties for “Slope (degrees)” type in 45, this will simulate the pitch of the roof of your school.

Properties

Lifetime (years)	<input type="text" value="20"/>	<input type="button" value="()"/>
Derating factor (%)	<input type="text" value="90"/>	<input type="button" value="()"/>
Tracking system	No Tracking	
Slope (degrees)	<input type="text" value="45"/>	<input type="button" value="()"/>
Azimuth (degrees W of S)	<input type="text" value="0"/>	<input type="button" value="()"/>
Ground reflectance (%)	<input type="text" value="20"/>	<input type="button" value="()"/>

18. Click “OK” to return to the Main Window.
19. Click on the Solar Resource icon  to open the Solar Resource inputs window.
20. Type in your latitude and longitude data from your Student Worksheet Track 1 and 2 Questions 4-5 into HOMER, and choose the Eastern Time Zone, US & Canada from the drop box:

For example: Allentown has a latitude of 40°, 39 North, and a longitude of 75°, 26 West as shown below.

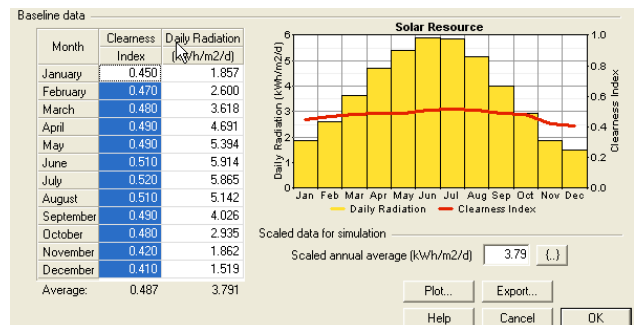
Location

Latitude	<input type="text" value="40"/>	°	<input type="text" value="39"/>	'	<input checked="" type="radio"/> North	<input type="radio"/> South	Time zone	<input type="text" value="(GMT-05:00) Eastern Time (US &amp; Canada), Colombia"/>
Longitude	<input type="text" value="75"/>	°	<input type="text" value="26"/>	'	<input type="radio"/> East	<input checked="" type="radio"/> West		


21. For Data Source select “Enter monthly averages.”

Data source:  Enter monthly averages  Import hourly data file



22. Next type in the your data from your Student Worksheet Tracks 1 and 2 Question 6 for Clearness Index (Kt). The Daily Radiation will be automatically calculated by HOMER and you will also notice that HOMER creates a Solar Resource graph on the right.



23. Click “OK” to return to the Main window.

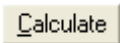
24. Click on the Converter icon  to open up the “Converter Inputs” window.

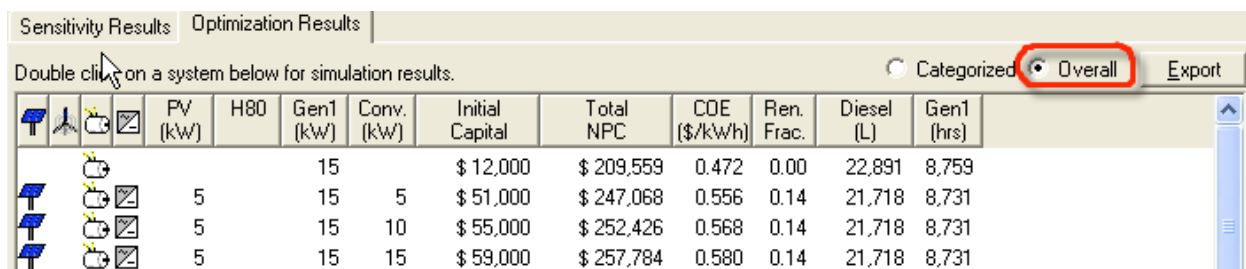


25. A converter is used to convert DC current to AC current which can be utilized by your school.
26. Your converter is 5 KW's in size and will cost \$4000.
27. Click "OK" to return to the Main window.
28. Click on the Diesel icon. 
29. Look at the chart below from your Student Worksheet Tracks 1 and 2 Question 7 and change the fuel price to \_\_\_\_\_ per liter based on the current cost of Diesel per gallon in your town. 
30. Click "OK" to return to the Main window.





## ■ Analyze the System and Examine the Results


You have just completed setting up HOMER, the software is now ready to calculate and analyze your data to see what is "the best" energy system for your school from least to most expensive. Whether it recommends that your school would benefit from a single solar panel or the installation of a wind turbine....let's sit back and see.

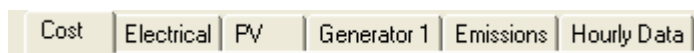
1. Click Calculate  to start the calculation.
2. After the simulation runs click on the "Overall button" to view all possible combinations for each component in the "Optimization Results" window.



The screenshot shows the "Optimization Results" window in HOMER. The "Overall" radio button is selected and circled in red. Below the window, a table lists various system configurations with their respective costs and performance metrics.

	PV (kW)	H80	Gen1 (kW)	Conv. (kW)	Initial Capital	Total NPC	COE (\$/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
			15		\$ 12,000	\$ 209,559	0.472	0.00	22,891	8,759
	5		15	5	\$ 51,000	\$ 247,068	0.556	0.14	21,718	8,731
	5		15	10	\$ 55,000	\$ 252,426	0.568	0.14	21,718	8,731
	5		15	15	\$ 59,000	\$ 257,784	0.580	0.14	21,718	8,731

3. Next click on the "Categorized" button in the "Optimization Results" window. This will show you the least expensive option for each different component configuration (e.g., diesel with PV cells, or PV cells with wind turbines).
4. Next choose a system of interest by double-clicking on one of the configurations to open up the "Simulation Results" window, where you can see the complete results of HOMER's analysis. 
5. You can explore the results for each of the configurations in the "Categorized" view to determine Cost, Electrical energy production, the efficiency of the generator, and the pollutants created under emissions by clicking on the different tabs.



- Double click on a simulation that has all 4 components of the system, a PV cell, a wind turbine a battery and a converter.

				10	1	25	5	\$ 79,000	\$ 486,463	0.736	0.17	35,669	8,678
---	---	---	---	----	---	----	---	-----------	------------	-------	------	--------	-------

- Next Click on the Electrical Tab.....you should see a window like the one shown below:


Annual electrical energy production		Annual electric loads served	
PV array:	14,223 kWh (16%)	AC primary load served:	51,684 kWh
Wind turbine:	749 kWh (1%)		
Generator 1:	73,251 kWh (83%)		
<b>Total production:</b>	<b>88,223 kWh</b>	<b>Total load served:</b>	<b>51,684 kWh</b>
Renewable fraction:	0.170	Excess electricity:	35,603 kWh (40%)
		Unmet electric load:	0.000496 kWh (0%)
		Capacity shortage:	4.11 kWh (0%)

- Notice that this system is relying mostly on the generator for electricity at 83%, next the PV array is 16% and the wind turbine at 1%.
- Complete the rest of your Student Worksheet Track 1 and 2 from the information calculated by HOMER.

# Running on Renewables

## Student Handout (Track 2): A Step-by-Step Guide to Using HOMER

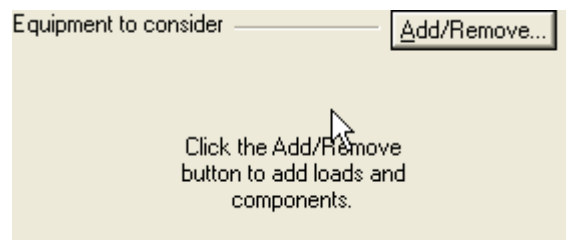
### Getting Started:

1. Open the HOMER program on your computer.
2. Select the New File Icon  to create a new file. HOMER will create a blank schematic window as on the left of your screen.

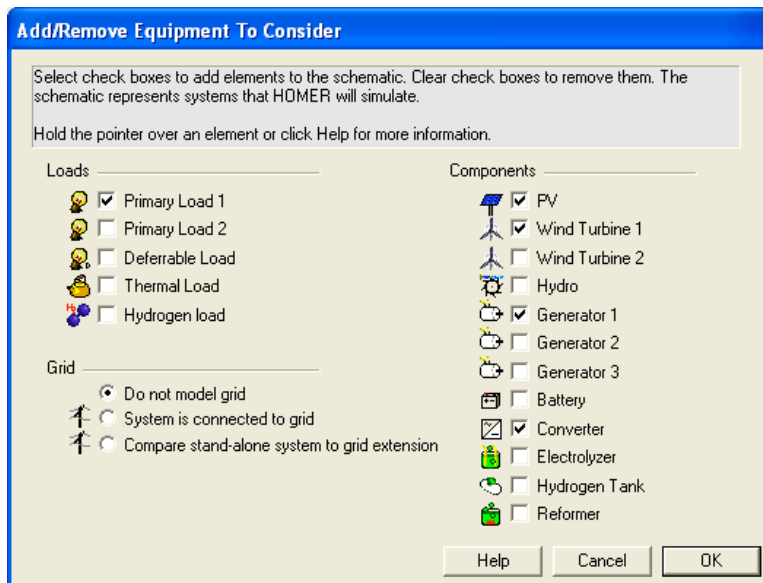


### ■ PART 1: Building your Schematic

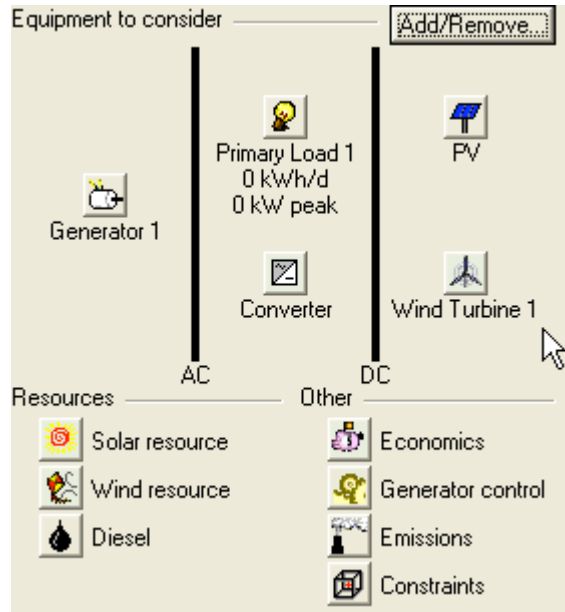
1. Click on the Add/Remove Button to build your schematic. Note: Your schematic will allow you to select your components to best answer your question: “How does the addition of a Photovoltaic (PV panels) and a wind turbine assist our schools energy usage?” Keep in mind that HOMER will consider all options and pick the best optimal design.



2. Check the box next to **Primary Load 1** under the heading “Loads”.  
Note: Every system must be assigned to one of the following, a Primary Load (a description of the energy demand), a Deferrable Load, or be connected to the grid.
3. Check the boxes for **PV (Solar Cell)**, **Wind Turbine 1**, **Generator 1** and **Converter**.
4. Click “OK” when finished to return to the Main window.




From the **Main Window** you will notice that HOMER displays buttons with your components and your load requirements. Also notice in the Resource section display buttons for your solar, wind and diesel resource appear.



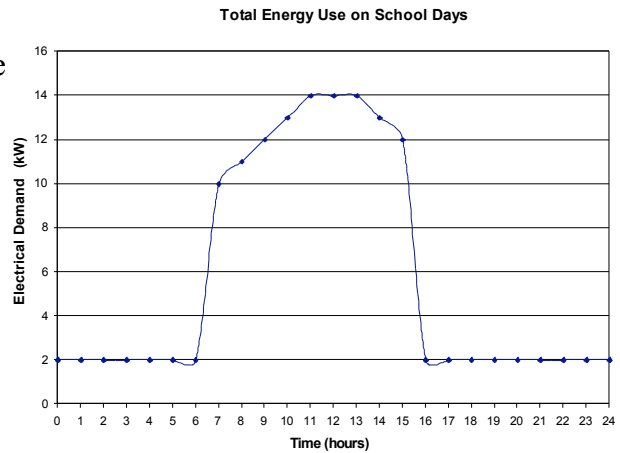
## ■ PART 2: Assigning your System’s Load

A key piece of information for the model is your school’s electricity load—the electricity demand of the system at any one time.

1. Next you will assign Load inputs for your system. Click on the Primary Load 1 Icon. 

2. Select **AC** as your load type. Label **Primary Load 1** Load type:  AC  DC

3. Next you will enter information explaining the average kW of energy used for each hour of the day in your school. Keep in mind that the normal hours for a school are approximately 7:00 a.m. to 4:00 p.m. as shown on the chart to the right, your school uses the most energy during these times. (Note: Military time is used; i.e. 1:00 p.m. = 13:00) Type in the following data into the baseline data chart.




Hour	Load (kW)	Hour	Load (kW)
00:00 - 01:00	2.000	12:00 - 13:00	14.000
01:00 - 02:00	2.000	13:00 - 14:00	14.000
02:00 - 03:00	2.000	14:00 - 15:00	13.000
03:00 - 04:00	2.000	15:00 - 16:00	12.000
04:00 - 05:00	2.000	16:00 - 17:00	11.000
05:00 - 06:00	2.000	17:00 - 18:00	2.000
06:00 - 07:00	2.000	18:00 - 19:00	2.000
07:00 - 08:00	10.000	19:00 - 20:00	2.000
08:00 - 09:00	11.000	20:00 - 21:00	2.000
09:00 - 10:00	12.000	21:00 - 22:00	2.000
10:00 - 11:00	13.000	22:00 - 23:00	2.000
11:00 - 12:00	14.000	23:00 - 00:00	2.000

4. After entering the data click “OK”, this will close the primary Load Window.

## ■ PART 3: Details for Components

### Generator 1

1. Click on the Generator 1 icon  to open up the “Generator Inputs” window. Input the following information into your table:

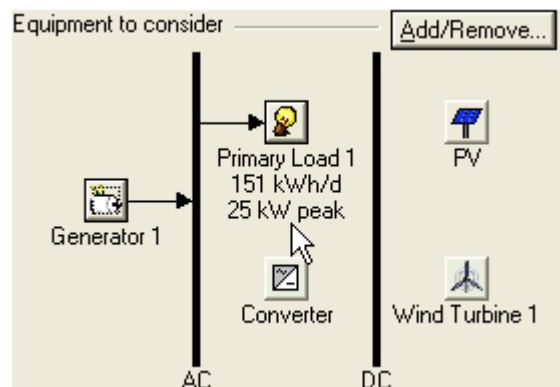
Costs			
Size (kW)	Capital (\$)	Replacement (\$)	O&M (\$/hr)
25.000	10000	9000	0.050


Sizes to consider
Size (kW)
0.000
25.000
30.000
35.000
40.000

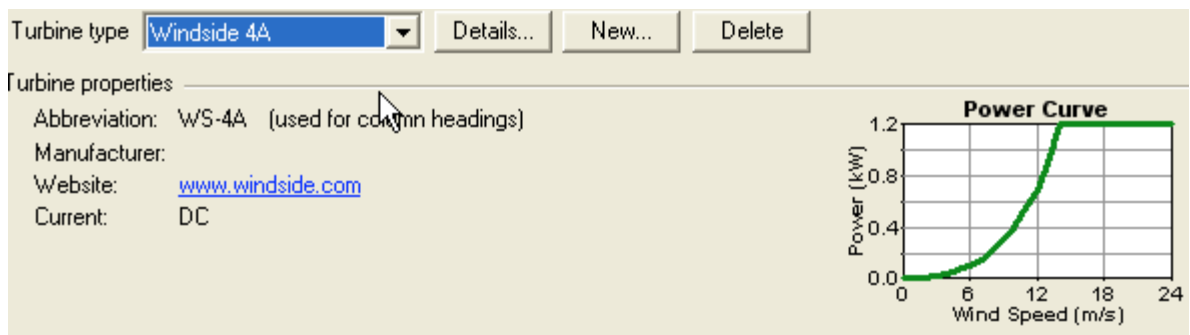
- These numbers tell HOMER that for the generator’s size it will produce 25 kW of energy. The generator costs \$10,000 and to replace it would cost \$9,000. It also costs 5 cents an hour to operate and maintain your generator.
  - In the “Size to consider” table HOMER will consider generators that produce 0, 25,30,35 and 40 kW of electricity, thus a 50.000 kW generator will cost twice as much as your 25.000 kW generator.
2. Click “OK” to return to the Main Window.

You will now notice that the arrow connects the generator 1 to the AC load and shows the direction of energy flow to the Primary Load 1. Also your system produces 151 kilowatt hours per day, and 25 kilowatts at it peak.



## Wind Turbine

1. Click on the Wind Turbine icon  to open the “Wind Turbine Inputs” window.
2. From the drop down list click through the wind turbines and look at the power curve that is shown on the right side of the screen. Try to find a Wind Turbine that would best maximize your Average Wind Speed (m/s) from your PA city found on your Student Worksheet Track 2, Question 3 and choose that Turbine.
  - b. From the example below we can see that the Windside 4A turbine produces 1.2 kW of energy when the Wind speed is at 14m/s. Would this Turbine be a good choice for PA? Probably not since it maximizes its performance at 14m/s.



9. After choosing your Wind Turbine input the following values in for the Costs:


Quantity	Capital (\$)	Replacement (\$)	O&M (\$/yr)
1	30000	25000	500

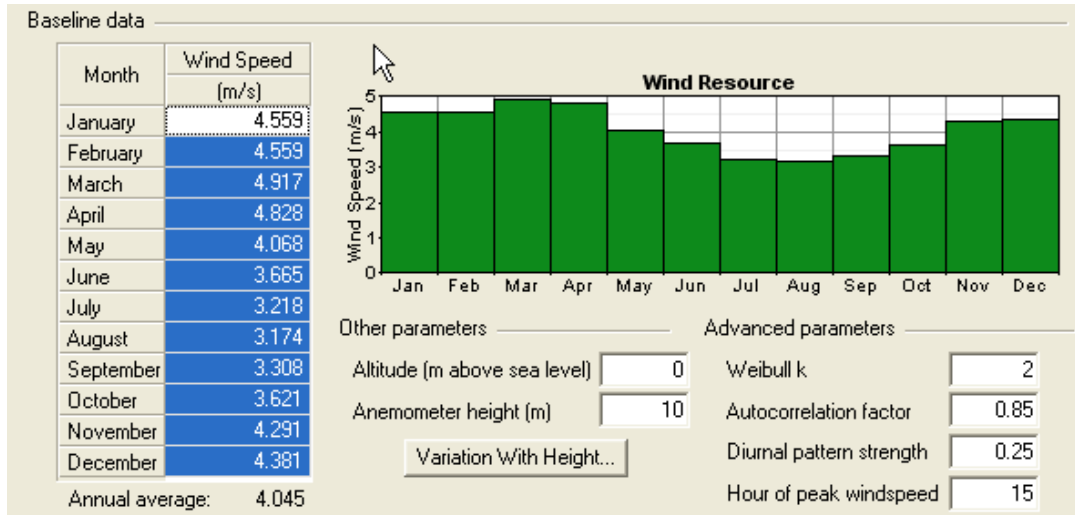
Quantity
0
1
2
3

7. Click “OK” to return to the Main Window.




## Wind Resource Data

1. Click on the Wind Resource icon  to open the Wind Resource inputs window.
2. For Data Source select “Enter monthly averages” Data source:  Enter monthly averages  Import hourly data file
3. Next, type in your monthly data from your Student Worksheet Track 2, Question 2 for Wind Speed (m/s). (Please refer to your chart for your cities Wind Speed (m/s)). You will also notice that HOMER creates a Wind Resource graph on the right.



4. Click “OK” to return to the Main window.

## Photovoltaic

1. Click on the Photovoltaic icon  to open up the “Photovoltaic Inputs” window.
2. Input the following information into your Costs table:

Size (kW)	Capital (\$)	Replacement (\$)	O&M (\$/yr)
10.000	35000	25000	0

Sizes to consider
Size (kW)
0.000
10.000
15.000
20.000
25.000

3. Input the following values for the Size in kW of your Photovoltaic:

- Under the Properties for Slope (degrees) type in 45, this will simulate the pitch of the roof of your school.

Properties

Lifetime (years)  (.)

Derating factor (%)  (.)

Tracking system


Slope (degrees)  (.)

Azimuth (degrees W of S)  (.)

Ground reflectance (%)  (.)

- Click "OK" to return to the Main Window.

## Photovoltaic Resource Data

- Click on the Solar Resource icon  to open the Solar Resource inputs window.
- Type in your latitude and longitude data from your Student Worksheet Track 2 Questions 4-5 into HOMER, and choose the Eastern Time Zone, US & Canada from the drop box:

For example: Allentown has a latitude of 40°, 39 North, and a longitude of 75°, 26 West as shown below.

Location

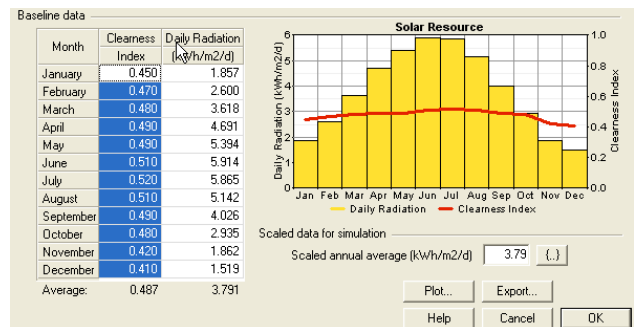
Latitude  °  '  North  South Time zone

Longitude  °  '  East  West

- For Data Source choose to enter monthly averages.

Data source:  Enter monthly averages  Import hourly data file


- Next type in your data from your Student Worksheet #1, question 6 for Clearness Index (Kt) and the Daily Radiation will be automatically calculated by HOMER, you will also notice that HOMER creates a Solar Resource graph on the right.



- Click "OK" to return to the Main window.

## Converter

A converter is used to convert DC current to AC current which can be utilized by your school.

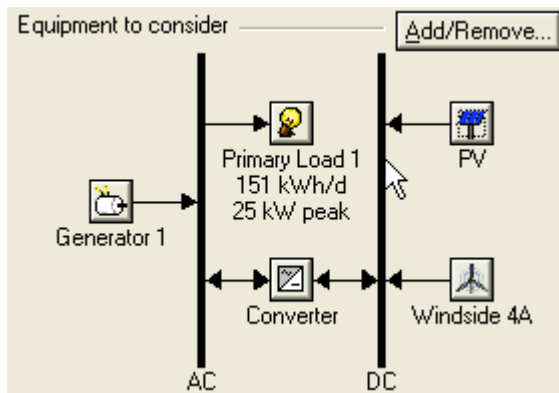
1. Click on the Converter icon  to open up the “Converter Inputs” window.
2. Input the following information into your Converter Cost table:

Size (kW)	Capital (\$)	Replacement (\$)	O&M (\$/yr)
5.000	4000	4000	0

3. Input the following values for the Size in kW of your Converter:

Sizes to consider
Size (kW)
0.000
5.000
10.000
15.000

4. Click “OK” to return to the Main Window.
5. You are now finished entering your components. The schematic should like as follows:




In looking at the schematic above, please write a brief explanation of the way the energy is flowing in the system in the box below:

## ■ PART 4: Assigning Resource Details

The resource data that you will now input will tell HOMER the availability of solar radiation and wind for each hour of the year.

### Diesel Resource

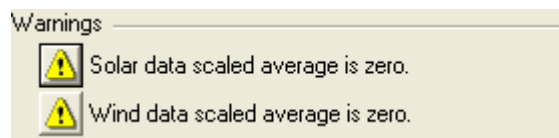
1. Click on the Diesel icon. 
2. Look at the chart from your [Student Worksheet Track 2 Question 7](#) and change the fuel price to \_\_\_\_\_ per liter based on the current cost of Diesel per gallon in your town.
3. Click “OK” to return to the Main window.




## ■ PART 5: Checking for Errors

Homer may give you a warning if any of the data that has been inputted is not correct.


**If you see a box like the following within HOMER:**



1. Click the Warning Icon to view a more detailed message.   
Follow the hint to correct the error.
2. Continue until all warning icons have disappeared.

## ■ PART 6: Analyze the System and Examine the Results

You have just completed setting up HOMER, the software is now ready to calculate and analyze your data to see what is “the best” energy system for your school from least to most expensive. Whether it recommends that your school would benefit from a single solar panel or the installation of a wind turbine....let’s sit back and see.

1. Click Calculate  to start the calculation.
2. After the simulation runs click on the “Overall button” to view all possible combinations for each component in the “Optimization Results” window.

		Optimization Results									
Double click on a system below for simulation results.											
<input type="radio"/> Categorized <input checked="" type="radio"/> Overall <input type="button" value="Export"/>											
		PV (kW)	H80	Gen1 (kW)	Conv. (kW)	Initial Capital	Total NPC	COE (\$/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
				15		\$ 12,000	\$ 209,559	0.472	0.00	22,891	8,759
		5		15	5	\$ 51,000	\$ 247,068	0.556	0.14	21,718	8,731
		5		15	10	\$ 55,000	\$ 252,426	0.568	0.14	21,718	8,731
		5		15	15	\$ 59,000	\$ 257,784	0.580	0.14	21,718	8,731

- Next click on the “Overall” button in the “Optimization Results” window. This will show you the least expensive option for each different component configuration (e.g., diesel with PV cells, or PV cells with wind turbines).
- Next choose a system of interest by double-clicking on one of the configurations to open up the “Simulation Results” window, where you can see the complete results of HOMER’s analysis.

				10	25	5	\$ 49,000	\$ 442,147	0.669	0.16	35,727	8,683
--	--	--	--	----	----	---	-----------	------------	-------	------	--------	-------

- You can explore the results for each of the configurations in the “Categorized” view to determine Cost, Electrical energy production, the efficiency of the generator, and the pollutants created under emissions by clicking on the different tabs.

Cost	Electrical	PV	Generator 1	Emissions	Hourly Data
------	------------	----	-------------	-----------	-------------

- Double click on a simulation that has all 4 components of the system, a PV cell, a wind turbine, a battery, and a converter.

				10	1	25	5	\$ 79,000	\$ 486,463	0.736	0.17	35,669	8,678
--	--	--	--	----	---	----	---	-----------	------------	-------	------	--------	-------

- Next Click on the Electrical Tab. You should see a window like the one shown below:

Annual electrical energy production			Annual electric loads served		
PV array:	14,223 kWh	(16%)	AC primary load served:	51,684 kWh	
Wind turbine:	749 kWh	(1%)			
Generator 1:	73,251 kWh	(83%)			
<b>Total production:</b>	<b>88,223 kWh</b>		<b>Total load served:</b>	<b>51,684 kWh</b>	
Renewable fraction:	0.170		Excess electricity:	35,603 kWh	(40%)
			Unmet electric load:	0.000496 kWh	(0%)
			Capacity shortage:	4.11 kWh	(0%)

- Notice that this system relies mostly on the generator for electricity at 83%, next the PV array is 16% and the wind turbine at 1%

Please complete the rest of your Student Worksheet Track 2 from the information calculated by HOMER.