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Advanced Manufacturing & Prototyping Integrated to Unlock Potential

FUNCTIONS

Experimental Design

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Clean Energy Challenge

Fall 2018

8EDM

SECTION 1 – THE CLEAN ENERGY CHALLENGE: POWER GENERATION

1.1 INTRODUCTION

Today, people in the United States use more energy compared to people in other countries in the world. We use over twice as much energy as people in countries such as England and Italy and ten times as much as people in India and Nigeria. A great amount of that energy is in the form of electricity.

Discuss this question as a class:

1. As you look around your classroom and in your pockets, how many items can you identify that require electricity to work?

Electricity might seem like a clean form of energy. Electric cars do not produce exhaust and smog, and our electric appliances do not produce smoke or bad smelling fumes. However, electricity is produced in power plants, like the one pictured above. Power plants that burn fossil fuels, particularly coal, produce harmful gasses that can cause breathing problems for people with asthma. They also pollute the air and produce carbon dioxide that contributes to global climate change.

Watch ***Power Plants and Pollution*** video #1.

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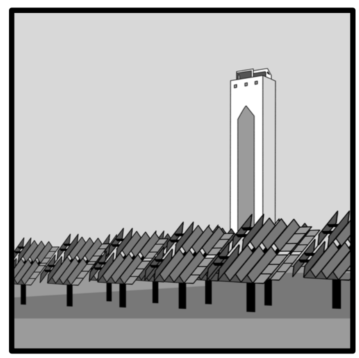
1.2 THE CHALLENGE

The old, coal-fired power plant in the city of Solville does not meet the new pollution standards and will need to be replaced. Solville is in a very sunny area of the country, so using solar power might be an efficient and clean way to produce electricity. In fact, Solville gets so much sun that if the planning is done right, the town might be able to make money by selling extra energy to a nearby city. This would be of great benefit to the community.

You are the chief engineer with the Solville power company and are in charge of planning for the upcoming changes. Your challenge is to investigate and recommend the best and most efficient power plant for the community of Solville.

1.3 ADD TO YOUR UNDERSTANDING: SOLAR THERMAL ENERGY

Some power plants can produce power using solar energy (from the sun) and thermal energy (heat). The solar-thermal power plants do not give off harmful gasses. Instead, the solar-thermal power plants produce electricity cleanly. An example solar-thermal power plant is pictured below. The power plants are effective in areas with lots of sun, like the deserts in the southwest United States, the Middle East, and Australia.



A solar-thermal power plant uses energy from the sun to heat a liquid up to a very high temperature, generating steam. Then, it uses the hot steam to turn a turbine to generate electricity. This is an example of energy being changed from one form to another, as you might have learned in your science class. Review the diagram below. The energy begins as sunlight and leaves the power plant as electricity carried by power lines. You can then use the electricity to charge up the chemical battery of your electrical device.

Solar energy (sunlight)	→	Thermal energy (hot liquid)	→	Mechanical Energy (Rotating turbine)	→	Electricity	→	Chemical energy (Charged cell phone battery)

Energy in Sun → Energy at Solar-Thermal Power Plant → Power Lines → Energy at your house

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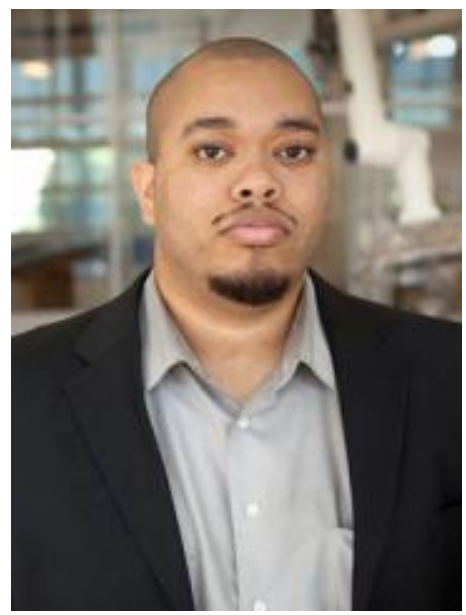
In order to work well, a solar-thermal power plant must keep the hot liquid at high temperatures. If the heat escapes into the air outside the plant, there will be no steam to turn the turbine and electricity cannot be generated to charge your cell phone. Therefore, all of the pipes need to be insulated very well. Insulating materials covers them with the goal of reducing heat loss. However, some insulating materials are better insulators than others and some are more expensive than others. Using the wrong insulator can make a significant difference in an effective power plant, an inefficient power plant, or an expensive power plant.

Mechanical engineers, such as Georgia Tech's Dr. Asegun Henry, use their knowledge of heat transfer and materials to make solar-thermal plants more efficient. Heat transfer is the exchange of heat between different types of materials. Efficient solar-thermal plants are well insulated which minimizes heat loss and knowing which materials to use will greatly impact how much heat is lost outside the plant.

1.4 MEET DR. HENRY

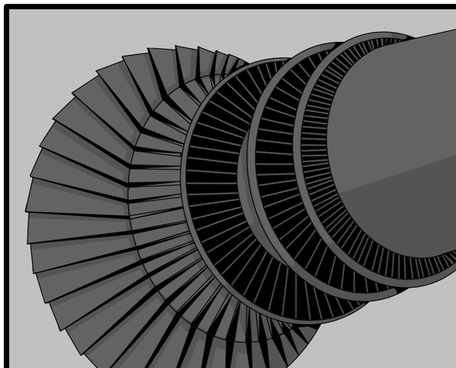
Dr. Asegun Henry is a professor of mechanical engineering at Georgia Tech. He researches solar energy and ways to improve the design of solar thermal power plants so that the liquid stays hot and the plant can produce clean energy.



Watch ***Meet Dr. Henry*** video #2.

1.5 INVESTIGATING A SOLAR-THERMAL POWER PLANT

The mayor and the city council of Solville have analyzed the city's budget and determined the size of the power generator turbine that Solville can afford. Your first job, as chief engineer, is to test whether that size turbine is big enough to provide electricity to the whole city, which has 120,000 homes and businesses. You will also determine if you have enough extra power to sell and make money for the city.



Power Generator Turbine

You will need to collect data in order to make a scientifically informed decision about how much electricity the turbine can provide. One way to collect that data would be to build a power plant and measure how much electricity it generates each day. This is an expensive idea since it costs millions of dollars to build a solar energy power plant. Additionally, if the power plant is not the right size, you would have to start over.

You will use a computer simulation to collect data from a computer-generated power generator and turbine. Using the simulation, you will test how many houses the turbine can power when it is running at different speeds, or **percent capacity.** If the power generator turbine is running at maximum speed, it is running at 100% capacity. If the power generator turbine is running at 10% capacity, it is only barely turned on.

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Discuss this question as a class:

1. How will this simulation tell you whether the generator can provide enough power for the whole city?

SECTION 2 – CHOOSING THE RIGHT EQUIPMENT

2.1 DETERMING WHETHER THE GENERATOR IS THE CORRECT SIZE

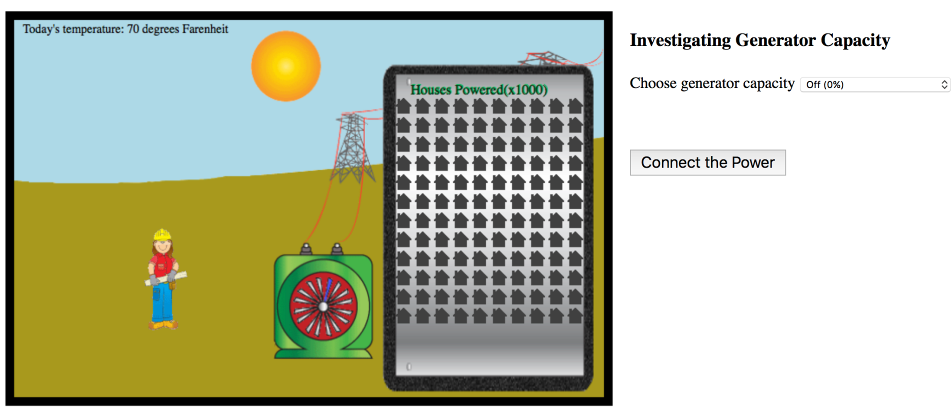
Research Question #1:
Can this generator provide enough electricity for 120,000 homes and businesses in Solville?

To answer this research question, you will need to collect data using an experiment. All experiments must have an experimental procedure that tells exactly what you did so that other people can understand it. For your data to be accurate, you need to conduct the experiment the same way each time. This is called having a consistent experimental procedure. You should also only change one thing, or variable, at a time.

In this experiment, you will investigate how changing one variable affects a different variable. You will use the computer simulation to change how fast the power generator is running, which is also the percent capacity. You will also record how many houses the generator can power. The variable you change (how fast the generator is running) is called the **independent variable**. The variable that you are studying (the number of houses that the generator can power) is called the **dependent variable**.

Follow this experimental procedure to collect your data. Your teacher will instruct you on how to access the computer simulation.

Procedure:



1. Click on “Generator Capacity” and start the generator at 10%.
2. Click “Connect the Power.”
3. On your *Simulation Data* student sheet, record the number of thousands of homes that can be powered if the generator is running at 10% capacity. Each house in the grid represents 1,000 homes.
4. Click “Disconnect Power” to stop the simulation and move to the next percentage.
5. Repeat for positions 20% and 30% generator capacity. Record each value on your *Simulation Data* student sheet.

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Now that you have conducted the experiment and recorded the data on your sheet, you need to analyze it so you understand what it means.

Procedure:

6. On the *Simulation Data* student sheet, create ordered pairs from the data in the table. Use the form (**Generator Capacity**, **# Houses Powered**) equals (X , Y).
7. Using the ordered pairs, plot the points on the graph.
8. Calculate how many more houses are powered each time you increase the percent of generator capacity by 10%. To do this, complete the data difference table for each capacity range by subtracting the smaller number from the larger.

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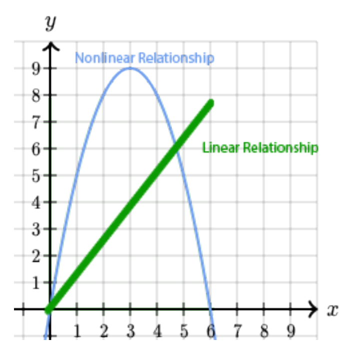
Discuss these questions as a class:

1. Did the number of houses powered change by the same amount each time you increased the generator capacity by 10%?

2. Where does the line cross the y-axis?

2.2 INTERPRETING GRAPHS

People make graphs of data so they can better visualize and understand data. This allows them to make claims or predictions based on actual evidence and trends. The shape of the data can provide important information. What does your data reveal?



Procedure:

1. Connect the data points on the graph on your *Simulation Data* sheet.

   If the data forms a straight line, it is called a **linear relationship**.

   If the data forms a curve, it is called a **nonlinear relationship**.

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Discuss these questions as a class:

1. How many houses would be powered when the generator is operating at 0% capacity? Why?

2. Was the relationship between the generator's percent capacity and the number of houses it can power a linear or a nonlinear relationship?

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Since the graph of generator capacity and number of houses powered shows a linear relationship, you can use it to predict what will happen when the generator is run at higher capacity.

Procedure:

2. Use a straight-edge (ruler) to extend the line to the edge of the graph.
3. As a class, return to the research question:

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Can this generator provide enough electricity for 120,000 homes and businesses?

Discuss these questions as a class:

1. At what capacity will the generator need to run in order to power those 120,000 homes? How do you know?
2. How many homes can the generator power if it is running at 75% capacity?
3. Will Solville have enough energy to sell to another city?
4. How reliable are these answers based on the graph you created?

2.3 MATHEMATICAL VERIFICATION

Extending a line on a graph with a straight-edge can show a trend and provide an approximation of what a result would be outside the region that was tested. However, if the angle of the ruler is slightly wrong when you draw the line, this can give a very inaccurate prediction. Instead, scientists and mathematicians use the data points to create a mathematical equation that describes the line. Using a mathematical equation for the line, you can then precisely predict the results anywhere on the graph, or even the results for points too big to fit on your paper graph.

Data from the Solville power generator showed a linear relationship. In other words, every time you increased the generator's percent capacity by 10%, you increased the number of houses powered by the same amount. Therefore, there is a simple equation that defines this line. Once you know that equation, you can predict how many houses will be powered at any level of generator capacity, or you can predict how much of the capacity of the generator would be required to power a certain number of houses. If you know how to predict it mathematically, you can save a lot of work.

The linear equation form that describes a line is called the slope-intercept form of a line. We write this equation as y = m x + b, where m = the slope of the line, and b is y-intercept.

SLOPE INTERCEPT FORM

y = m x + b

To write the equation for your line, you must know two points of the line. With those points, you can compute the **slope** of the line (m) which is the rate of change of the line, also known as "change in y" / "change in x". The y-intercept (b) is the point on the y-axis where the line intersects the axis. At that point X=0, so any point on the y-axis would have the ordered pair (0 , y).

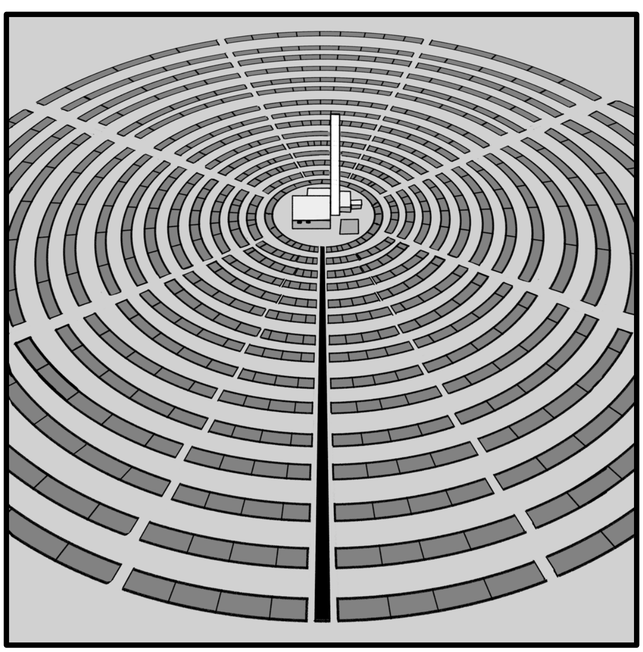
Procedure:

1. Complete the information on the *Mathematical Verification* student sheet to mathematically determine if the selected generator is a good one for the community.

Example: If you have the following two points (0, 4) and (3 , 10)

Slope (m) = $\frac{10 - 4}{3 - 0} = \frac{6}{3} = 2$ **y-intercept** = 4

Slope Intercept Equation for the line would be: y = 2x + 4



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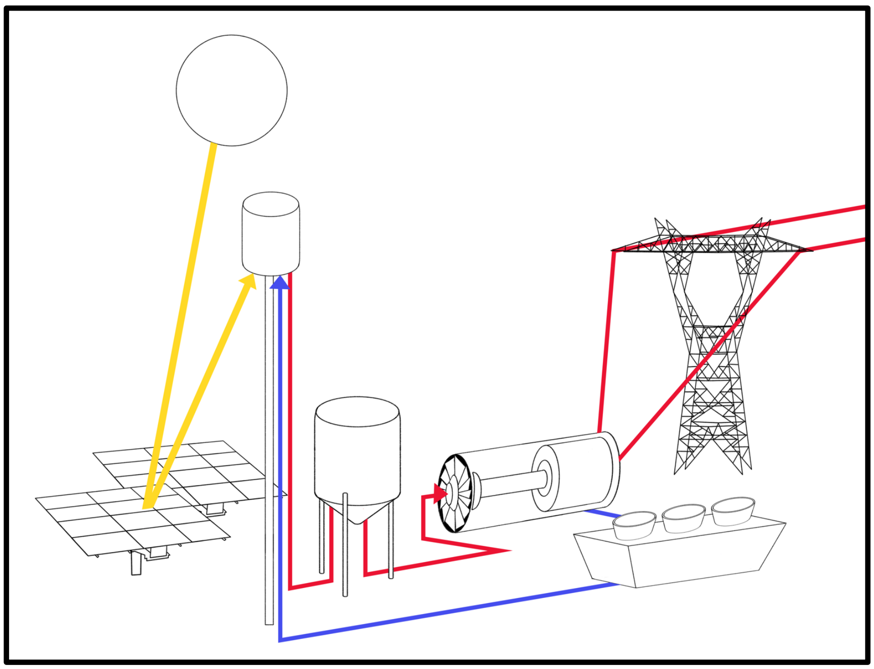
SECTION 3 – MAXIMIZING YOUR POWER

3.1 ADD TO YOUR UNDERSTANDING: HOW SOLAR THERMAL POWER PLANTS WORK

Solar thermal energy power plants contain a few basic components which are shown in the picture below. The sun is reflected by a set of movable mirrors to a **receiver** on top of a tower. In the receiver, water is super-heated and turned into steam. The super-hot steam, which can get up to 1,000 degrees Fahrenheit, travels through pipes from the receiver to a **steam drum**, then into the **turbine** of a **generator**. These pipes of super-hot steam are the red lines in the picture below. The steam makes the turbine turn, and this movement generates electricity that flows out to houses through power lines. The blue lines in the picture below are the pipes that take the cooled water back up to the top of the tower so it can be re-heated.



Discuss these questions as a class:

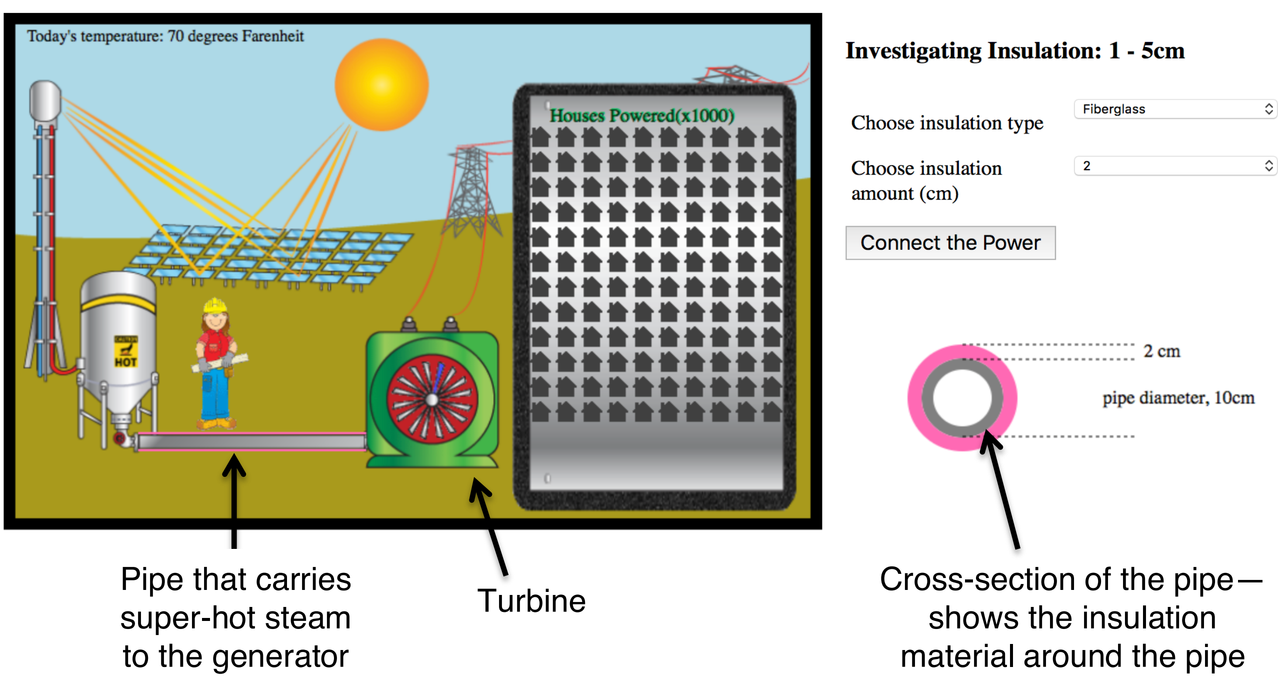
1. What would the outside of a metal pipe feel like if it has super-hot steam inside it?
2. How might you keep from losing lots of heat to the environment before the steam gets to the generator?
3. How is this similar to what people do in their houses to make their heater and air conditioner more effective?

3.2 INVESTIGATING INSUALTION

Insulating the pipes in a solar thermal power plant reduces the amount of heat lost to the environment. The less heat that is lost, the more effectively the generator can run. In our simulation, an effective generator runs at a higher percent capacity. Different materials provide better or worse insulation. You may have experienced that with different types of clothes as some clothes keep you warmer than others. Most materials insulate better when the layer is thicker. As chief engineer, you will need to decide which insulation to buy and how much to use. However, first you need to investigate how well each one works.

Research Question #2:
How does the type and thickness of insulation affect the amount of power produced by the solar thermal plant?

To conduct this research, you will again use the computer simulation to run an experiment and collect data. You will receive three types of insulation materials to test. In your experiment, you will investigate how the type and amount of insulation material affects how well the power plant runs, and therefore how many homes it can power. As you change the thickness of the insulation, the simulation shows you what the cross-section of the pipe will look like. It also shows you visually how hot the water will be and how fast the turbine will spin.



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In the generator capacity experiment, you were provided with an experimental procedure to follow. This time you will need to write your own procedure. The simulation will enable you to test how effective different insulation materials are in keeping the water hot, and therefore how many houses the generator can power. You can do this by changing the type and thickness of insulation material and recording how many houses are powered. But remember, you should only change one variable at a time.

In this first experiment, you, as chief engineer, need to test how well the power plant runs using two different types of insulation to keep in the heat – Adobe and Fiberglass. Since you can make the insulation layers thicker or thinner, you will need to test multiple thicknesses to see how well each works.

Procedure:

1. Using the *Insulation Procedure* student sheet, write a procedure that uses the simulation to provide accurate data about how many houses are powered when using different thicknesses of these two types of insulation. When you have finished writing your procedure, show your teacher before proceeding.
2. Open the simulation and follow your procedure to collect data with the simulation. Record the results in the first two columns of Data Table #1, at the bottom of the *Insulation Procedure* student sheet.
3. Write the equations for the lines for both Adobe and Fiberglass below the data table.
4. Graph the data for both insulators on the *Insulation Graph* student sheet. Use a dot for Adobe, and an X for Fiberglass, so that you can tell the lines apart.

Discuss these questions as a group:

1. Was the relationship between the insulation material thickness and the number of houses powered a linear or nonlinear relationship?
2. What do you notice about the y-intercepts (b) of the two materials?
3. What do notice about the slope (m) and the graph of the line?

Procedure:

5. Your teacher will now assign you or your group a third insulation material to test.
6. Write the name of the material in the third column (3.) of Data Table #1 on the *Insulation Procedure* student sheet.
7. Follow your procedure again and collect data for your third insulator. Record the data in the Data Table.
8. Write the equation of the line at the bottom of the page. From the equation, you should be able to predict what the line will look like on the graph. Will it be steeper or flatter than the other two?
9. Add the line for material #3 to the graph on the *Insulation Graph* student sheet.

Discuss these questions as a group:

1. When you graphed it, did the slope for material #3 look like what you predicted from the formula?
2. Was the power plant able to power the entire city when you used 5 cm or less of one of your insulation materials?
3. If 5 cm of an insulation material wasn't able to keep the water hot enough to power the entire city, how can you use mathematics or your graph to determine how much insulation would be needed? (This assumes that the relationship stays linear). Would it even be physically possible to use that thickness of material?

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3.3 EXPLORING MULTIPLE INSULATION MATERIALS

Since the insulation data you collected is linear for all the materials, you only need two coordinate points to determine the equation of the line for the material. You will now compare all of the insulation materials that the class tested.

Procedure:

1. Transfer two data points for each material that you tested—for 1 cm and 5 cm—from Data Table #1 on the *Insulation Procedure* student sheet, to Data Table #2 on the *Insulation Data* student sheet. The ordered pair should be in the format (Thickness , # of Houses (x1000))
2. Transfer the number for the y-intercept (b) for each material.
3. As a class, share results for all the insulation materials that were tested so everyone has a complete set of data. Record the new data in the table.
4. Using the two points, calculate the slope (m) of each line.
5. Use the slope and the y-intercept to write the equation of the line for each material.
6. Answer the questions at the bottom of the *Insulation Data* student sheet.

Let us use Adobe as an example:

(1 cm , 37) (5 cm , 92)

y-intercept (b) for Adobe = 23

$$\text{Slope(m)} = \frac{92 - 37}{5 - 1} = \frac{55}{4} = 13.75$$

Equation for Adobe= y = 13.75x + 23

Discuss these questions as a class:

1. Which material was the most effective in keeping the water hot and powering houses? What part of the mathematical equation tells you that?
2. Which material was the least effective?

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SECTION 4 – THE PLANT RECOMMENDATION

4.1 WRITING THE RECOMMENDATIONS

As chief engineer for Solvlle, your challenge is to decide whether the turbine that the mayor and city council picked is sufficient to power all of Solville. You are also required to make a recommendation about the type of insulation to use. When making your recommendation, remember that extra power can be sold to other cities. However, the different insulation materials have different costs so keep the following in mind when deciding upon your recommendation:

Insulation Material Prices

Very Cheap Materials: Grass and Mud

Cheap Materials: Adobe, Brick, Wood

Moderately Priced Materials: Fiberglass

Expensive Materials: Aerogels, Vacuum Panels

Discuss these questions as a Class:

1. Will any of the insulation materials enable the power plant to produce more power than the city of Solville needs?
2. Is there other information you would like to know in order to make a good recommendation?

Procedure:

1. On the *Clean Energy Recommendation* student sheet, write a letter to the mayor of Solville and make a recommendation about what insulation material the city should use. In your letter, you must include evidence about the generator and the insulation materials from your experiments with the simulation.

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