

Investigating the Impact of Choosing High Efficiency Light Bulbs

Introduction

Electricity. It's the energy that runs our civilization. Yet its production and use incur steep environmental costs. It's a complex equation with big questions:

- > Do the benefits of electricity outweigh the costs?
- > How will we meet increasing demand with sustainable production of electricity?
- > How can we balance our own daily use of electricity with the broader needs of society?

This lesson introduces students to these broad questions by bringing the topic of electricity use and production into students' daily lives. A combination of inquiry-based learning, factual knowledge and hands on activities helps the student appreciate how energy is used and the economic context of electricity. Students will assess the efficiency of different light bulbs in an inquiry. They will research how their local power is generated and at what economic and environmental cost. In particular, the lesson emphasizes how the student's own behavior affects demand for electricity and hence, their environmental and social impact. Finally, this lesson offers a launch point for students to initiate a service learning project that can go on to change not only their behavior but additionally change the behavior of their community.

Objectives

1. Understand the different ways electricity is produced and how it is used by businesses and individuals (Teacher input/Research)
2. Differentiate between the environmental consequences of using renewable versus nonrenewable resources for electricity production. (Teacher input/Research)
3. Demonstrate that low wattage light bulbs are more efficient and hence sustainable than traditional light bulbs Inquiry/Hands on activity
4. Highlight straightforward and inexpensive changes people can make to reduce their individual demand for electricity
5. Understand that our use of electricity is linked to the health of our oceans. (Research)

Materials

Research

- > Computer with Internet access
- > Library and/or classroom resources

Inquiry (Suggested materials)

- > Tub of room temperature water
- > 1 Clamp Lamp with shield for each group
- > Ring stand or chair on lab stations to hold clamp lamp

- > Two incandescent light bulbs (60 Watt and 100Watt)*
- > Two compact fluorescent light bulbs (60 Watt and 100Watt equivalent Lumens)*
- > Two LED light bulbs (60 Watt and 100 Watt equivalent Lumens)*
- > Thermometer for each lab group
- > 1 Soda can for each lab group painted black
- > Test Tube
- > Ruler or meter stick
- > White piece of tag board or poster board
- > Watch or stopwatch
- > Probe ware to measure luminescence if available

*Choose light bulbs of comparable luminosity. The purpose of this inquiry is to compare the efficiency, or power required by bulbs to produce visible light and to become aware that electrical energy transformed to energy types other than visible light in light bulbs. It is therefore important to control the light output, or lumens of the bulbs. For example, a 60W incandescent has the same light output as a 15W CFL. A 100W incandescent has the same light output as a 25W CFL. L.E.D lights are expensive. You may want to double up on the incandescent and fluorescent bulbs and add a 150 Watt equivalent pair.

Vocabulary

- > Energy - capacity of a system to do work
- > Watts - amount of energy used per unit time
- > Lumen - amount of light output
- > Heat - thermal energy transferred into or out of a system
- > Calories (c) - a measure of the amount of energy required to raise the temperature of 1g (1ml) of water 1°C.
- > Electricity - energy available from the flow of charge
- > Natural resources - things that we use provided by the environment
- > Fossil fuels - hydrocarbon compounds formed from organic matter
- > Renewable - natural resources renewed by nature over time
- > Non-renewable - natural resources that are not renewed by nature over time

Essential background for teacher

This section is need-to-know information for the teacher to teach the lesson effectively.

Key questions:

- > Why should we care about electricity efficiency?
- > What are our choices of source energy for generating electricity?
- > What are the economic, health and environmental implications of using renewable versus nonrenewable resources to generate electricity?
- > What information is required for us to make changes in our daily behavior and use of electricity to reduce electricity demand?
- > How many pounds of CO₂ can be saved by switching to more energy efficient light bulbs?
- > What is the cost of switching to LED's compared to cost of a new power plant?

Key facts:

- > More than 90 per cent of our electricity is produced using nonrenewable resources. More than three-quarters of our electricity is produced using fossil fuels. Nonrenewable resources will run out, so using them to generate electricity is not sustainable. If we do not switch away from nonrenewable resources our present way of life cannot be continued. Any measure to improve efficiency will lessen demand on nonrenewable resources and help sustain our way of life.
- > Use of renewable resources is sustainable since these resources will not run out. By using renewable resources we can sustain our civilization indefinitely. Renewable resources have a smaller “carbon footprint” and so contribute less to global warming than fossil fuel-based nonrenewables.
- > Coal fired power plants are the most common method for producing electricity in this country and across the world. The modern method of mountain top removal for the mining of coal is inexpensive for the mining companies and power plants but expensive for the land, watersheds and people. Waste from mountain top mining destroys watersheds through the release of toxins and increased turbidity. The burning of fossil fuels, including coal, to generate electricity releases toxins that lead to an increased rate of asthma downwind from the plants. Coal fired power plants release methyl mercury into the atmosphere which bioconcentrates to toxic levels in our commercial fish such as tuna. Fossil fuel plants also pollute the atmosphere with greenhouse gases including carbon dioxide, and sulfur dioxide, which contribute to global warming, and cause acid rain.
- > Nuclear power generation creates radioactive waste that needs special handling procedures and fortified storage facilities. The waste is a health and national security risk. Extraction of nuclear fuels also incurs a substantial environmental cost through pollution risk to humans, land and water. Significant amounts of water are used in the cooling of nuclear power plants and this leads to excessive heat being released into rivers and oceans, which in turn reduces the amount of dissolved oxygen available and other issues. The environmental impact of renewable sources of energy is much lower.
- > Electricity production can impact on marine ecosystems in several ways. Acid rain runoff and mixing of atmospheric CO₂ into the polar oceans can damage fragile ecosystems such as coral reefs. It can cause imbalances in water chemistry of lakes and oceans. Oil spills can devastate marine ecosystems and cause long-term damage to shoreline habitats. Discharge of warm water (a byproduct of cooling systems) can disrupt the ecology around a power station. Coal burning power plants emit mercury which bioconcentrates in marine organisms including commercially fished tuna. Although renewable resources are desirable, there is little research on the environmental impact of large tide or wave power installations.
- > Daily choices can significantly reduce electricity demand. For example, if you switch an incandescent 100W light bulb in your home for a low-energy 100W equivalent, you will save the amount of electricity required to boil 210 liters of water. Over a year, this could save \$10 on your electric bill. Since most house have at least 20 electric bulbs, switching to low energy alternatives house-wide could save \$200 on the annual electric bill.
- > In order to facilitate a switch from nonrenewables to renewable sources of electricity generation, we must first limit demand, or at least the growth of demand. The easiest way to do this is to increase the efficiency with which we use electricity.

General Background for Teacher

This section provides additional information for the teacher who wishes to delve more into the topic.

How we use electricity

Since the Industrial Revolution, we have come to rely on electricity for innumerable everyday uses. Businesses use electricity to power industry and manufacturing. In the home we use electricity for numerous labor-saving devices, lighting, heating and cooling our homes, cooking food, and entertainment. Without electricity, our present day civilization would not be possible.

How we generate electricity

Power stations use renewable and nonrenewable natural resources to generate electricity.

The primary non-renewable resources are coal, petroleum (or crude oil), natural gas and nuclear fuels. They are most often found underground.

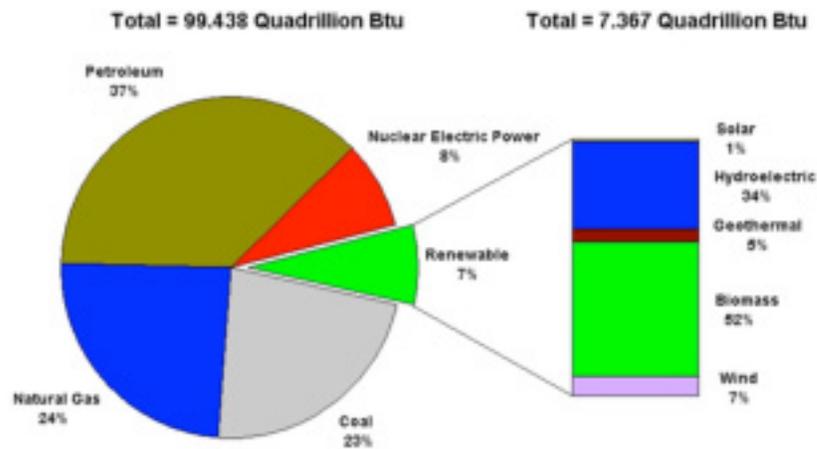
Fossil fuels are typically recovered by drilling wells, or digging surface and deep mines. They are comprised of organic compounds (hydrocarbons) formed from the remains of plants and animals that lived millions of years ago. Layers of sand and silt covered the dead organic material, usually in a marine environment. Heat and pressure deep beneath Earth's surface transformed this organic matter into coal, oil, and natural gas.

Besides power generation, we use fossil fuels for transport, and producing plastics and a wide range of chemicals. Fossil fuels are nonrenewable resources -- any natural resource from the earth that exists in limited supply and cannot be replaced if it is used up. When fossil fuels are gone, we'll have to find alternatives for their multitude of uses. Quite likely we won't find suitable alternatives in some cases.

Renewable resources are any natural resource that can replenish itself naturally over time. Use of these resources does relatively less harm to the environment than nonrenewables. Use of renewable resources is potentially indefinitely sustainable. Examples include wind, geothermal, solar, hydroelectric, tide or wave energy and biomass.

Despite the obvious advantages of using renewable resources to produce electricity, most power stations in the United States use coal, oil, or natural gas. This is primarily due to history and economics. The technology to generate power using fossil fuels was developed first. As the country industrialized, investment was put into these established technologies. At the time, no need was seen for an alternative. Today, we have a legacy of past policies and practices, which are no longer appropriate for a future in which fossil fuels will be increasingly scarce. You can see that legacy in the statistics of our current sources of electric power generation. More than four fifths is generated using fossil fuels. Less than a tenth of the country's electricity is generated by nuclear power and less than that is generated using renewable resources. In order to prepare for a sustainable future, we must switch to a higher proportion of electricity generation from renewables.

However, there is a "chicken and egg" situation. Proponents of the status quo assert that renewables are unable to meet electricity demand. Without investment in renewables that will always be true. One way out of the conundrum is to reduce demand. The easiest way to do this is to improve energy efficiency.



<http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html>

How we can improve energy efficiency

The best way to improve energy efficiency is to make simple changes to reduce the amount of electricity that we use. To demonstrate how easy it is to improve efficiency, provide with students the following examples. From these, students can see that just by changing light bulbs they can directly help to improve energy efficiency.

1. *Replace older, full-size fluorescent lamps with newer, more efficient models.* Fluorescent lighting is more efficient than incandescent lighting. However, many homes still use older fluorescent fixtures. By switching to new, full-sized fluorescent fixtures that are even more efficient, homes can improve their energy efficiency.
2. *Replace incandescent lights with compact fluorescent lamps.* Most homes use primarily incandescent bulbs for lighting. These bulbs heat a filament until it's white hot to create light. Incandescent bulbs convert about 98 percent of the electricity to heat. Only 2 percent of the electricity goes to making light. Fluorescent bulbs on the other hand, convert about 10 percent of the electricity into light. Most incandescent fixtures can use compact fluorescent lamps (CFLs)..
3. *Use of LED lighting.* Use of LEDs (light emitting diode) for domestic lighting is relatively new. LEDs work by passing current through a semiconductor material, which is stimulated to emit light. These bulbs are expensive but emit the least amount of heat. Currently available LEDs are at least three times as efficient as incandescent lighting. LED "solid state lighting" could halve the US's energy use for lighting by 2025.

www.management.energy.gov/documents/LEDPresentation.pdf

4. *Install lighting controls.* Light switches control lighting equipment in the home. Light switches are often left on when not in use. To reduce waste, timers and occupancy sensors will turn off lights when they're not needed. Timers will turn off the lights after a set time interval. Timers work well in places, such as stairways, hallways, and closets, where use is intermittent and the space is occupied only for short periods..

Adapted from <http://www.pasolar.ncat.org/lesson01.php>

Engage

1. Show students the current and projected global energy needs. Ask them for input on the economic, environmental and political implications of this projection. Create a class T-chart to record their ideas. Use the categories of economic, environmental, political and other. Have them designate whether each idea is positive or negative for the United States.
2. Introduce students to the key concepts: heat, light, watts, lumens, energy, calories and electricity.

Pre-assessment

Directions:

Have the students complete the Energy Efficiency Knowledge Survey Questions on the front of the Student Response Page. Have students share some of their thinking to the questions. This will help all students gain a base line of understandings and give you an opportunity to gauge where they most need to direct their research following the activity. Do not use this page for grading. It is meant to be updated as students learn more on the topic. They will complete their Light Bulb Inventory during the inquiry. After they have completed their own light bulb inventory, have them enter the data on the class data table you provide. A Sample table is provided in the Teacher Master section. You may copy or project this for your students to enter their information throughout the period.

Student Response Page included at the end of the lesson

Inquiry

A copy of a procedure is included with this activity. This is a simple enough investigation for your students to write their own procedure. A short class discussion of the question and what needs to be controlled, specific materials you are supplying and review of safety could get them started. You might want to have them share common amounts of water and time of the trials in order to compare class data later.

Note: The **Engage**, **Preassessment** and **Inquiry** procedure reading could be initiated at the end of a class period and assigned for homework.

Analysis

Use these answers to help explain the concepts and ideas behind the lab activity (Analysis in the Student Resource Section). Some of the answers may differ according to the results from the activity.

1, 2. Incandescent lights give off heat as well as light energy. The higher the wattage of the light bulb the higher the temperature, which means it is giving off more heat. A compact fluorescent bulb gives off very little heat energy because they do not use resistance to produce light. LED or solid state bulbs give off the least amount of heat to produce light.

3, 4. Since the bulbs are the same luminosity they will not differ in the brightness of the light. Therefore since the LED gave off least heat, it is the most efficient in converting electricity into light energy.

Application

1. For example, assume a house has 20 40W bulbs, each on for eight hours a day, it will use $40 \times 8 = 0.32$ kWh per bulb = $0.32 \times 20 = 6.4$ kW per day for the house. Given a cost of 12 cents per kWh (11.62 is US average in 2011) for 30 days a month, the monthly lighting cost is $6.4 \times 0.12 \times 30 = \23.04 . Assume that the house switched to CFLs. A 9W CFL has the same light output as a 40W incandescent. Daily usage is $0.072 \times 20 = 1.44$ kW. Therefore the monthly lighting cost is \$5.18, a difference of \$17.86

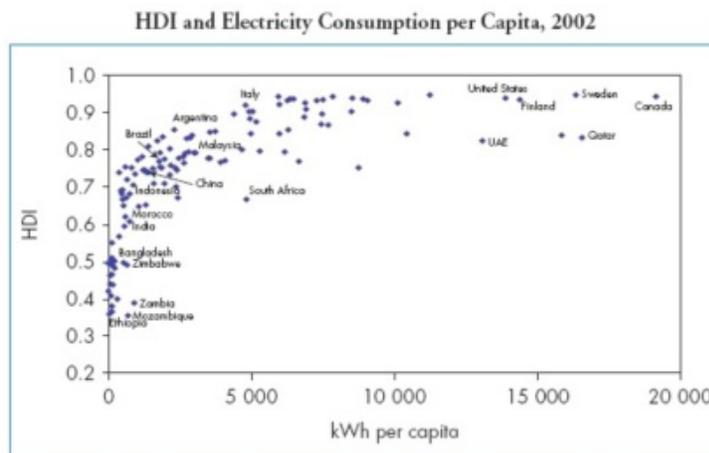
2. Cost of different light bulbs and manufacturers claims on lifetime can be obtained online or by a field trip to a local hardware store.
3. See example calculations: <http://www.thesimpledollar.com/2009/02/10/the-light-bulb-showdown-leds-vs-cfls-vs-incandescent-bulbs-whats-the-best-deal-now-and-in-the-future/>
4. a. Use the class average for the Total # Hours Used/day x Each Bulb Type's KW/H X 1.325lb/KWH x 365days/year.
b. Idaho's CO2 emission rate is so low because they get a significant portion of their power from hydroelectric generation. North Dakota, on the other hand generates significant power by burning coal.
5. Assume the power station serves a population of 100,000. If the data in question 1 is typical, the total demand for electricity for lighting using incandescent bulbs is $6.4 \times 100,000 = 640,000$ kW per day. By switching to CFLs, the total demand would drop to 144,000 kW.
6. If demand for electric lighting were dramatically cut, there would be less need to build new power stations. Demand could be more readily met with renewable energy sources.
7. In a home or office, the air conditioner would have to use more energy during the summer to remove the extra heat given off by incandescent lights.

Side Bar

Many state and city highway departments have replaced changed incandescent bulb traffic stoplights with LED lights. During the February 2011 East coast snowstorms an unexpected problem arose. The snow to quickly melted off the older traditional stoplights because they give off heat. The new LED lights—which emit less heat— did not melt the snow, causing a safety hazard because motorists could not see the red lights. Can you think of a solution to this problem?

Elaborate or Extend

1. Show students the following graph of Human Development Index and per capita electricity consumption. Ask the students:
 - Note the current situation of Brazil and China. As these countries develop what will happen to their per capita electricity consumption?
 - What are the likely environmental and economic consequences?



Sources: IEA analysis; UNDP (2004).

2. Show the students the following video: <http://www.youtube.com/watch?v=Iait4-aTypg>

Ask the students:

Discuss the implications of the video. Do you agree or disagree with the viewpoints in the video? Explain your reasoning.

Evaluate

Have students return to the pre-assessment survey to keep or change their answers and explain their responses in light of the evidence from the lesson. Discuss and write answers to the following questions:

1. Summarize the advantages and disadvantages of different types of lighting for household use.
2. Summarize the advantages and disadvantages of different types of lighting for public use (parking lots, etc.)
3. What are the main hindrances to mass adoption of more efficient light bulbs?
4. Besides switching light bulbs, what other steps can you take at home to increase efficiency of energy use?

Connections to Service Learning

See end of student activity worksheet. Needs development.

1. National Standards

A. ESS Core Idea 4: Human activities are constrained by and, in turn, affect all other processes at Earth's surface.

[Human Interactions with Earth] Grades 9 - 12

1. *What sources of energy generation provide options other than fossil fuels?*
 - All forms of energy production, and other resource extraction, have associated economic, human, environmental and geo-political costs and risks, as well as benefits. New technology and regulation can change the balance of these factors.

A. ESS Core Idea 4: Human activities are constrained by and, in turn, affect all other processes at Earth's surface.

[Human Interactions with Earth] Grade 9-12

Sub-question: How do humans change the Earth?

Humans have become one of the most significant agents of geologic change at Earth's surface. The activities that have built human civilizations have both positive and negative consequences related to the sustainability of these civilizations.

1. *How can humans exist sustainably and indefinitely on Earth?*
 - Human populations are increasing. As human populations and per capita consumption of natural resources increase, so do the rates of our impacts on Earth.
 - Human sustainability requires responsible management of natural resources. Scientists and engineers contribute by developing new technologies to extract resources while reducing the pollution, waste, and ecosystem degradation and by using recycled materials.
 - Some negative effects of human activities are reversible with proper management; for example, regulations on water and air pollution have greatly reduced acid rain and stream pollution, and regulations on the use of certain gases have halted the growth of the annual ozone hole over Antarctica.
 - Alternate energy sources can continue to be developed, reducing the environmental impacts of using fossil fuels.

Explore: Hands on Activity - Compare the efficiency of three types of different light bulbs

Investigative Question: What is the difference in heat output of different types of light bulbs?

Materials (your teacher will direct you to the bulbs available):

- Clamp Lamp
- Ring stand or chair set on counter for clamp lamp to be secured
- Extension cord
- Two different wattage incandescent light bulbs*
- Two different wattage compact fluorescent light bulbs*
- Two different wattage LED light bulbs*
- Thermometer
- Graduated cylinder
- Soda can painted black
- Ruler or meter stick
- White piece of tag board or poster board
- Watch or stopwatch
- Additional room temperature water
- Probe to measure luminescence if available.

Procedures:

1. Mount the clamp lamp on the ring stand or chair leg so the lamp shines horizontally.
2. Place 100 ml of room temperature water in the black can.
3. Fold the white cardboard/ poster board in half and stand it close behind the can like an open book with the white interior facing the can.
4. Measure the distance from the open edge of the shield to the can and record. 10 to 15 cm is recommended.
5. Ensure the lamp is unplugged and screw in the wattage light bulb you are testing.
6. Measure and record the temperature of the water in the can before the light is turned on.
7. Plug in the lamp and turn it on.
8. Leave lamp shining on the can with the thermometer for 10 minutes and record the temperature on the thermometer at the end of thirty minutes.
9. Turn off the clamp lamp and allow the light bulb and thermometer to return to the starting temperature.
10. Dump the warm water in the sink and replace it with the same amount of room temperature water.
11. Repeat the steps above two more times for a total for three trials.
12. Record the data collected from the other lab groups.
13. Subtract the start temperature from the end temperature to get the difference.
14. Calculate amount of heat transferred from the light bulbs to the cans of water. Your answer will be in calories. Remember a calorie is the energy required to raise the temperature of 1g or 1ml of water 1°C.

Hints

- After recording the end temperature, let the thermometer cool. The starting temperature for the thermometer should be about the same for each trial. The difference from beginning to end temperature is the important calculation.

Safety:

- Have different groups test different light bulbs or allow the lamp and desk to cool for 5 minutes between each bulb.
- Do not unscrew the light bulb right after turning off the lamp as the bulb may be hot and can burn you. Do not touch the metal cover around the light bulb, as it is HOT.
- Unplug the lamp before changing the bulb.

Analysis:

Write a paragraph describing the results of your investigation. Include data from you entire class and consider the following questions in your answer:

1. Which bulb gave off the most heat?
2. Which bulb gave off the least heat?
3. Which bulb appears to give off the brightest light?
4. Which bulb is the most efficient in terms of converting electricity into light energy?

Application:

1. Your home electric bill is based on how many kilowatts per hour are used in your house use over a month. (See table for state by state cost.) Using the information from the pre-assessment survey and the results of this investigation, estimate the difference in the amount of electricity used if you changed all the light bulbs to the most efficient.
2. Find the cost of the different light bulbs and the companies' claims about the lifetime of the bulb. Calculate the lifetime cost of the lightbulb (= initial cost + (cost per kilowatt hour x bulb wattage x estimated lifetime). Which bulb is initially the most expensive? Which bulb has the lowest lifetime cost?
3. Using the data from question 1, calculate the reduced demand for energy if all the households served by your local power station switched to the more efficient bulb.
4. a. Using the data from question 1, estimate the differences in pound of CO₂ saved each year for the average household for each bulb type. If you do not have the value for your local utility, use the national average value of 1.325 pounds/KWH of CO₂.
b. Explain why Idaho with 0.03 pounds/KWH of CO₂ emits so much less CO₂ than North Dakota which emits 2.24 pounds/KWH of CO₂.
5. How many KWH could your power company save per day if all households switched to more efficient light bulbs.?
6. Discuss the implications of mass adoption of more efficient lighting.
7. What are some other ways that using a bulb that emits less heat can save energy?

Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State

http://www.eia.doe.gov/electricity/epm/table5_6_b.html

Service Learning extensions:

MEDIA

1. Awareness campaign to educate the community on the impacts of saving energy; include dollar savings and health savings in reduced power use and reduced need for additional power plants.
2. Public information poster to outline bulb cost benefits for your area to post in local hardware/grocery outlets
3. Positive impacts on local watersheds brought about by reducing electrical consumption. Include watersheds linked to your areas electricity consumption,
4. Use local public access stations and time slots to broadcast your findings/campaign.

Class data Sheet
Light bulb Inventory
Average light bulb use for class

Student #	Total daily hours of use/bulb type					
	Type of Bulb					
	Incandescent		Fluorescent		L.E.D.	
	Total # Bulbs	Total # hours used/ day	Total # Bulbs	Total # hours used/ day	Total # Bulbs	Total # hours used/ day
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
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19						
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21						
23						
24						
25						
26						
27						
28						
29						
30						
Class Total:						
Class Average:						

Energy Efficiency Knowledge Survey Student Worksheet

1. How do you think the electricity used in your home generated? If you list more than one method of generation, assign percentage values to each method.

2. How is electricity used in this country? Rank what you believe to be the top 6 uses and list them from most electricity used to least.

3. In what way (or ways) is (are) the oceans possibly affected by the different methods of electricity generation above?

4. Complete the inventory from your home in Table 1 and put your cumulative information on the class data chart provided by your teacher. Then transfer the compiled class information to Table 2.

Table 1: Inventory of lighting from your household.

Type of light bulb	Total number of each bulb type	Total number of hours use for all bulbs of that type
Incandescent		
Fluorescent		
L.E.D.		

Table 2: Inventory of lighting from your class (Complete after class has entered their data with teacher).

Type of light bulb	Average number of bulbs/household	Average lit hours/bulb type
Incandescent		
Fluorescent		
L.E.D.		

Data Collection Student Worksheet

Amount of water _____ml
Time light was on _____min

Type of light bulb (watts)	Start Temperature (°C)	End Temperature (°C)	Change in Temperature (°C)	Calories (c)

Have students research where the electricity for their house is generated. Is it a fossil fuel, nuclear or renewable energy power station? What is the number of households served by this power station?