Visualizing the Impact of Burning Coal

By Molly Hazel and Steve Mattox-Grand Valley State University

Introduction:

The United States has enough coal to meet its energy needs for the next few hundred years. Although this fossil fuel offers the possibility of energy independence, it is also directly linked with increasing carbon dioxide and mercury emissions. This lesson guides students through a set of activities that allows them to see their personal environmental impact of consuming coal.

Notes for the teacher:

Sample calculations and examples are presented in the lesson using data from the authors' local power plant in West Olive, MI. Teachers can obtain data from their local power plants to use in their lesson. This lesson follows a guided inquiry format; teachers can follow the lesson as described our select individual activities that best match their teaching goals and students. Answers to calculations are provided at the end of the lesson. Teachers may obtain sample coal kits can from the American Coal Foundation website. We suggest having students keep a notebook or binder for notes and organizing handouts.

Grade Level:

8-10th grade

Objectives:

1. A student will be able to calculate their daily energy consumption and relate it to the amount of coal being burned to produce that energy.
2. A student will be able to visualize the volume of coal being consumed by an individual to produce electricity.
3. A student will be able to calculate mercury emissions from burning coal and relate them to the amount of time required to see a droplet of mercury in the palm of their hand.
4. A student will be able to understand the negative impacts of mercury and other pollutants from coal combustion in the environment.

MI HSCE Benchmarks met or partially met:

- E2.3A Explain how carbon exists in different forms such as limestone (rock), carbon dioxide (gas), carbonic acid (water), and animals (life) within Earth systems and how those forms can be beneficial or harmful to humans.
- E2.3D Explain how carbon moves through the Earth system (including the geosphere) and how it may benefit (e.g., improve soils for agriculture) or harm (e.g., act as a pollutant) society.
- E2.4A Describe renewable and nonrenewable sources of energy for human consumption (electricity, fuels), compare their effects on the environment, and include overall costs and benefits.
- E2.4D Describe the life cycle of a product, including the resources, production, packaging, transportation, disposal, and pollution.

Safety: There are no hazardous materials used in these exercises. Students should wash their hands after handling coal samples.

Engage – *How Much of This Natural Resource Do You Use?* (~10 minutes)

In this first activity, use a set of photos (Appendix A) to gain insights into your students' prior knowledge about coal. We suggest the following questions:

1. What do you use this resource for?
2. Do you think that one of these pictures is representative of the quantity of coal you use in one day? Which one and why?

Note: It may be necessary to mention/explain that coal has a relatively low density. In this respect, a very heavy piece will take up a lot of volume. It is not necessarily important that students select the correct representative picture. The activity is geared to give the instructor information about students' prior knowledge of coal use for electricity.

Have students compare and discuss their responses in groups of 3 to 4 students and then report their thoughts and estimates to the group.

The average American uses about 20 pounds of coal a day to produce the electricity that they use (Goodell, 2006).

Explore 1 – *What do we use coal for in Michigan and the United States?* (~15 minutes)

In this activity, students will determine the uses for coal in Michigan and estimate the percentages for each source of coal-generated electrical power in the state.

Have students compile a list of what they use coal for in Michigan and the United States. (Answers may include electricity, industry, energy resources, etc. Electricity will be our focus.) Allow about 3 minutes.

Obtain a map of Michigan from the Michigan Economic Development Corporation. **Remove percentages** and pass out one map per group or project the modified map to the class. The map shows the location the major Michigan Electric Power Plants (not all plants). The map is available online at: http://ref.michiganadvantage.org/cm/attach/ab7251e3-c65b-4867-8584-90278c437381/electr.pdf

Have students estimate the percentage of electricity generated by each source listed in the bottom corner of the map. They may wish to consider the location of the plant when making predictions. Students should explain why they made particular predictions (why does x% of the electricity come from nuclear power, etc.).

- Expected student responses: Oil/Gas and hydroelectric are the highest, followed by coal. Nuclear with the least (nuclear energy often has a negative connotation, so we suspect that students will predict that the least amount of energy comes from nuclear power.) Student responses will vary, especially if there is a power plant in the community.

After students complete the task, put an overhead up with all electrical source percentages provided by the website. Lead a class discussion exploring if their predictions were correct, the importance of coal in generating electricity, and the meaning of a non-renewable resource.

ACTIVITY CONTINUED ON NEXT PAGE →

Explore 2 – *How much coal do you (student) consume in one day, based on electricity use?*
(~40 minutes in class)

Next, students will determine how much electricity the use everyday (approximation). Students will calculate their daily electricity usage depending on appliances, computer, cell phone, iPod and other electrical devises used. Students will perform the calculations, and then use that number to determine the amount of coal consumed. They will first calculate weight consumed and then convert to volume.

To begin, have students make a list of all the electrical appliances that they use on any given day.
Then, have students compare responses with a group. Hopefully some students will have thought of indirect appliances such as the hot water heater, refrigerator, room lights, vacuum, washer, dryer (for the washer and dryer, they may not personally do their laundry. However, their clothes are being cleaned somehow, so they are indirectly consuming energy).

- Walk around the class and ask them how they clean their clothes?
- Do they take hot showers?
- Do they have an icehouse with big blocks of ice to keep their food from spoiling? Or do they have a refrigerator?

If students are struggling, have them walk through their daily routine including turning on lights, water, etc. This could help them generate their list of appliances.

Pass out the U.S. Department of Energy (DOE) document "A Consumer's Guide to Energy Efficiency and Renewable Energy: Estimating Appliance and Home Electronic Energy Use." Available online at http://www.eere.energy.gov/consumer/your_home/appliances/index.cfm/mytopic=10040.

An additional resource for describing the use of electricity is http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040.

Pass out Appendix B handout. Work as a class on the first section and then have students complete the rest individually or in small groups. The calculations may take awhile. It would be reasonable to assign some of this as homework. Then, students would have the opportunity to count light bulbs, check other wattages, etc.

Notes for calculations: If students use an electrical devise that is not on the list, the energy use can be calculated by multiplying the wattage by the number of hours used in one day and dividing it by 1000. This will give the daily kilowatt-hour (kWh) consumption for that device.

If the amps are given on an appliance, the wattage can be calculated by multiplying the amps by the voltage (usually 120 V in a standard outlet or 240 V for major appliances such as refrigerator or electric range/oven).

Heating value and density information from USGS website is available at http://pubs.usgs.gov/fs/fs095-01/fs095-01.html. Values were calculated using the COALQUAL database.

- Heating value of Powder River coal (mean value) = 8,090 Btu/lb (subbituminous). However, due to low burning efficiencies of U.S. Power Plants, only 1/3 of the potential energy from coal is turned into electricity (DOE website). Students should use the heating value of 2,697 Btu/lb for Power River coal.
- Density of subbituminous (Powder River Basin) Coal 1.01 to 1.34 g/cm^3 Median = 1.175 g/cc
- When students are finished, go over the worksheet as a class to check for understanding.

Explore 3 – *How Much Electricity does the Average American Consume?* (~15 minutes)

To gain another perspective on electricity used, this activity uses different data (national) to produce the same results as in Explore 2.

Pass out the Appendix C activity.
Questions for class discussion upon completion of activity:

- How do these numbers compare to your calculations from earlier?
- Do you think these are accurate estimations?
- Many sources publish that the average American consumes about 20 pounds of coal every day, (Goodell, 2006) and using national data, the numbers come out to about 20 pounds.

Explore 4 – *Visualizing the Volume* (~50 minutes)

It is difficult to visualize how much space the coal will take up. Students will use rulers, meter sticks, books, balloons, or other materials to build a model of their coal pile. This will help make a connection between numbers and actual (visual) amount of coal needed. Instruct students to use their calculations from Explore 1 to build a model of their pile of coal. Students may work individually or with a partner.

Once students have their model made (about 15 minutes), check around to make sure the sizes look reasonable and then put up the Appendix A pictures on the overhead again. Have students match up their model to one of the pictures on the overhead. Most students will probably be close to the picture of about 20 pounds of coal.

Next have students figure out how much space one years worth of coal would take up? Would it take up the space of the closet? Room? Building? Discuss with students how they might figure it out.

If the student is using the 20 lbs./per day in his or her calculation, the volume for 1 year is about 2.8 m^3. Therefore, it would take up about the space of a large closet.

__For discussion__: Most coal is transported by railroad. Surprisingly, the (typical) coal consumed by a person in one year would not even come close to filling up one railcar with coal. A BNSF railcar can hold about 100 tons of coal (Goodell, 2006). Even if you consumed 20 pounds of coal every day for a year, you would only use a total of 3.65 tons (which is not small by any means!).

If there are between 25 and 30 students in class, the total of everyone's coal together would fill up a whole railcar! A railcar can hold about 100 tons of coal. When calculated out, the total capacity is about 77m^3. Students could determine how big that is in relation to the size of the room if time allows.

__Optional Visualizing Activity__ (class discussion style):
Write on the board: 5,000,000; 100; 125; 1.3. Ask students to guess how these numbers are connected to coal used at the J.H. Campbell plant and to each other.

As the discussion progresses, write the explanation next to each number:

- Every year, the power plant in West Olive near Grand Haven burns 5,000,000 tons of coal (Consumer's Energy).
- One railcar can carry 100 tons of coal (Goodell, 2006).
- One train can haul 125 railcars (Goodell, 2006).
- A train with 125 railcars is about 1.3 miles long (Goodell, 2006).

ACTIVITY CONTINUED ON NEXT PAGE →

Suggested Questions for Discussion:

- How many railcars of coal come into West Olive every year? 50,000 railcars
- How many total trains, if each one hauls 125 cars? 400 trains.
- Every year about 400 trains deliver coal. If they were lined end to end, how many miles would there be? 520 miles of train.
- 520 miles of trains deliver a total of 5,000,000 tons of coal to the J.H. Campbell Electric Plant every year to supply coal for 1,000,000 people's electric needs (Consumer's Energy).
- That distance—520 miles—is the same as driving from Bowling Green, KY to Grand Rapids, MI or from Washington, DC to Detroit, MI. (Show students a map).

Have students reflect on the discussion in their notebooks.

Explore 5 – *What is Released into the Atmosphere When Coal is Burned?* (~50 minutes)

Often times, the only concern about burning fossil fuels is the carbon dioxide emissions. While these are extremely important, there are other toxins that we should be concerned about. In this activity, students will look at carbon dioxide emissions and then at mercury emissions related to coal combustion.

Introduction to the class: While coal is mostly carbon, other trace elements such as sulfur and nitrogen pose a threat to public health when they are released into the atmosphere. Depending on where the coal is mined and the type of coal, different amounts of chemicals and toxins are present. In the past major problems have resulted from lax regulations on power plant emissions. Environmental problems, such as acid rain have led to more emissions control in the United States.The main cause of acid rain is sulfur dioxide and nitrogen oxides emissions from burning fossil fuels. Stricter restrictions on sulfur and nitrogen emissions have helped to reduce the effects of acid rain. (U.S EPA Acid Rain).

After discussing acid rain, ask students about:

- What other gas is talked about frequently in conjunction with climate change trends? CO_2 emissions.
- Show students the graph that depicts carbon dioxide emissions from the burning of fossil fuels in the U.S. (Figure 1).
- Refer to the graph: Is

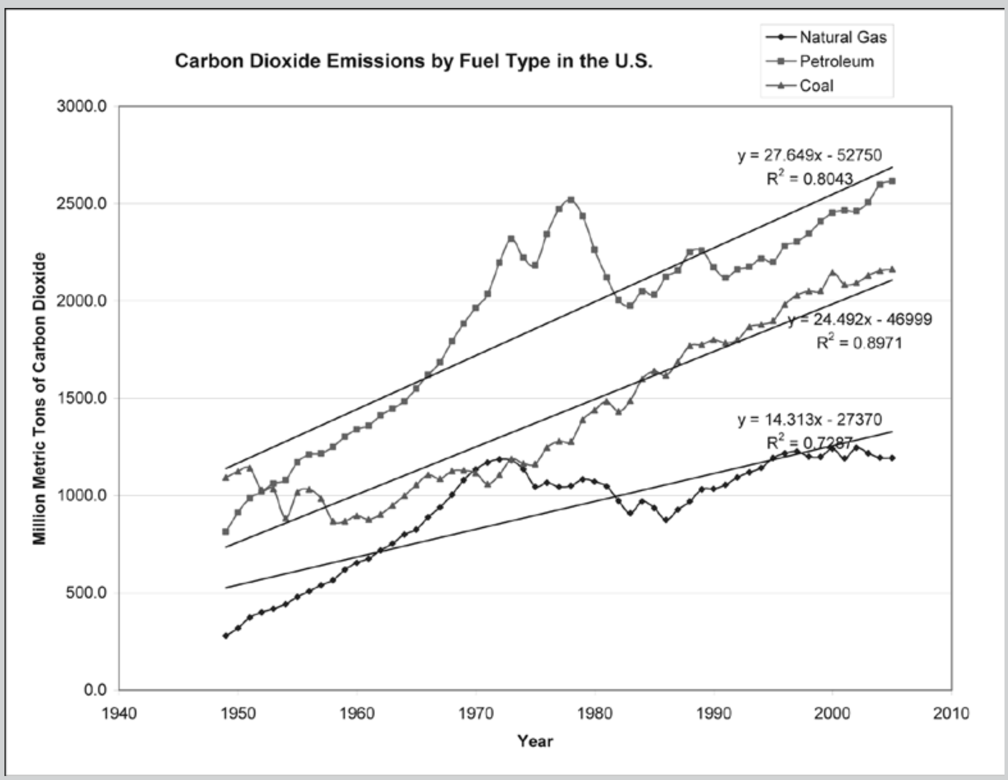

Figure 1: Carbon Dioxide Emissions by Fuel Type in the U.S.
Graph made with data from Energy Information Administration; "(CO_2) History from 1949." Official Energy Statistics from the U.S. Government. http://www.eia.doe.gov/environment.html.

the rate of coal-produced carbon dioxide emissions increasing, decreasing, or staying constant? How do the rates of increase compare to the emissions from the other two sources?

- Students should be able to respond that the rate of coal related emissions is greater than natural gas, but less than petroleum.

Pass out the Appendix D student activity and two handouts with mercury safety, available at

- http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf
- http://www.atsdr.cdc.gov/toxfaq.html

Introduce the material to the students: The first information is from the Consumers Energy website. They offer good ways to increase energy efficiency. They suggest recycling compact fluorescent light bulbs (CFL) because they contain a small amount of mercury, which could be harmful. The second information sheet provides information about mercury dangers, hazards, and safety precautions, including the steps to clean up a spill. Have students take a few minutes to read over this information. Briefly discuss hazards associated with mercury and mercury spills.

In this activity students will calculate how much coal is burnt to produce a droplet of mercury? How long would it take to get the drop? Appendix D directs students through the calculations.

Students should be able to work independently on the activity. After the worksheet is complete, have students reflect in their notebooks. Does it seem strange that such careful precautions must be taken for cleaning up mercury from a broken CFL when so much more mercury is released into the atmosphere when coal is burned?
Ask students if there should be more restrictions on mercury emission? Have them refer back to the handouts. (Some students may struggle putting everything together. Try to help students make connections as needed.)

Authors' reflection: We think that this is really strange because the precautions taken to cleanup a 5 mg spill and quite extreme. In reality, over 200,000 g of mercury are released into the atmosphere every year our own local power plant in West Olive.

Note*: It may be beneficial to review major concepts before continuing with the lesson.*

Elaborate 1 – *How Close are the Mercury Estimations?* (~15 minutes)

An interactive map available online provides information about mercury emissions in the United States. The J.H. Campbell Plant made the map as one of the top 100 emitters of mercury! Students can go online to see if their estimations were close. Students can also see how the power plant compares to other power plants and states. The source of information was EPA Toxics Release Inventory. Individuals at the newspaper created the graphic.

Pass out Appendix E or put questions on an overhead to complete as a class..

Have students go to: http://www.usatoday.com/news/mercury-emitter-map.htm or project the interactive map/screen on the overhead.

ACTIVITY CONTINUED ON NEXT PAGE →

Elaborate 2 – ***Other Costs to Using Coal*** (~20 minutes in class)

In prior activities, the class learned about the pollutants associated with the burning of coal, such as greenhouse gases and mercury. What are some other hidden costs that people must pay with the use of coal? They are usually not reflected in the electricity bill or even at the power plant. In this activity, students will investigate the health effects of coal combustion.

Have students read the articles below, or compile their own similar search results.

- *Coal Mine Deaths Spike Upward. By Thomas Frank, USA Today* http://www.usatoday.com/news/nation/2007-01-01-mine_x.htm
- *Study: Coal counties have higher disease rates. By Ken Ward Jr., Charleston Gazette, WV* http://www.wvgazette.com/latest/200803250025
- *Coal Power: Providing Energy, Asthma, Cardiovascular Disease, and Free Abortions. Ethan Helm & Benjamin Larsen, Lake Forest College* http://www.lakeforest.edu/images/userImages/eukaryon/Page_6561/p65CoalPower_Helm.pdf

Also, visit the following website

- *Coal Miner's Stories About Black Lung*: http://www.courier-journal.com/cjextra/blacklung/index.html

In addition to air pollution, what other consequences are there to burning coal? Are these costs reflected on the electricity bill? Students will write a one page, single-spaced essay about their findings. How would they propose to combat these problems? Sources should be cited.

Acknowledgements

We would like to thank Dennis McKee of Consumers Energy, J.H. Campbell plant of West Olive, MI.

About the Authors

Molly Hazel is a Biology & Chemistry Teacher at Louisville Male High School, Louisville, KY 40213-2063. Molly can be reached at mollyhazel@gmail.com
Steve Mattox is an Associate Professor of Geology at Grand Valley State University, Allendale, MI 49401-9403. Steve can be reached at mattoxs@gvsu.edu

Resources:

Consumer's Energy Website. Energy Efficiency. Accessed 7-2-09. Available online at http://www.consumersenergy.com/print/print.asp?SSID=119.

Consumer's Energy Website. J.H. Campbell Power Plant. Accessed 7-2-09. Available online at http://www.consumersenergy.com/welcome.htm.

Energy Star.gov. Compact Fluorescent Light Bulbs. Accessed 7-2-09. Available online at http://www.energystar.gov/index.cfm?c=cfls.pr_cfls.

Environment Canada. Mercury and the Environment: Mercury-Containing Sources. Article accessed on 7-2-09via the internet http://www.ec.gc.ca/MERCURY/SM/EN/sm-mcp.cfm?SELECT=SM.

EPA Report on Coal Combustion. Article was accessed on 7-2-09via the internet http://epa.gov/airmarkt/resource/docs/multipreport2005.pdf Unit conversion information, p. ix; p.1-4; p. 2-8.

Goodell, Jeff. (2006). Big Coal: The Dirty Secret Behind America's Energy Future. New York: Houghton Mifflin Company.

Michigan High School Content Expectations. Michigan Department of Education. Earth Science October 2006.

Monazam, E.R. (1994). Characterization of mass and density distributions of sized coal fractions. Energy Citations Database. Accessed 7-2-09. Available online at http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6832551.

U.S. Department of Energy "Mercury Emission Control R&D." Article was accessed on 7-2-09via the internet http://fossil.energy.gov/programs/powersystems/pollutioncontrols/overview_mercurycontrols.html.

U.S. EPA. Acid Rain Information Sheet. Accessed 7-2-09. Available online at http://www.epa.gov/acidrain/what/index.html.

U.S. EPA Report on Coal Combustion. Article was accessed on 7-2-09via the internet http://epa.gov/airmarkt/resource/docs/multipreport2005.pdf.

USGS Fact Sheet FS-095-01 September 2001. Mercury in U.S. Coal—Abundance, Distribution, and Modes of Occurrence. Accessed on 7-2-09via the internet http://pubs.usgs.gov/fs/fs095-01/fs095-01.html.

USGS Fact Sheet FS 171-97 October 2007. Coal-Quality Information—Key to the Efficient and Environmentally Sound Use of Coal.

Appendix A: How much of this natural resource do you consume in one day?

~1 lb.

~3 lbs.

~ 10 lbs.

~ 20 lbs.

Appendix B: How Much Coal Do You Consume in One Day?

A. Work with the Class:

1. How many watts (W) are in a kilowatt (kW)?
2. Electricity use is often given in watts. The number of watts printed on a label represents the number of watts used by that electrical device in one hour.
3. Practice Problem: If you use a 100 W light bulb for 4 hours, how many kilowatt-hours did you use?
   a. How many watts are used in one hour?
   b. How many kWh is this?
   c. If you have the light bulb on for 4 hours, how many total kWh are used?

B. Estimate Your Daily Consumption of Electricity:

For the next section, you may work individually. Compare your calculations in your group.
Using the list you formulated earlier, calculate the total kWh used for a day.

Appliance	Watts (1 hour)	Kilowatts	Total Hours Used	Total kWh
Total				

C. Using your estimated electricity consumption:

Calculate the weight of coal burned to produce _________kWh of electricity. (write in your total). Depending on where the coal came from, it will have different energy values. This means that it will produce different amounts of heat when it is burned. The coal and electric industry measure this value in Btu/lb (British thermal units per pound of coal). We will assume that the coal is from the Powder River basin in Wyoming, which has an average of 8,090 Btu/lb. Due to lower energy efficiencies at power plants, only 1/3 of the energy available in the coal is turned into electricity. For every pound of western coal, about 2,697 Btu's of energy is produced.

Conversion factors:
1 kWh = 3415 Btu   1 lb coal = 2,697 Btu
Use the conversion factors to calculate the weight of coal burned in the space below.

What is the volume of coal burned to produce ________kWh of electricity?
Coal has a very low density compared to most rocks. For coal from the Powder River basin, the median density is 1.175 grams per cubic centimeter (1.175 g/cc).

From the step above, you determine the weight of coal in pounds: ________pounds.
To change pounds to grams, multiply your number by 453.6, because there are 453.6 grams in one pound. Use the space below to show your work.

Now, to calculate the volume in cubic centimeters, divide the total grams by the density.
The grams will cancel and leave cubic centimeters as the units. Use the space below.

Sum it up!
In one day, I use ________kWh of electricity. It takes about _______pounds, or ______cubic centimeters of coal to produce that amount of electricity to meet my electrical needs.

Appendix C: How Much Coal Does the Average American Consume in One Day?

Another way to calculate daily consumption is to use information about the coal mined per year and the number of people in the U.S. population. We can get reliable information from the U.S.G.S. Mineral Commodity Summaries, the Energy Information Administration, and the U.S. Census Bureau to calculate how much coal the average American consumes. Two different methods are shown. The amount of coal calculated will vary slightly depending on the source of information. However, this gives a general picture of daily coal consumption.

Version 1:

- For the most up-to-date population estimate, visit the U.S. Census website. http://www.census.gov/.
- For easier calculations, round off the estimate to the nearest thousand.
  As of April 12, 2008, the U.S. population was about *303,837,000 people*.
- For information about the coal mined in the United States, visit the EIA website http://www.eia.doe.gov/cneaf/coal/page/acr/acr_sum.html. Scroll down to Table ES1 and the total consumption of coal for electric power.
  As of April 12, 2008, the 2006 data was available reporting 1026.6 million short tons of coal. A short ton is equal to 2000 pounds. Therefore, 1,026,600,000 short tons of coal are equal to *2,053,200,000,000 pounds of coal per year* for electric power generation.

1. Using the numbers above, or more recent numbers from the internet, calculate the average amount of coal consumed by each person per year.

2. How much coal is that per day? Remember there are 365 days in one year.

Version 2:

- For information about life expectancy of Americans, visit the National Center for Health Statistics website http://www.cdc.gov/nchs/fastats/lifexpec.htm.
  For easier calculations, round off to the nearest year.
  As of April 12, 2008, the average life expectancy was *78 years*.
- For information about how much coal is consumed in one lifetime, visit the Mineral Information Institute website http://www.mii.org/.
  As of April 12, 2008, the average coal consumed per lifetime is *578,956 pounds*.

1. Calculate the number of pounds of coal consumed per year.

2. How much coal per day (365 days per year)?

3. What is the average amount of coal consumed per person everyday (using these two sources)?

4. Use your daily consumption that you calculated and average it with the values obtained above.

ACTIVITY CONTINUED ON NEXT PAGE →

Appendix D: Burning Coal for Electricity—Putting Mercury in the Atmosphere

Coal is the most abundant fossil fuel in the United States, and coal-fired power plants generate over half of our electricity. Although many people would like to think that modern coal plants are cleaner burning than their dirty, toxins-emitting ancestors, coal plants are one of the largest sources of anthropogenic (human-generated) mercury emissions in the United States today. There are many different factors to consider with mercury emissions, including the type of coal burned and the pollution controls at the power plant (U.S.EPA). The power plants have an especially strong influence on the amount of mercury released as they make the decision to install pollution controls that can remove zero to 90 percent of the mercury in coal (U.S. Department of Energy).

According to the U.S EPA, an average of 36 percent of the mercury in coal is removed through special washing processes and filters. The remaining 64 percent is released into the atmosphere. To simplify calculations, we are going to say that about 50 percent of the mercury is removed in the combustion of coal.

Part 1:

To meet the "electric needs" of 1 million West Michiganders, the J.H. Campbell Power Plant in West Olive burns more than 5 million tons of coal every year (McKee). To meet the demand of consumers, how much mercury is released into the atmosphere?

a. The majority of coal burned at the power plant is Wyoming coal, which contains an average of 0.08 grams of mercury for every 1000 kilograms of coal (USGS). To account for the smaller percentage of eastern coal, we will estimate **0.09 grams of mercury for every 1000 kg of coal***.
   If 50% of the mercury is removed before combustion, how much mercury will be released into the atmosphere for every 1000 kg?
b. If 5 million tons of coal are burned in 1 year, how many kilograms are burned? (1 ton = 2000 lbs.; 1 kg = 2.2 lbs.)
c. How much mercury is released when 5 million tons of coal are combusted at a power plant? (Hint: use information from parts a & b. How much mercury is released for every 1000 kg of coal burned?).
d. How big is this? To help visualize this amount of mercury, calculate the volume using the density. (Density = 0.01357 kg/cm^3).

Part 2:

If you could (safely) collect all the mercury emitted from your coal consumption by electricity use, how long would it take to have a "visible" droplet?

Here we are going to define a visible droplet by the amount of mercury contained in old thermometers, about **2 g**. Thermometers contained between 0.5-3 g Hg (Environment Canada).

How long would it take to emit 2 grams of mercury if you consume about 20 pounds of coal each day?

a. How many kilograms of coal are burned everyday?
b. How many kilograms of coal are burned to get the 2 grams of mercury? (Recall the amount of mercury that is emitted for every 1000 kg that you calculated in Part 1a).
c. How much time would it take to accumulate 2 grams of mercury? Hint: divide the number of kg of coal burned to get 2 grams mercury (part b) by the number of kg burned everyday (part a).
d. In a lifetime, how much mercury is released in the atmosphere to produce the electricity that you use?
   i. According to the Mineral Information Institute, the average American consumes about 578,956 pounds of coal in one lifetime. This translates into about 263,162 kg of coal. Calculate the number of grams of mercury released when 263,162 kg of coal is burned.
   ii. How many broken thermometers does this equate to?
   iii. Finally, about how much space would this quantity of mercury take up? Hint: use the density of mercury.

*Eastern coal has a higher concentration of mercury than does Western coal. Eastern coal can have concentrations as high 0.24 ppm in the Northern Appalachian (USGS).

Appendix E: How Accurate are the Mercury Emission Estimations?

Visit the Interactive Mercury Emitters Map Online at http://www.usatoday.com/news/mercury-emitter-map.htm

1. What does this map show?

2. What emissions category does the J.H. Campbell power plant fit into?

3. For the most recent data presented, how much mercury was emitted for a year of burning coal?

4. How many grams of mercury were estimated from the Explore 5 activity? If you cannot remember, or do not have your worksheet, ask your neighbor or your teacher.

5. How many pounds mercury is this? Recall there are about 453.6 grams in 1 pound.

6. Comparing the two numbers, what does this suggest about the amount of mercury actually removed at J.H.Campbell? Is it more or less than estimated?

7. Estimate a percent error in our calculation.
   $$\% \text{ error} = \frac{\text{experimental} - \text{actual}}{\text{actual}} * 100$$

8. Discuss with your partner if you think this is a large error. Are the calculations for mercury emission a good approximation?

ACTIVITY CONTINUED ON NEXT PAGE →

Appendix F: Answer Keys

For Appendix B:

1. 1000 Watts in 1 kW
3. a. 100 W b. 0.100 kWh c. 0.400 kWh

Part C (using example calculations below): 25.025 kWh; 31.7 lb coal; 14,379 g coal; 12,238 cc (cm^3).

Example of Daily Electricity Consumption (Estimate of Student Consumption)

Appliance	Watts	Hours	kWh
Alarm clock	10	24	0.24
Humidifier	785	8	6.28
Laptop computer	50	5	0.25
Desk lamp	60	3	0.18
Blow dryer	1500	0.1	0.25
Bathroom light	2 x 60	1	0.12
Electric water heater	4500	0.3	1.5
Refrigerator *	2 x 725	24	11.6
Living room light	3 x 60	4	0.64
Microwave	900	0.2	0.18
Toaster oven	1225	0.2	0.245
Coffee pot	950	3	2.85
Television	80	1	0.08
Kitchen light	3 x 60	4	0.48
DVD player	20	1	0.02
Vacuum	1000	0.1	0.1

*This has an exception, divide the total hours by 3

Total **25.015** kWh

1 kWh = 3415 Btu Coal fromPowder River:

25.015 kWh	3415 Btu	1 lb	31.7 lb	* 453.6 g/lb	14379.1 Grams
	1 kWh	2697 Btu			

Powder River coal is *Subituminous* Coal (Mid-grade) with a density of about 1.175 g/cc.

Powder River:
grams x density = 12238 cc

By taking the cube root of the volume calcuations, students could use a ruler to visualize the size of the piece of coal. Remind students that this much is used *every*day. This will lead into later discussions about the amount of coal used in a person's lifetime or the amount of coal needed to supply the electricity for a particular city/state, etc.
This estimation for coal usage would require a piece approximately 23cm x 23cm x 23cm.

For Appendix C:

1. 6757.6 lb/person/yr
2. 18.5 lbs. of coal per day
3. 7422.5 lb/yr
4. 20.3 lbs. coal per day
5. 19.4 lb. of coal everyday

For Appendix D:

Part 1

- a. 0.045 g/ 1000 kg coal
- b. 4,545,454,545 kg OR ~ 4.5 billion kg coal
- c. 204,545 g Hg
- d. 204.5 kg = 15,070 cm3

Part 2

- a. 12,453,300 kg/day
- b. 44,444 kg
- c. ~5 minutes
  - i. 11.8 g
  - ii. 5-6 thermometers
  - iii. ~1 cm3 (have blocks of this size available to make a visible comparison)

For Appendix E:

1. The map shows the top 100 emitters of mercury in the United States. J.H. Campbell is one of them.
2. The 0-425 pounds of mercury per year category
3. 402 pounds
4. 204,545 g
5. About 450 pounds of mercury
6. The "actual" was less than what the class estimated, so J.H. Campbell probably removes more mercury than we estimated.
7. About 12 % error
8. Statistically speaking, 12% error is pretty large. But, for our purposes, this was a relatively good estimate. Note: The error may be smaller that 12% because the map does not explicitly say which form of mercury is being measured. (There are 3 forms of mercury.)