Assessment Conundrum:
CFLs, Energy Efficiency, & Mercury

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Length of Unit: Six Days
Grade Level: High School
Content Domains: Technology Education, Science, and Ecology

Goal: Students analyze the risks and benefits of replacing incandescent with compact fluorescent lamps (CFL) and predict how this decision might impact the environment, individual, and society. In so doing, students refine their decision-making and analytical skills while deepening their understandings about biotic and abiotic systems.

Learning Objectives: Upon completion of this unit, students will be able to:

1. Describe an appropriate procedure for disposing of broken or spent fluorescent lamps.
2. Accurately measure electrical power, light intensity, and temperature.
3. Compare incandescents and CFLS in terms of initial cost, power consumption, life of lamp, heat generation, and their impact on animals and human health.
4. Describe several impacts of coal-fired electricity generation in terms of environment and human health, e.g., habitat destruction, loss of biodiversity, bioaccumulation of mercury in fish, and the cognitive development of humans.
5. Characterize technology assessment in terms of its purpose, process, and methods.

Standards: Standards for Technological Literacy (ITEA, 2000)

4. Students will develop an understanding of the cultural, social, economic, and political effects of technology.
5. Students will develop an understanding of the effects of technology on the environment.
13. Students will develop abilities to assess the impact of products and systems.

Materials & Equipment List (Per Team of 3-4 Students)

#	Item	Description	Qty - Size
3	Compact Fluorescent Light Bulbs	Medium Base 120 Volt	1 - 13 W 1- 20 W 1- 32 W
3	Incandescent Light Bulbs	Medium Base 120 Volt	1 - 25 W 1- 60 W 1 - 100 W
1	Hooded Lamp, Clip Light or Balance Point Cube (See Appendix A)	Light Socket Medium Base	100 W - 120 Volt
1	Thermometer, with probe	Range: 0° -100 °C 32° -212 °F	
1	Watt Meter, e.g., Kill-A-Watt EZ	Functions: V, A, W, kWh	
1	Light Meter, e.g., EXTECH Foot-Candle	Functions: Foot-candle or lux Range: 0-200 fc	

Safety Concerns

Safe handling practices should be emphasized before students handle mercury-containing lamps and before students install lamps into electrical sockets or take power readings. When spent, all mercury-containing lamps should be treated as hazardous waste; therefore, they should be taken to a hazardous waste collection site or lamp recycler.

If a CFL or any mercury-containing lamp is broken, the Environmental Protection Agency (2008) recommends the following course of action:

1. **Open a window and leave the room for 15 minutes or more**.
2. **Carefully scoop up the fragments and powder with stiff paper or cardboard and place them in a sealed plastic bag**.
    - Use disposable rubber gloves, if available (i.e., do not use bare hands). Wipe the area clean with damp paper towels or disposable wet wipes and place them in the plastic bag.
    - Do not use a vacuum or broom to clean up the broken bulb on hard surfaces.
3. **Place all cleanup materials in a second sealed plastic bag**.
    - Place the first bag in a second sealed plastic bag and put it in the outdoor trash container or in another outdoor protected area for the next normal trash disposal. Note: Some states prohibit such trash disposal and require that broken and unbroken lamps be taken to a local recycling center.
    - Wash your hands after disposing of the bag.
4. **If a fluorescent bulb breaks on a rug or carpet**:
    - First, remove all materials you can without using a vacuum cleaner, following the steps above. Sticky tape (such as duct tape) can be used to pick up small pieces and powder.
    - If vacuuming is needed after all visible materials are removed, vacuum the area where the bulb was broken, remove the vacuum bag (or empty and wipe the canister) and put the bag or vacuum debris in two sealed plastic bags in the outdoor trash or protected outdoor location for normal disposal.

Teaching and Learning Procedure

Day 1. Stimulate students' intellectual curiosity about CFLs.

A. View the streaming video *New Light Bulbs in Plain English* (LeFever & LeFever, 2007).
B. Ask students "What were the issues or problems identified by LeFever? What action did LeFever advocate?
C. Challenge students to conduct a technology assessment which addresses the following questions:

    What are the risks and benefits of replacing incandescent with compact fluorescent lamps (CFL)? How might this impact the, environment, the individual and society?

D. Encourage student discussion about these questions.
E. Divide the class into teams of 3 to 4 students.
F. Identify, describe levels, and give examples of impacts.
G. Challenge students to develop a list of potential Level 1, 2, 3, and 4 impacts.
H. Explain the goals and outcomes of technology assessment.
I. Present a process for technology assessment, e.g., Hutchinson & Karsnitz's (1994) strategy for resolving a technological dilemma.

1. Identify the Issue or Problem
2. Identify the Impacts
3. Identify the Options
4. Develop Arguments for the Options
5. Evaluate the Options

J. Encourage teams to conduct independent literature review to identify potential "impacts" of this decision.

Day 2. Analyze the energy efficiency of lamps.

A. Describe how a CFL and incandescent lamp works.
B. Review energy efficiency as it applies to lighting technology. Specifically, define electrical power and illuminance (light intensity) and review units (Watt, foot-candle, and lumen) and possibly the following conversion factor.

$$efficiency = \frac{output}{input} = \frac{\text{illuminance}}{\text{electrical power}} = \frac{lumen/m^2}{Watt}$$

$$\text{To convert units (foot-candle/ft}^2\text{ to lumen/m}^2\text{)}$$

$$\frac{\text{foot-candle/ft}^2 \times 10.764}{\text{electrical power}} = \frac{lumen/m^2}{Watt}$$

C. Challenge students to compare the energy efficiency of incandescent and compact fluorescent lamps.
D. Demonstrate how to use a light meter and power meter with a testing apparatus, e.g., hooded camp, clip light, or cube.
E. Emphasize electrical safety and safe handling of light bulbs.
F. Distribute or direct teams to develop a data record sheet similar to Appendix B.
G. Direct teams to calculate efficiency and create a line graph using a spreadsheet to compare these differences (see Appendix C).
H. Direct students to compose and record conclusions about the temperature and efficiency differences between the types of lamps.
I. Homework: Direct students to (1) count and record the number of lamps they have in their home/apartment, and (2) identify the cost of electricity from their most recent electrical bill.

Day 3. Analyze the life cycle of lamps and coal-fired electricity generation.

A. Define and describe life cycle analysis in terms of economics, specially the initial cost, operating costs, longevity of the lamp, and payback period.
B. With teams of students working at a computer with Microsoft Excel, direct teams to complete ENERGY STAR's Life Cycle Cost Estimate (2008).
C. Require teams to print out their calculations and compose a narrative which reports their conclusions about the life cycle costs of converting from incandescent to CFLs.
D. Define and describe life cycle analysis in terms of all the processes required to acquire/extract, refine, generate, use, and dispose of energy.
E. Ask: If electricity is the form of energy which powers CFLs, what is the life cycle of electricity?
F. Lead a class discussion assuring that the following questions are raised:

    1. What energy source is employed in your region to generate electricity?
    2. What are the major tools and processes employed in each phase of the life cycle?
    3. Who performs each process?
    4. How does the process impact the user?
    5. How does the process impact the air, water, plants, animals, and soil?
    6. How does the process impact society, e.g., employment, economy, or the legal system?

G. Assign teams to examine different facets of the life cycle of coal as it applies to electricity generation, e.g., strip mining or mountain top removal and combustion emissions (COx, SOx, NOx, Hg, and heat). Challenge teams to conduct literature search to discover evidence of how these technological actions impact the environment (air, water, soil, animals, and plants), human health, and society. For example, one team might seek evidence of the effect of SOx on forests and lakes and another might examine the loss of biodiversity associated with destroying a forest ecosystem.
H. As teams report new pieces of information, direct them to post the item (cite source) on a public display board which illustrates a life cycle of coal-fired electricity generation.

Day 4. Identify impacts of coal-fired electricity generation.

A. Begin class by discussing the life cycle of a CFL in terms of the disposal of spent CFLs.
B. Ask: How does your family dispose of lamps, especially CFLs? What disposal options exist in your community? What is the impact of disposing of CFLs in residential trash?
C. Show students an example of a Force Field Analysis (see Appendix D). Explain that it can be used as an analytic tool because if identifies the forces for and against change.
D. Inform teams that they should synthesize their research in three ways: a written summary, a Force Field Analysis, and a reference list. Remind students that their synthesis must directly respond to the following questions:
    1. What are the risks and benefits of replacing incandescent with compact fluorescent lamps (CFL)?
    2. How might this impact the, environment, the individual and society?
E. Teams continue their research during class.

Day 5. Identify impacts of coal-fired electricity generation.

A. Ask: What chemical does a CFL and coal emissions have in common?
B. Lead a class discussion about mercury which highlights:
   1. Flow model of mercury applied to fluorescent lamps (Cain et al., 2007).
   2. Mercury release potential of a CFL compared to the emissions from coal combustion which occur to power the lamp (Table 1).
   3. Mercury deposition, bioaccumulation, and human exposure through the consumption of fish (U.S. EPA, 2007).
   4. Proper disposal as a hazardous waste.
   5. Safety issues related to mercury, including clean-up of a broken lamp.
C. Direct students to complete their research and synthesize their results into a final report which includes: a written summary, a Force Field Analysis, and a reference list

Table 1. Comparison of CFLs & incandescent lamps by Mercury Release Potential.

	Lamp	Lifetime Energy[1]	Total Mercury
CFL	5.0 mg	3.3 mg	8.3 mg Hg
Incandescent	0.0 mg	13.6 mg	13.6 mg Hg

Day 6. Debate the Options and Impacts

A. Collect the team reports.
B. Divide the class into two halves with each half facing each other. Designate one-half of the class as those in favor of replacing ALL incandescent lamps in their community with CFLs and then one-half who are opposed to this idea.
C. Conduct a debate between the two halves. Begin by allowing one person from each side to make an opening remark. Then, provide opportunities for rebuttals from each side. As remarks decrease, ask leading questions to review issues related to energy efficiency, emissions, mercury deposition, COx and global warming, and CFL disposition.

Assessment

A. Evaluate the team's reports on coherence, validity, appropriate scope, reliability of the references, and application of standard rules of English composition.
B. Participation scores may also be generated based upon the frequency and quality of contributions to the class debate.
C. Alternatively, a quiz could be given to assesses individual's understanding of:
   1. Technology assessment, purpose and process
   2. Energy efficiency, heat generation, and lifetime differences between of CFLs and incandescent lamps.
   3. Impacts of coal mining and emission of COx, NOx, SOx, and Hg on the environment and human health.

Resources:

Cain, A., Disch, S., Twarski, C., Reindl, J.& Case, C.R. (2007). Substance flow analysis of mercury intentionally used in products in the United States. *Journal of Industrial Ecology, 11*(3). Retrieved December 7, 2007, from http://www.mitpressjournals.org/doi/pdf/10.1162/jiec.2007.1214

Energy Star. (2008). Life cycle cost estimate for ENERGY STAR qualified compact fluorescent lamps: Savings Calculator [Microsoft Excel file]. Retrieved February 19, 2008, from www.energystar.gov

Hutchinson, J. & Karsnitz, J.R.(1994). *Design and problem solving*. Albany, NY: Delmar Publishers, Inc.

LeFever, L. & LeFever, S. (2007). New light bulbs in plain English [Media]. Retrieved January 30, 2008, from http://www.commoncraft.com/cfl

U.S. Environmental Protection Agency. (2008). Spills, disposal and site cleanup. Retrieved February 19, 2008, from http://www.epa.gov/mercury/spills/index.htm#flourescent

U.S. Environmental Protection Agency. (n.d.). Frequently asked questions: Information on compact fluorescent light bulbs (CFLs) and mercury. Retrieved http://www.energystar.gov/ia/partners/promotions/

U.S. Environmental Protection Agency. (2007). How mercury enters the environment. [Image]. Retrieved February 19, 2008, from http://www.epa.gov/mercury/exposure.htm#1

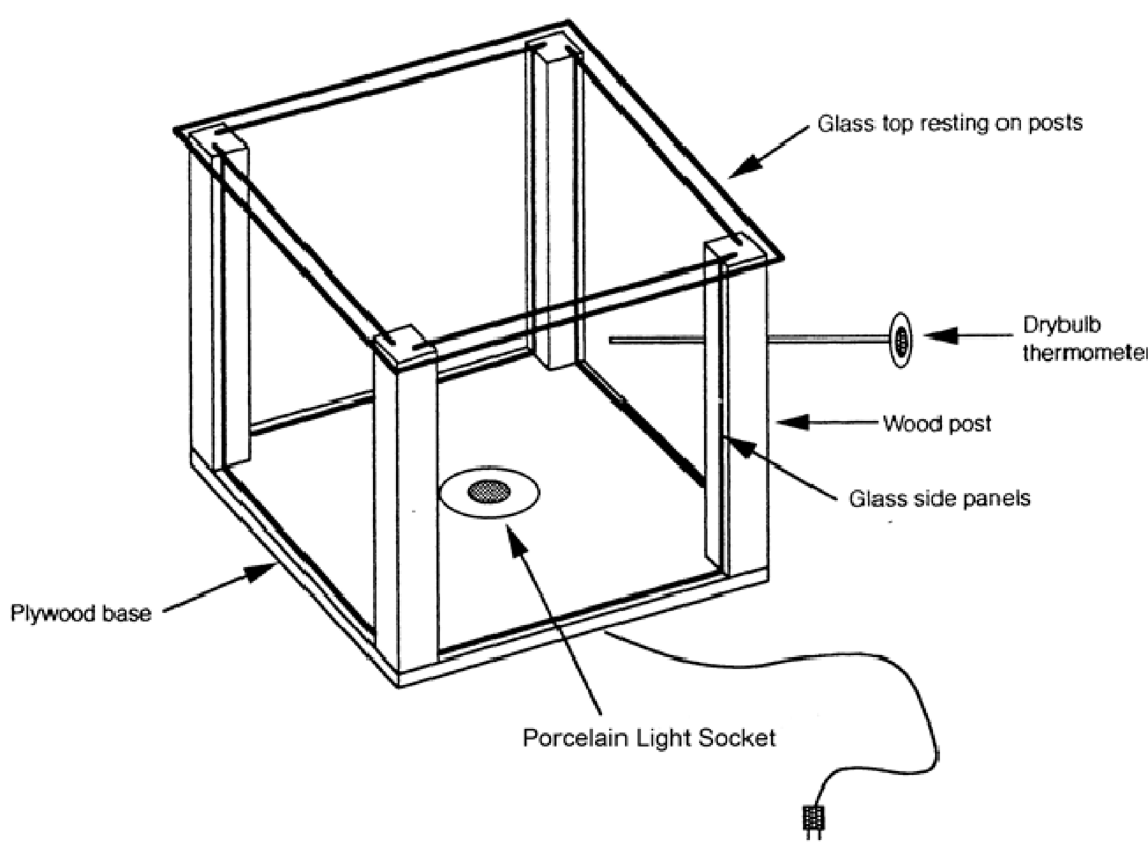
Appendix A

Testing Apparatus

Materials

4 – Corner posts (wood)	1½” x 1½” x 10”
1 – Base (plywood)	½” x 12” x 12”
1 – Porcelain Light socket	
4 – Sides (single-pane glass)	9 3/8” x 10”
1 – Top (single-pane glass)	12” x 12”
1 – Wire lamp cord	8’ long

For thermal heat experiments, leave ¼” space at top and bottom of glass sides.



Source: Wescott, J. & Leduc, A. (1992). Balance point cube [Image]. Design brief: Balance point exercise. Muncie, IN: Center for Energy Research/Education/Service, Ball State University

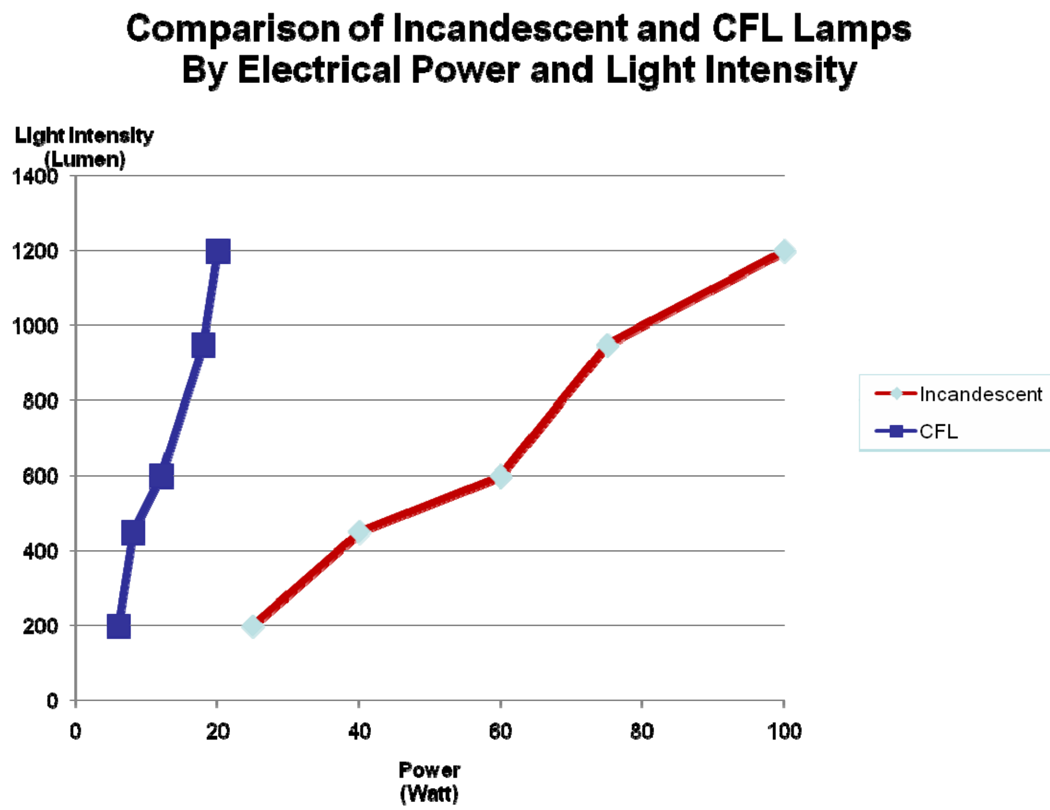
Appendix B

Record sheet for temperature, power, and light measurements.

	Incandescent Lamps					Compact Fluorescents				
Sample	**Temp.** (0/3 Min) °F	**Temp.** Diff. °F	**Power** W	**Light** fc	**Eff.** %	**Temp.** (0/3 Min) °F	**Temp** Diff. °F	**Power** W	**Light** fc	**Eff.** %
1	/					/				
2	/					/				
3	/					/				

Appendix C

Example of a graph comparing the electrical power and light intensity of lamps.



Appendix D

Force Field Analysis