Lesson Plan: Efficiency

Concepts

1. The efficiency of a system is defined as the ratio of the useful output energy (or power) to the input energy (or power). These can be measured and calculated.
2. The second law of thermodynamics can describe the energy that cannot be captured and used by humans.
3. The efficiency of a system will decrease as the number of energy conversions increases.
4. A goal of technology is to increase efficiency both directly and indirectly.

Key Questions

1. What is the value in finding a use for energy by-products and where might you find uses for them?
2. If each energy conversion decreases the efficiency, why do we convert the energy several times before we use it?
3. What are the main causes of inefficiency?
4. How can we improve a system's efficiency?

Student Learning Objectives
The students will be able to explain where energy is "lost" in conversions and why.
The students will be able to compute the efficiency of an energy conversion given input and output.
The students will be able to identify system by-products and explain how they can be used effectively to increase overall system efficiency
The students will be able to design a simple energy conversion system and test its efficiency.
Students will be able to use data they have collected to calculate the efficiency of a system.

Educational Standards

ITEA Tech: 3, 10, 16
NSES Science (5-8): A1.3, A1.4, A1.5, A1.8, A2.3, B3.1, B3.2, E2.4, E2.6
NCTM Math (6-8): A1.1, A1.4, A3.1, A3.4, B1.2, B3.1, D1.1, D2.1, D2.2, D2.5, F2, I3

Anticipatory Set

- This Lesson will give the students a background in energy efficiency.
- In class they will measure energy outputs and inputs to determine the efficiency of conversions and simple systems. They will learn about by products of energy conversions and how to improve upon efficiency.
- The efficiency of a process can sometimes be improved by recovering energy that is lost through inefficient energy conversions. For example, a typical cogeneration facility burns fuel to heat steam which turns electricity-generating turbines. The steam, partially cooled in the first step, is then used to heat homes and businesses. Cogeneration effectively combines two processes of electric and thermal production. Electric generation is roughly 30-40% efficient, adding thermal production in a cogeneration facility can result in overall efficiencies from 80-90%.

Key Terms

Entropy	Entropy is a thermodynamic measure of how dispersed and unusable energy becomes over time as it is converted between forms.
Generator	A machine to convert mechanical energy into electricity
Motor	A machine that converts electricity into mechanical energy, generally for a rotational device
Second Law of Thermodynamics	The Second Law of Thermodynamics, which is also known as the Law of Increased Entropy, helps to explain energy (or mass) “losses.” It explains why the ***quality*** of energy deteriorates gradually over time as it gets dispersed in unusable forms. The usable energy is irretrievably lost from productive activities.
Thermodynamics	is the study of energy – derived from the Greek roots “heat” and “power”

Teaching Plan

Day 1 (or used as brief intro to either of the efficiency experiments)

- Review combustion demo done in earlier conversions lesson
    - Does all of heat go into heating the water and/or spinning the turbine? Discuss where energy is “lost” (at least lost from our ability to do work). Where does this energy go?
    - Reintroduce the laws of thermodynamics:
        - Law of conservation of energy: energy can neither be created nor destroyed (by ordinary means).
    - So how do we “lose” energy? We don’t – we just don’t recover all of it in a usable form following energy conversion processes. Sometimes we want to capture the work (i.e., moving a car), but also generate heat in the process that is not captured and used (in this case – the

engine does not capture and use all of the heat energy released in the internal combustion engine)

- Introduce Efficiency
    - o Discuss fuel efficiency in automobiles – what does that mean? (more efficient cars use less gas to travel same miles/speed) Why do we care? (may want to even have pictures of different cars, such as hybrid cars, or different systems that are more/less efficient)
    - o What does it mean when you are more efficient? You get the job done using less energy!
    - o Efficiency is a measure of how well our system works. That is, how much of the energy that is consumed is actually converted into a form that is useful to us.
    - o Efficiency = 100% * useful energy output / energy input
    - o *Stress terms input and output!!*
    - o Why is it important to consider the efficiency of our energy systems? (open question)
        - ▪ Helps us save natural resources
        - ▪ Less effort, energy used if we have a more efficient system.
- Review efficiency calculation:
    - ▪ Efficiency = (useful energy out/energy in) x 100%
    - ▪ We must be able to measure energy in some fashion in order to calculate efficiency

Day 2

- Activity - Efficiency of an Electro-mechanical System
- Explain that we will do an experiment with a motor and generator that allows us to calculate the efficiency of a system designed to lift a weight (do work)
    - o Ask the students: What happens to a motor shaft when electricity is applied to the terminals? (use a battery or the Lego solar panels to show that the motor turns an axel). Ask about the forms and states of what is happening (chemical to electric to mechanical)
    - o Ask: Does anyone have any ideas about what happens to the terminals when the motor shaft is turned manually (e.g., running the motor backwards)? (show that the motor can turn into an electricity "generator" and make it light a Lego light bulb.) Ask about the forms (mechanical to radiant). Tell the students that they will be powering their own generators today to lift a weight.

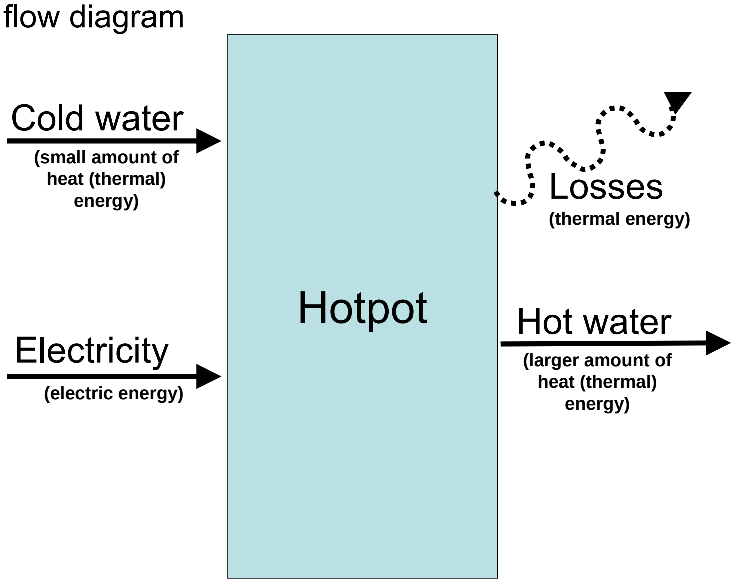
Play with the apparatus to get a sense of how it works

- o Have them break into groups of 3-4 students and work at stations with the Lego setup. Work through the activity procedures 1-5.
- o Explain that you can never have both washers reach the top at the same time because then the system would be 100% efficient. If a system is 100% efficient, all of the energy is being used. Even if the light from the Lego light bulb was useful to us, there is still heat escaping in the lamp and in the wire. (Maybe talk about recent efforts to achieve 100% efficiency by super-cooling to keep heat from escaping). This might be a good time to look back and compare the efficiencies of sources: solar, wind, gas turbines.

- If appropriate for students – go through the derivation that shows how to calculate efficiency from the height each washer raised (see teachers guide below). Otherwise, just provide equation – efficiency = height/height

Complete activity and calculations
- Go through the rest of the procedure.
- Go through calculations and questions on the activity sheet. The least efficient trial should be trial 3 where loss goes through the wires, 2 bulbs, the motor, and the generator. The most efficient trial should be trial 2 where energy is only lost in the wires, motor and generator.
- Fun Extra: Have the groups connect all of their modules together, and watch the efficiency decrease from motor to motor.

Day 3 (or alternative to Day 2 experiment)
- Activity – Efficiency of a water heating system
- Review combustion demo done in earlier conversions lesson
  - Does all of heat go into heating the water and/or spinning the turbine? Discuss where energy is lost (at least lost from our ability to do work). Where does this energy go?
  - Reintroduce the laws of thermodynamics:
    - Law of conservation of energy: energy can neither be created nor destroyed (by ordinary means).
    - There is also a second law of thermodynamics that helps to explain these losses. The heat losses can be called “entropy,” which is a measure of how much energy is dispersed to the environment and is no longer usable. The second law of thermodynamics states that the entropy of the universe always increases. That means that things get increasingly disordered and are irreversible (or, there will always be heat losses in any energy conversion process)
- Show example of a hotpot or other simple water heating device – draw process flow diagram



- Explain system
    - Energy into the system determined by electricity supply
        - Energy = power X time (W s = J)
        - We can use watt meter to measure power and stop watch to measure time
    - The theoretical amount of energy needed to heat a substance such as water can be calculated based on the mass, temperature rise and specific heat of the substance

$$Q = mC_p \Delta T$$

Where:

Q is the energy required (joules, J);
m is the mass of the substance (g);
C_p is the specific heat (J/g/°C)
ΔT is the change in temperature (°C).

The specific heat of water is 4.186 J/g/°C.

    - Efficiency is defined as energy in output / energy in input
        - $\xi = \dfrac{mC_p \Delta T}{Pt}$
        - If power is used in units of watts and time in seconds, then both the denominator and numerator have units of Joules
- Show how watt meter is operated
- Do activity
- Close with discussion of what efficiencies the students found in the various water heating systems. Which one is most efficient? Least? What is it about the design of the system that affects the efficiency?

Resources

Teacher's Guide- Efficiency of a System (below)
Activity- Efficiency of an Electro-Mechanical System (below)
Activity-Efficiency of a Water Heating System

URL

All lesson plans in this unit are included at
http://www.clarkson.edu/highschool/k12/project/energysystems.html

This URL has been included in the Engineering Pathways web site (http://www.engineeringpathway.com/ep/index.jhtml) and can be found with a search on "energy choices."

Owner

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Contributors

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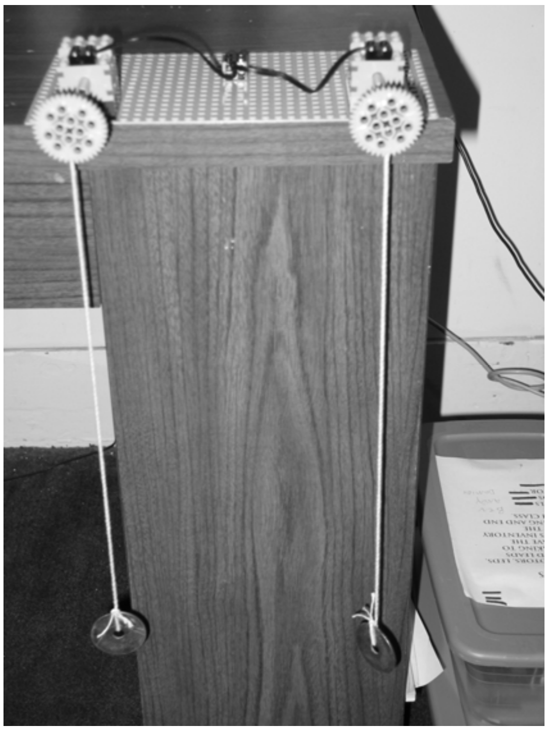
Teacher's Guide: Efficiency of an Electro-Mechanical System

It is strongly recommended that the stations be made the day before, to make sure there are enough motors (they may need to be borrowed from other kits). A Photograph of trial 1 (generator-motor) is shown below and included in the schematic drawing. This is not the only way to set it up. It is important to make sure that all of the washers hang at the same height when fully unraveled.



In theory, both washers would rise to the same height if the system was 100% efficient. If we define the "useful energy output as the work done to lift the right washer, then the basis for this experiment can be summarized as:

1. The energy into the system can be estimated from the work done to raise the left washer by twisting the large knob on the left.
2. $energy\ in = work\ to\ move\ left\ washer = force \times dis\tan ce = mass_{washer}\ g\ height_{L\ washer\ moved}$
3. $energy\ out = work\ to\ move\ right\ washer = force \times dis\tan ce = mass_{washer}\ g\ height_{R\ washer\ moved}$
4. the efficiency defined by energy out/energy in:

$$efficiency(\%) = 100\% \times \frac{mass_{washer}\ g\ height_{R\ washer\ moved}}{mass_{washer}\ g\ height_{L\ washer\ moved}} = 100\% \times \frac{height_{R\ washer\ moved}}{height_{L\ washer\ moved}}$$

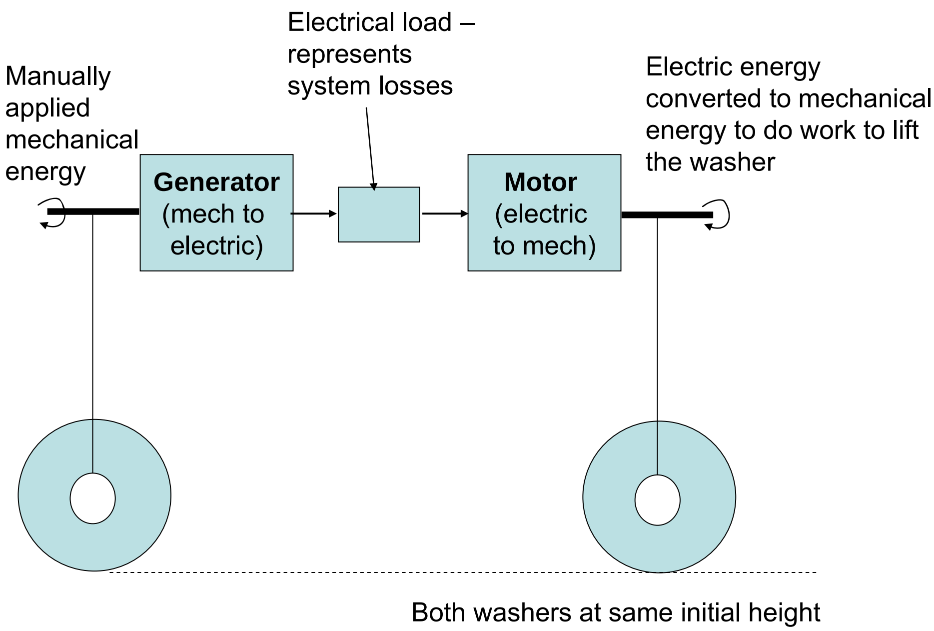


Fig. 1: initial set up of experiment

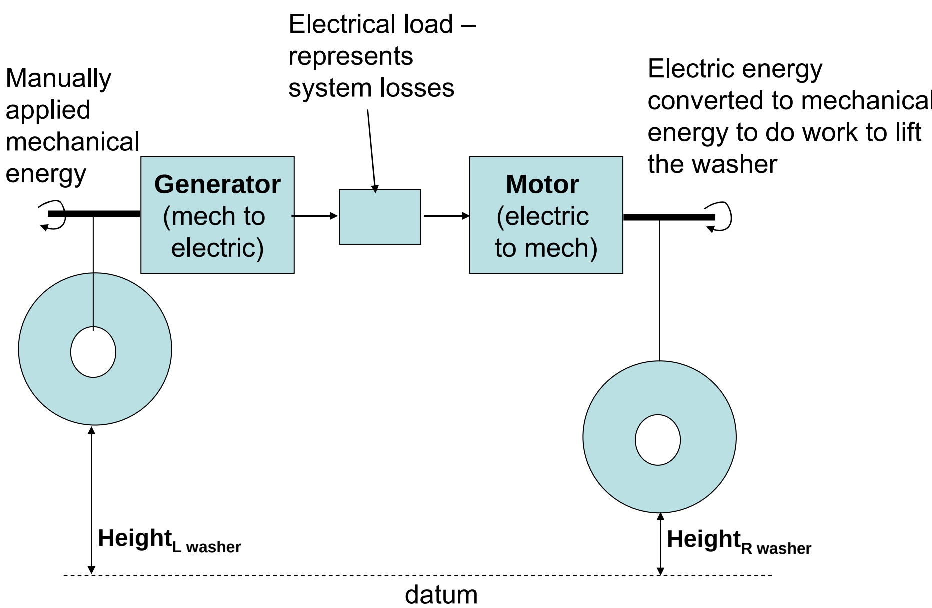


Fig. 2: Experiment after manually spinning axel on left

The expected answers to the questions are also included here. These are not necessarily the right answers, but rather the student's answers based on their observations can be nothing but correct. A bit of troubleshooting back and forth with the student could lead to why their answers deviate from the expected. I strongly suggest that you don't look at or use these expected answers if you feel comfortable with the material. They may not fit the mold of the unique conclusions that the students make.

The last part is the setup for connecting all of the stations in series if there is extra class time. (A bit more complicated than expected)

Procedure

1. Work in a group of 3-4 students at each station
2. Turn the left gear.   What do you notice happening to the gear on the right?

Expected: The gear on the right should also move up. **It is important that the students strive to turn the gears quickly but at a fairly constant rate throughout this activity**

3. Which side is acting like a generator? Which side is acting like a motor?

The side that you are turning (in this case left side) is acting like a generator.

The other side is acting like a motor.

4. Unwrap the string and bring the washers back down to the same height.
5. Turn the left gear again until the left washer reaches the motor. This time try to get both of the washers to reach the top at the same time.   Is this possible? Why or why not?

Expected: This should not be possible because the energy used to lift the left washer is not completely sent to the right washer, some energy is lost along the way.   Energy is lost in the generator, the electrical connectors, the motor, the strings, and whatever other components make up the system.

6. Is your generator-motor system 100% efficient?

Expected: No, the system is not 100% efficient since the left washer reached the top before the right washer during the same time period. If it was 100% efficient, they would reach the top at the same time.   Achieving 100% efficiency is next to impossible.

13. Unwrap the string and bring the washers back down to the same height. Put 2 lego lamps on top of each over and on top of the black connector. What do you think is going to happen this time?

Expected: The right washer should go up even less.

13. Based on what you saw, which trial do you think was the most efficient? Which   trial do you think was the least efficient?

Expected: Most efficient: generator-motor trial, Leas efficient: generator-double lamp-motor trial.

Discussion Questions:

3. What do you think would happen if you connected the motor on the right to yet another motor with a weight attached?

You should lose efficiency with each new component.   Each washer from left to right should be a little lower.

Activity: Efficiency of an Electro-Mechanical System

Purpose

Electromagnetic conversions are one of the most common ways to convert energy into a useful form. From electric pencil sharpeners to automobiles, electromagnetic conversions are anywhere a motor is. A motor can also be used as a generator to produce electricity. In this is experiment, you will determine the efficiency of a motor-generator system.

Equipment

- Lego Kit: 2 motor-mass assemblies, 2 Lego light bulbs, 3 electrical connectors, and platform.
- Two equal weight washers each tied to ~0.5m thread or fishing line. Other end of thread tied to extension on motor/generator
- Calculator.
- Yard stick.

Procedure

1. Work in a group of 3-4 students at each station
2. Turn the left gear. What do you notice happening to the gear on the right?
3. Which side is acting like a generator? Which side is acting like a motor?
4. Unwrap the string and bring the washers back down to the same height.
5. Turn the left gear again until the left washer reaches the motor. This time try to get both of the washers to reach the top at the same time. Is this possible? Why or why not?
6. Is your generator-motor system 100% efficient? Explain

The efficiency of a system is the ratio of your output to your input.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\%$$

In this case, we will use the height each washer raised as a measure of work (energy) done. We will now measure height and calculate the efficiency of our system.

7. Unwrap the string and bring the washers back down to the same height. Measure the distance from the floor to the bottom of the washers (should be same for both washers). Record your data on the table provided.

   - Initial Height = _______cm

Trial 1: Generator-Motor

8. Turn the left gear until the left washer reaches the motor and stops. Use a steady and fairly fast rotational speed. Measure the height of each washer. Record your data on the table provided.

   - Height of left washer = _______cm

   - Height of right washer = _______cm

Trial 2: Generator-Light bulb-Motor

9. Unwrap the string and bring the washers back down to the same height. Connect a Lego light bulb to the top of the black connector.

10. Turn the left gear until the left washer reaches the motor and stops. Use a the same steady and fairly fast rotational speed. Measure the height of each washer. Record your data on table provided.

   - Height of left washer = _______cm

   - Height of right washer = _______cm

Trial 3: Generator-Double Lamp-Motor

11. Unwrap the string and bring the washers back down to the same height. Put 2 Lego light bulbs on top of each over and on top of the black connector. What do you think is going to happen this time?

12. Turn the left gear until the left washer reaches the motor and stops. Measure the height of each washer. Record your data on table provided.

    - Height of left washer = _______cm

    - Height of right washer = _______cm

13. Based on what you saw, which trial do you think was the most efficient? Which trial do you think was the least efficient?

14. Enter your height data in the table and calculate Efficiency.

Discussion Questions

1. Which trial had the lowest efficiency? Why?

2. How was energy lost in each trial?

Trial 1 (generator-motor):

Trial 2 (generator-light bulb-motor):

Trial 3 (generator-double light bulb-motor):

3. What do you think would happen if you connected the motor on the right to yet another motor with a weight attached?

NAME : ____________________________ DATE: ___________

Trial	Initial Height (cm)	Final Height of Left Washer (cm)	Final Height of Right Washer (cm)	Left Washer Distance (cm) (Height of Left Washer- Initial Height)	Right Washer Distance (cm) (Height of Right Washer- Initial Height)	Efficiency (%) $efficiency(\%) = 100\% \times \frac{height_{R\ washer\ moved}}{height_{L\ washer\ moved}}$
Generator-light bulb-Motor						
Generator-Motor	(same as above)					
Generator-Double bulb-Motor	(same as above)					

Activity – Efficiency of a Water Heating System

Goal: Participants gain a sense for how much energy is consumed in a daily activity and how the efficiency varies based on method used

Learning objectives. By the end of the activity the participants:

1. can theoretically calculate the energy required to heat water to a boil
2. are competent in using the Watt-meter and basic measuring tools (thermometer, graduated cylinder)
3. can calculate energy consumed to boil water based on experimental measurements
4. can convert energy units between kWh, kJ, Btu
5. can compare the energy used to make a cup of tea to some relevant reference point (e.g., 85 wooden matches)
6. can calculate the efficiency of water heating devices.

Key concepts:

Power vs. energy
Energy units / conversions
Energy efficiency (ratios, percent calculations)
Measuring/calculating energy consumption

Supplies:

Graduated cylinders (one per group)
Thermometers (one per group)
Hotpot (could have a couple of different models)
Microwave
Watt meter (one per group)
Calculators

Background:

The theoretical amount of energy needed to heat a substance such as water can be calculated based on the mass, temperature rise and specific heat of the substance:

$$Q = m C_p \Delta T$$

Where:

Q is the energy required (joules, J);
m is the mass of the substance (g);
C_p is the specific heat (J/g/°C); The specific heat of water is 4.186 J/g/°C.
ΔT is the change in temperature (°C).

When we actually heat a substance, however, there are inefficiencies in the process and some heat energy is lost to the surroundings. We can measure the actual energy consumed by electrical appliances to heat water with a watt meter. The electrical energy is generally expressed in units of kWh. It is determined as the product of the power consumed by the appliance and the time of heating:

$$energy\,(kWh) = power\,(W) \times time\,(h) \times \frac{kW}{1000W}$$

The energy units of kWh and J can easily be interchanged through the definition of a watt: W=J/s. The English unit of Btu (British thermal unit) is also used for expressing quantities of energy. Burning one wooden match releases approximately one Btu. There are 1055 joules in a Btu. Thus, a kJ (1000 J) is approximately equal to a Btu.

Activity:

1. Heat 500 mL of water to a temperature close to boiling (do not boil) with either the hot pot or the microwave. Create a data table to record initial temperature, final temperature and energy or power consumed.

2. Calculate the actual energy required to heat the water (J or Btu)

3. Calculate the theoretical amount of energy required to heat the water and use this to quantify the efficiency of the appliance (efficiency = theoretical energy / actual energy)

Discussion questions:

1. What are your thoughts on the efficiency of the appliances? How could this information be used to help you chose how to heat water?

2. Identify any potential mechanisms by which heat energy was "lost" in the appliance and technique used to heat water. Discuss ways that these losses could be reduced to increase the efficiency of the appliance.

3. Estimate how many wooden matches it would take to heat your water. Show your calculations. What did you assume about the efficiency?