Section Preview of the Student Book for

Science and Sustainability, Revised Edition

Activity 31

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Fueling Trade-offs

31

31.1

How Much Energy Is There?

Purpose

Determine which of two fuels—kerosene or ethanol—releases more energy as it combusts. Decide which fuel is better for use in automobiles and identify the trade-offs in attempting to create the perfect fuel.

Introduction

All human activity requires energy—from sleeping to constructing roads and buildings, from watching television to generating electricity. In this activity, you will explore combustion reactions. **Combustion**, commonly called burning, is the source of much of the energy we use for transportation, cooking, heating, generating electricity, and other activities. Combustion also produces chemical products, some of which are pollutants. Two commonly combusted fuels are kerosene, which is a petroleum product, and ethanol, which is an alcohol often produced from crops. You will burn each of these fuels to compare the amount of energy released and some of the chemical wastes produced.

Prediction

Which fuel—kerosene or ethanol—do you think will release the most energy when it combusts? Explain your reasoning.

Materials

For each group of four students

1	glass fuel burner containing kerosene
1	glass fuel burner containing ethanol
1	book of matches
1	balance
1	100-mL graduated cylinder
1	metric ruler

access to a clock with a second hand

access to water

For each team of two students

1	aluminum soda can
1	can holder (for soda can)
1	immersion thermometer
1	calculator (optional)

For each student

1	pair of safety glasses

Safety Note

Exercise extreme caution when using an open flame in the classroom. Be sure you know how to extinguish the burner and where to find a fire blanket or fire extinguisher to put out any accidental fires. Always wear safety glasses during this activity, and wash your hands before leaving the lab.

Procedure

1. Within your group of four, discuss and decide upon an experimental procedure that uses only the equipment listed in the Materials section and will allow you to collect evidence that indicates whether or not your prediction is correct.

Hint: Recall Activity 1.3, "Burn A Nut," and Activity 4.1, "Are You In Hot Water?"

2. Write out the step-by-step procedure that your group will follow. Make sure that the procedure is stated clearly enough so that any other group in your class could perform your investigation.

3. Prepare a data table to record your observations and measurements.

4. Carry out your investigation.

5. Analyze your results, making sure to record any calculations made. Prepare a written report that includes your prediction, your experimental procedure, your collected data, your analysis, and your conclusions.

Analysis

?

Group Analysis

1. The results of any experiment may be affected by a variety of errors. Errors can often account for variations in data. Identify some potential sources of error in this experiment that may have affected your results.

2. The energy content of a fuel can be measured as the amount of energy per mass (cal/g or J/g) or the amount of energy per volume (cal/mL or J/mL). Which of these measures of energy content do you think is more useful when comparing fuels? Explain your reasoning.

Individual Analysis

3. Gasoline is chemically very similar to kerosene. How could the results of this experiment affect your decision to buy fuel for your car that contains ethanol rather than pure gasoline?

4. If you were considering the use of one of these fuels for your car, what other information would you like to have before deciding which to use?

31.2 Fuels for the Future

Purpose

Explore some of the more promising sources of energy that are not fossil fuels.

Introduction

Vast amounts of energy are used every day to heat and cool buildings, to provide light, to produce the goods and services people rely on, and to transport people and goods. Most of this energy is supplied by the combustion of fossil fuels. Currently, these fuels are well accepted by consumers, in part because they are abundant, relatively low in cost, and perceived as safe to use. Petroleum is a versatile fuel, and convenient for many different purposes: it is easily transported, it can produce electricity, it can heat homes, and it can supply power for transportation and industrial processes. In many ways, the physical properties of petroleum have shaped the ways we use and produce energy. In fact, we have come to rely upon petroleum for many of our energy needs, and even take it for granted. However, petroleum fuels are not perfect. Their production and use contributes to environmental degradation, and they will not always be available in such abundance or at such low cost.


Wind power can be used to propel boats, pump water, grind grain into flour, and generate electricity.

For sustainable development to occur, energy must be supplied in a fashion that is socially acceptable, dependable, and economical. To be sustainable, energy use must result in

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(cont.)

minimal negative environmental impact—now and in the future. There are a number of **alternative energy sources** that can replace or supplement fossil fuels as human society's main source of energy. Several of these alternatives are briefly described here.

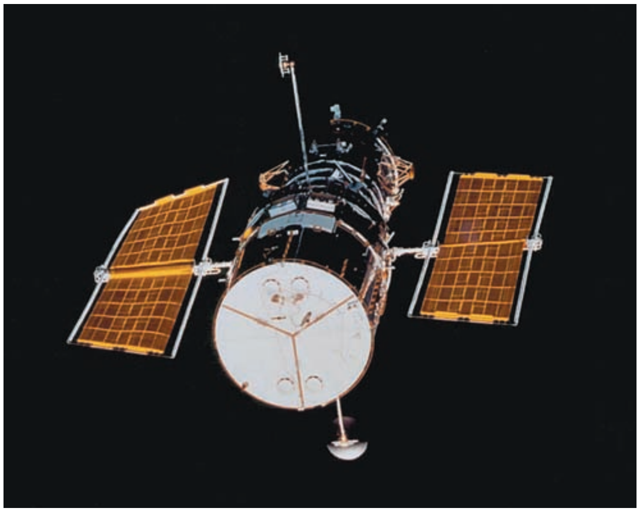
In general, it can be said that all alternatives to fossil fuels are more expensive, at least in the short term, and less convenient, less versatile, and less adaptable to existing patterns of use. However, the full "cost" of providing and using energy includes the cost associated with impacts on global environmental and human health. If the full cost of today's energy were in fact paid by the users—rather than by people in other countries or by future generations—prices would be substantially higher. As a result, people would use less energy, and preferences for technology would shift toward options that create less risk of environmental damage.

Alternative Energy Sources

Solar

Solar energy is available wherever sunlight strikes. Because sunlight does not shine constantly on any one part of our planet, solar energy cannot provide a continuous supply of useful energy unless it is collected and stored for later use. Most living organisms would not survive without Earth's many natural systems for the collection and storage of solar energy—the atmosphere, surface water and rocks, plant and animal tissues. The functioning of present-day human society requires more intense, more continuous, or different forms of energy than nature provides. While the solar energy supply is "unlimited and free," the structures required for collecting, storing, and converting the sun's rays into useful forms of energy can be expensive. Environmental impacts and risks associated with the construction and operation of solar technologies are low, but not negligible.

Sunlight can be used to directly heat collectors filled with water or other materials that are then used to heat other items. For example, a solar collector installed on the roof of a house can heat water that is then used to heat the air inside the house. Attaining temperatures that are high enough to be useful typically requires several hours of direct sunlight and a solar collector with a surface area of at least 10 m^2. In many warm-weather countries, on-site solar collectors can be used to meet a significant percentage of household heating needs. It is not economically practical to move the heated materials any significant distance for use in other, "off-site" locations. Also, without equipment that can significantly intensify natural solar radiation, the sun's rays cannot provide all of the energy required to heat most large buildings, much less provide the amounts of energy required for industry or transportation purposes.



Electricity needed to operate this satellite is generated when sunlight strikes the photovoltaic cells located on its "wings."

Another type of solar technology can generate electricity directly from sunlight. This technology takes advantage of a phenomenon known as the **photovoltaic effect**. Photovoltaic cells, which are usually manufactured from silicon, produce electric current when exposed to light. Small arrays of photovoltaic cells, some no larger than 2 cm^2, can provide enough electricity to operate devices such as solar calculators and emergency roadside phones. Much larger photovoltaic arrays, of at least 10 m^2, are needed to provide all the electricity required by a satellite, space station, or typical home. Presently, high cost is a key barrier to the use of photovoltaics as a major source of society's energy. Photovoltaic electricity will not be competitive until the cost of manufacturing photovoltaic cells decreases or the cost of fossil-fuel derived electricity increases, or both.

Nuclear

Nuclear energy can be produced in two ways: fusion and fission. **Nuclear fusion** involves the combining, or fusing, of atomic nuclei. Fusion reactions produce the energy emitted by the sun and other stars. **Nuclear fission** involves the breaking apart of atomic nuclei. Nuclear fission occurs when an atomic nucleus breaks into smaller parts. Nuclear fission can be spontaneous or can occur when a nucleus is bombarded with neutrons. Radioactive decay occurs when a nucleus spontaneously loses energy by giving off radiation. Radioactive decay always releases energy, and may also release small particles. Elements that undergo radioactive decay are said to be radioactive. Fission reactions are currently used in many countries to supply significant amounts of energy, primarily for generating electricity, for heating purposes, and for military uses, such as nuclear-powered ships.

All nuclear reactions convert a small amount of mass into a large quantity of energy without producing any of the chemical emissions, such as soot or CO_2, that are associated with the combustion of fossil fuels. Albert Einstein quantified the relationship between mass and energy in the equation , where **E** is energy, **m** is mass, and **c** is the speed of light. Because the speed of light is such a large number (3×10^8 meters per second), nuclear reactions produce huge amounts of energy—in the form of heat and intense radiation—from tiny amounts of fuel. Earth contains enough nuclear fuel to meet all our present and future energy needs.

The safe use of nuclear energy for peaceful purposes requires careful management. Fission reactions produce large amounts of "waste" heat and radiation that can cause damage if released directly into the environment. These reactions must be enclosed in centralized structures that contain expensive equipment and systems designed to control the release of heat and radiation. Nuclear power has not become as widespread as many people once predicted it would. There are a number of reasons for this, including high cost and fear of exposure to radiation or nuclear explosions caused by accidents or sabotage. In addition, some people associate the use of nuclear power with the spread of nuclear weapons technology.

The elements most commonly used as nuclear fuels are isotopes of uranium or plutonium. Safety concerns include the potential for accidental release of radioactive substances during the production and storage of radioactive fuel, during the routine operation of nuclear power plants, or from disastrous accidents that could lead to the overheating, or "meltdown," of the reactor. Radioactive wastes produced during nuclear power generation can remain dangerous for thousands of years, leading to concerns about ensuring the safe, long-term storage of these materials. Plutonium is especially toxic; small quantities can poison an entire city's water or air supply. There is also the potential for sabotage, and for the authorized or unauthorized use of radioactive materials for the construction of atomic bombs. Safe operation of the entire nuclear power generation process, from mining and processing of fuels to waste disposal, requires stable, highly centralized political and governmental control. Despite the promise of newer reactor designs and other technological innovations that will reduce risks to public health and safety, overcoming public concern about the use of nuclear reactors will not be easy.

Fusion reactions generate energy when the nuclei of light elements, most commonly hydrogen, combine or fuse together. Humans have been able to create explosions derived from uncontrolled fusion reactions, but have not yet been able to initiate a controlled, long-lasting fusion reaction suitable for producing heat and electricity. Using the hydrogen atoms in one liter of seawater as fuel, fusion could theoretically generate the energy equivalent of 300 liters of gasoline. The elements used as fuel for fusion reactions do not pose any of the radiation risks associated with fissionable fuels. However, fusion reactions produce intense radiation that bombards all the materials in the reactor, causing them to become intensely radioactive. Depending on the design of the reactor, these irradiated materials can be very dangerous and potentially as expensive to handle as the fuels and by-products of fission reactions. Although fusion reactors hold some promise for the future, they are prohibitively expensive. With current technology, more energy is consumed in the initiation and control of the reaction than is produced. Practical fusion reactors are not expected to be developed for at least several decades.

Wind and Water

Throughout history, technologies as varied as water wheels, wind mills, rafts, and sailboats have harnessed the energy of wind and flowing water for use in manufacturing or transportation. Today's turbines and generators can efficiently convert the energy of wind and water into electricity, which has thousands of uses.

In regions with consistent winds it is not uncommon to use arrays of windmills called "wind farms" to generate large quantities of electricity.

Although hydroelectric dams are an important source of electricity, there are significant environmental concerns associated with their construction and use.

Wind and water power have many of the same drawbacks as solar power. These energy sources vary with season and geographic location, which means that a continuous energy supply would require storage capabilities. The large-scale generation of electricity by "wind farms" and hydroelectric facilities requires large initial investments, covers large geographic areas, and contributes to habitat destruction and other environmental damage.

Hydroelectric dams currently produce a significant fraction of the electricity used in the U.S. and other countries, in part because dams can provide year-round water storage. Unfortunately, the lakes created by these dams gradually fill with silt, slowly but surely reducing both the amount of water stored behind the dam and the capacity to generate power. Dams severely disrupt local ecosystems. They also have the potential to break and cause catastrophic floods.

"Wind farms" currently exist and continue to be built in many regions of the world that have consistently strong winds. However, because wind cannot be stored, all energy generation stops when the wind is not blowing. As a result, wind is used mainly to supplement other energy sources. Ecological impacts of wind farms include habitat destruction, noise pollution, and unintended killing of birds that may be caught in the rotating propellers.

Earth's oceans offer several possibilities for energy production. One promising source of energy is the daily rise and fall of the tides. Technology capable of converting this motion into electricity already exists. Another possibility is to use the difference in temperature between surface waters, which are heated by the sun, and much colder, deeper waters. A temperature difference of at least 15°C can be harnessed for the generation of electricity. Serious problems with this technology include the need for stabilization and mooring of large, submerged structures and the impact such structures would likely have on ocean-dwelling organisms.

Biomass

Biomass, or organic material derived from living or recently living organisms, can be used to create electrical energy, known as biopower, or used to create transportation fuels such as ethanol and biodiesel, known as biofuels. Biomass comes from many sources, including food wastes, crop residues, manure, and by-products of lumber and paper industries. These organic materials can be used to produce energy in a variety of ways. They can be burned directly, much like coal or natural gas. Alternatively, they can be fermented to create highly combustible alcohol or anaerobically digested to produce biogas, a mixture of gases including methane and CO_2. Or, they can be gasified to produce methane and hydrogen, which can be used in fuel cells. Though biomass energy production is currently more popular abroad than in the U.S, there are several biopower plants currently in use across the United States that can power up to 50,000 homes each. Though biopower production is primarily done at large power plants, small-scale operations are being researched in the hopes that someday homes could become energy-independent, generating power from nothing but food and yard waste.

Although there are many reasons to convert biomass to energy, there are also trade-offs. Large-scale use of farm and forest residue to produce energy would interrupt the natural recycling of nutrients and could contribute to loss of soil fertility. Currently, most farm and forest residues are returned to the soil, where they decompose and release nutrients back into the soil. Another drawback to the conversion of biomass to energy is the production of large quantities of pollutants. The production of biogas, for example, can generate large quantities of air pollutants. Biogas reactors can be constructed with air pollution control devices, but these are often very expensive and require consistent maintenance. Direct combustion of biomass also produces large quantities of air pollutants. To prevent the release of these pollutants into the atmosphere, biomass combusters must be fitted with effective air pollution control devices.

Alcohol is produced by the fermentation of biomass materials that have a fairly high sugar content. Biogas can be produced from almost any organic matter, regardless of its sugar content, that can be digested by certain types of anaerobic bacteria. The CO_2 and other gaseous components of biogas can be removed with fairly simple technology to yield nearly pure methane. Nitrogen, phosphorus, and other nutrients contained in the organic matter used to produce alcohol or biogas remain in the residue but need not be wasted; these nutrient-rich residues can be used as fertilizer.

Geothermal

Earth contains an immense amount of heat, most of which lies buried deep beneath the planet's crust. In regions with hot springs or volcanic activity, this heat comes close to the surface in the form of hot water and gases. These forms of **geothermal energy** can be used to heat homes and water and to generate electricity for local communities. New technology now being developed could be capable of drilling wells up to six miles deep to tap Earth's thermal energy in areas that are not volcanically active; these technologies are still in an experimental stage. Geographic restrictions, cost, and environmental impact are the major factors that limit current use of geothermal energy. Environmental impacts include disturbance of habitats and the need to dispose of large quantities of noxious gases and very saline (salty) water.

Hydrogen

Hydrogen gas reacts with oxygen to produce only heat and water. This reaction produces none of the SO_x, NO_x, or CO_2 pollutants associated with hydrocarbon combustion. However, unlike wood, coal, and other carbon-based fuels, hydrogen fuel must be manufactured. At present, hydrogen gas is most commonly made from methane gas (CH_4), in a process called steam reforming, or from the decomposition of water by electricity. New technologies may allow us to extract hydrogen from water or methanol more efficiently and at less cost.

Because hydrogen is a gas, its energy density (ratio of energy to volume) is much lower than that of most liquid fuels. A low energy density means that hydrogen-fueled vehicles, particularly heavy ones, must either be equipped with very large fuel tanks or be refueled frequently. Hydrogen gas can be compressed or cooled to a liquid state, which reduces the volume of the fuel considerably. The decrease in volume increases energy density, but the technologies required for this process are expensive.

Fuel cells, a technology now under development, makes use of the energy released when hydrogen and oxygen react chemically to form water. Fuel cells require a constant supply of hydrogen gas as a fuel, but water is the only waste they produce. Small groups of fuel cells could eventually be used to produce all of a building's heat and electricity needs. Fuel cells also have potential for use in hybrid fuel cell–electric vehicles that produce no air pollutants. Fuel cells are discussed in more detail in Activity 33.3, "Energy as You Like It."

Major drawbacks to the widespread use of hydrogen as a fuel are its high cost of production and its extreme flammability, which requires the use of costly safety equipment. Careful precautions must be taken during its storage, transportation, and use. Uncontrolled combustion of hydrogen, however, is much less destructive than uncontrolled hydrocarbon combustion. For example, the Hindenburg, a hydrogen-filled air ship similar to a blimp, burst into flames while landing in New Jersey in the 1930s. People survived the crash despite being very near the fiery wreckage.

Analysis

Individual Analysis

1. List the characteristics of an ideal energy source for use in vehicles. What energy source has characteristics most similar to those you listed?
2. What characteristics would you look for in the ideal source of energy for generating electricity? Which of the energy sources discussed in the reading has characteristics most similar to those you described?
3. Fossil-fuel combustion is currently used to produce a large percentage of our electricity. Compare the characteristics of the energy source you chose in Analysis Question 2 to those of fossil-fuel combustion. Explain the trade-offs that should be considered when deciding whether to build an electricity-generation facility that consumes fossil fuels or one that uses your chosen energy source.
4. Which of the alternative sources of energy presented in this reading do you think provides energy in the most sustainable way? Why is this energy source not more widely used? Explain your reasoning.

31.3 Combustion

Purpose

Model the chemical and structural changes that occur when a hydrocarbon molecule reacts with oxygen, and relate these changes to the energy released during combustion.

Introduction

Combustion is a chemical reaction that can occur between a fuel and oxygen. **Complete** (100%) **combustion** of a pure hydrocarbon fuel results in the production of nothing other than water, carbon dioxide, and energy. Energy is released during a combustion reaction because bonds between atoms in the reactants store more energy than bonds in the products. Part of the reason that hydrocarbon molecules make such good fuels is that the amount of energy stored in a carbon-carbon bond or carbon-hydrogen bond is much larger than the amount of energy stored in the bonds of the waste products—oxygen-hydrogen or carbon-oxygen bonds.

Combustion of hydrocarbons, such as the beeswax or paraffin used to make candles, releases light and thermal energy.

Combustion of commonly used carbon-based fuels—gasoline, diesel fuel, natural gas, propane, fuel oil, coal, wood, and charcoal—produces not only water, carbon dioxide, and energy, but also small amounts of other products, such as solid ash particles and gases containing sulfur and nitrogen. These products are created because elements other than hydrogen and carbon are found in the fuel, and air is not pure oxygen gas. Additional waste products are

Introduction (cont.)

formed if complete combustion does not take place. **Incomplete combustion** results from a lack of sufficient oxygen. This lack of oxygen causes the production of **carbon monoxide** (CO). Fires are the most common cause of accidental carbon monoxide fatalities. Other causes include vehicles accidentally left running indoors, faulty furnaces, gas heaters, or gas appliances, and use of charcoal grills in homes and garages. When air containing a large amount of CO is inhaled into the lungs, it enters the bloodstream and takes the place of oxygen (O_2). When blood transports CO rather than O_2, the supply of oxygen to the body's cells is reduced. Depending upon the concentration and duration of CO inhalation, CO poisoning can cause tissue damage, loss of consciousness, and death.

Materials

■■ **For each team of two students**

1 molecular model set

Procedure

1. Make models of one methane (CH_4) molecule and two oxygen (O_2) molecules. Break the bonds, rearrange the atoms, and form new bonds to construct water and carbon dioxide molecules.

   Count how many of each "new" molecule is produced, then fill in the blanks in front of the products in the chemical equation that describes this reaction:

   $$CH_4 + 2O_2 \rightarrow \_\_\_\_CO_2 + \_\_\_\_\ H_2O + \text{energy}$$

> **Note:** You have just written a balanced chemical equation. Each atom of each reactant appears in the products, and the products do not contain any atoms that do not appear in the reactants.

2. Make models of one ethanol (C_2H_5OH) molecule and eight O_2 molecules.
3. Use as many oxygen molecules as needed to completely combust the ethanol molecule into CO_2 and H_2O molecules. Count the number of O_2 molecules needed and the number of CO_2 and H_2O molecules produced.
4. Write a balanced chemical equation to describe the combustion of a single ethanol molecule.
5. Repeat Steps 2–4 for
   - **a.** benzene (C_6H_6).
   - **b.** hexane (C_6H_{14}).
6. Take apart your molecules and put all the pieces back in their container.

Analysis

Group Analysis

1. The incomplete combustion of methane (CH_4) produces carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O). Write a balanced chemical equation for this reaction. (**Hint:** Try starting with more than one methane molecule.)

Individual Analysis

2. Draw structural formulas for the reactant and product molecules you constructed in Procedure Step 1.

3. **a.** Find the molecular mass for each of the reactant molecule(s) you drew for Analysis Question 2.

   b. Find the molecular mass for each of the product molecule(s) you drew for Analysis Question 2.

   c. Calculate the total mass of all the reactant molecules in your balanced equation from Procedure Step 1.

   d. Calculate the total mass of all the product molecules in your balanced equation from Procedure Step 1.

   e. Write a sentence comparing the total mass of the products to that of the reactants.

4. What is the source of the energy released during combustion?

5. Use your knowledge of chemistry to rank four hydrocarbon molecules—methane, ethanol, benzene, and hexane—according to which releases the most energy during combustion. Explain your reasoning.