SUPERCHARGED SCIENCE

Unit 12: Alternative Energy

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Appropriate for Grades:
K-12 (see notes on each project)

Duration: 5-40 hours, depending on how many activities you do!

Solar cells, wind turbines, and hydroelectric power plants (like the Hoover Dam) are all examples of alternative energy sources. Although lots of folks still argue about what's considered alternative, the general idea is that alternative energy sources produce the same energy at a lower cost, both money-wise and environmentally, as traditionally used non-renewable fuel sources. In this unit, we're going to explore ways to get power from the sun, wind, magnetism, and molecules by studying solar batteries, wind turbines, crystal radios, fuel cells, and more.

NOTE: Make sure you complete Unit 8 (Chemistry), Unit 9 (Light), Unit 10 (Electricity), and Unit 11 (Magnetism) before starting here. This unit builds on principles from those previous units.

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Key Vocabulary

BEAM robots (BEAM stands for **b**iology, **e**lectronics, **a**esthetics, and **m**echanics) use solar cells to store energy from the sun into capacitors (think electricity storage tanks) until the tanks are full (which is when the robot starts to move). Instead of having complicated brains, BEAM robots rely on nervous-system type of sensors to interact with their world.

The source of power in an AM **crystal radio** comes directly from the radio waves themselves.

Molecules can also be split chemically, or by getting hit by a fast-moving particle. It takes energy, to split a water molecule, called **electrolysis**.

Energy is the ability to do work. Energy can be transferred. In other words it can be changed from one form to another and from one object to another.

When you combine oxygen and hydrogen atoms together, it makes water and a puff of energy. That's what a **fuel cell** does.

A propeller placed in a moving fluid will turn a motor shaft (which has coils of wire and magnets inside). The faster the shaft turns, the more the magnets create an electrical current. This is how a **generator** works.

Power measures how quickly work can be done. Mathematically, power is work divided by time. Power can be measured in horsepower or Watts.

Renewable energy is the energy created from natural sources, like sunlight, water, wind, and temperature differences from within the Earth (geothermal).

A **solar cell** converts sunlight straight into electricity. Solar cells are usually made of silicon. Light (photons) hits a solar cell and gets absorbed, knocking electrons out of their shell. The electron starts flowing through the silicon to create DC current.

Work is moving something against a force over a distance. Mathematically, work = force x distance. Work can be measured in Joules or calories.

Unit Description

Earth, our home in space, has supported life for a long time. But with a growing human population, people are having a greater effect on the environment than ever before. Together we must learn about the problems facing our environment and work to protect the earth.

There are many ways we can work together to protect the Earth. We can ask adults to use more fuel-efficient cars (cars that get more miles per gallon of gasoline). We can ride bikes or walk instead of getting rides in cars. We can recycle aluminum, paper, plastic, and glass, and we can plant trees. We can save energy by turning off lights when they are not in use. We can save energy by not keeping rooms and buildings too hot in the winter or too cold in the summer. Another way we can help the Earth is to learn more about the environment.

Solar cells, wind turbines, and hydroelectric power plants (like the Hoover Dam) are all examples of alternative energy sources. Although lots of folks still argue about what's considered alternative, the general idea is that the sources produce the same energy at a lower cost, both money-wise and environmentally, as traditionally used non-renewable fuel sources.

Scientists are now working on substitutes for traditional methods of generating power. For example, they have figured out ways to use alcohol instead of fossil fuels, coal instead of wood, and petroleum instead of whale oil.

This unit is designed to help you better understand our environment by doing experiments with air, water, land, energy, and life. It’s your guide to doing those experiments, and observing and thinking about the environment.

By understanding our environment, we can learn to protect the Earth and to use our natural resources wisely for generations to come.

Objectives

Since alternative energy experiments in this area require power plants and machinery the size of a small town, we're going to focus on a very specialized form of alternative energy called *renewable energy.*

Renewable energy is energy created from natural sources like sunlight, water, wind, and temperature differences from within the Earth (geothermal). We'll be making solar-powered robots, building solar batteries, lighting up bulbs using a blast from a hair dryer, and capturing the energy in light waves on our battery-free radio.

We're also going to study the energy locked in substances by learning how to split the water molecule and extracting the energy using fuel cells and electrochemistry. We'll also have a peek at the power from steam and how apples can power your clocks.

How many of these things do you remember from our previous lessons?

- Energy is the ability to do work.
- Work is moving something against a force over a distance.
- Power measures how quickly work can be done.

As you sit there reading this, there is energy flowing all around you in the form of light, sound, and radio waves, heat and more. You are constantly being bombarded by energy. Energy is everywhere all the time. We're going to learn how to tap into the potential that's all around you.

Highlights

- A solar cell converts sunlight straight into electricity.
- Solar cells are usually made of silicon.
- Light (photons) hits a solar cell and gets absorbed, knocking electrons out of their shell. The electrons then start flowing through the silicon to create DC current.
- A propeller placed in a moving fluid will turn a motor shaft (which has coils of wire and magnets inside). The faster the shaft turns, the more the magnets create an electrical current.
- The source of power in an AM (crystal) radio comes directly from the radio waves themselves.

- Molecules can also be split chemically or by getting hit by a fast-moving particle. It takes energy to split a water molecule (electrolysis).
- When you combine oxygen and hydrogen atoms together, it makes water and a puff of energy. (That's what a fuel cell does.)
- BEAM (BEAM stands for **b**iology, **e**lectronics, **a**esthetics, and **m**echanics) robots use solar cells to store energy from the sun into capacitors (think electricity storage tanks) until the tanks are full (which is when the robot starts to move). Instead of having complicated brains, BEAM robots rely on nervous-system type of sensors to interact with their world.

Textbook Reading

Lesson 1: Basics of Alternative Energy

Earth, our home in space, has supported life for a long time. But with a growing human population, people are having a greater effect on the environment than ever before. Together we must learn about the problems facing our environment and work to protect the Earth.

There are many ways we can work together to protect the Earth. We can ask adults to use more fuel-efficient cars (cars that get more miles per gallon of gasoline). We can ride bikes or walk instead of getting rides in cars. We can recycle aluminum, paper, plastic, and glass, and we can plant trees. We can save energy by turning off lights when they are not in use. We can save energy by not keeping rooms and buildings too hot in the winter or too cold in the summer. Another way we can help the Earth is to learn more about the environment.

This lesson is designed to help you better understand our environment by doing experiments with air, water, land, energy, and life. It's your guide to doing those experiments, and observing, and thinking about the environment.

By understanding our environment, we can learn to protect the Earth and to use our natural resources wisely for generations to come.

Atoms and Molecules

Understanding something about atoms and molecules will help you understand our environment.

Everything in the world around us is made of atoms and molecules. We talked about this in Units 3 and 8 extensively, but here's a quick review:

Atoms are the basic building blocks of all things. There are about 100 different kinds of atoms. Molecules are combinations of tightly bound atoms. For example, a water molecule is a combination of two hydrogen atoms and one oxygen atom.

Molecules that are made of only a few atoms are very small. Just one drop of water contains about two million quadrillion (2,000,000,000,000,000,000,000) water molecules.

Polymers are large molecules that may contain millions of atoms. Important natural polymers include natural rubber, starch, and DNA. Some important artificial polymers are nylon, which is used in making fabrics; polyethylene, which is used in making plastic bags and plastic bottles; and polystyrene, which is used in making Styrofoam cups and insulation.

Atoms are made of smaller particles called electrons, protons, and neutrons. The nucleus is the center of the atom and contains protons and neutrons. Protons are positively charged, but neutrons have no charge. Electrons are negatively charged, surround the nucleus, and give the atom its size.

Atoms and molecules that are charged are called ions. Ions have either a positive charge or a negative charge. Positive ions have more protons than electrons. Negative ions have more electrons than protons.

Sodium chloride, which is the chemical name for table salt, is made of positive sodium ions and negative chlorine ions.

Atoms, ions, and molecules can combine in chemical reactions to make new substances. Chemical reactions can change one substance into another or break one substance down into smaller parts of molecules, atoms, or ions.

A Note about Science and Experiments

One way to learn more about the environment and science is to do experiments. Science experiments provide a way of asking questions and finding answers. The results that come from experiments and observations increase our knowledge and improve our understanding of the world around us.

Science will never have all the answers because there are always new questions to ask. However, science is the most important way we gather new knowledge about our world.

Not every experiment you do will work the way you expect every time. Something may be different in the experiment when you do it. Repeat the experiment if it gives an unexpected result and think about what may be different.

Not all of the experiments in this book give immediate results. Some experiments in this book will take time to see observable results.

Some of the experiments may take a shorter or longer time than that suggested in the experiment.

Science is not merely a collection of facts, but a way of thinking. You can play a key role in maintaining and encouraging someone's interest in science and the surrounding world by sharing what you know with them in a way that really makes them want to know more.

Energy, Temperature and Heat

Without the sun, there would be no life on Earth. The sun warms the Earth, generates wind, and carries water into the air to produce rain and snow. The energy of the sun provides sunlight for all the plant life on our planet, and through plants provides energy for all animals.

The sun is like a giant furnace in which hydrogen nuclei (atoms without electrons) are constantly smashed together to form helium nuclei. This process is called nuclear fusion. In this process, 3.6 billion kilograms (8 billion pounds) of matter are converted to pure energy every second. The temperature in the sun exceeds 15 million degrees.

Nuclear fusion is one kind of energy. Other forms of energy include mechanical energy, heat, electrical energy, chemical energy, and light. Mechanical energy is the energy of organized motion, such as a turning wheel. Heat is the energy of random motion, such as a cup of hot water. Electrical energy is the energy of moving charged particles or electrons, such as a current in a wire. Chemical energy is the energy stored in bonds that hold atoms together. Light is any form of electromagnetic waves, such as X-rays, microwaves, radio waves, ultraviolet light, or visible light.

Energy can be converted from one from to another. For example, the nuclear energy of the sun is converted to light, which goes through space to the Earth. Solar collectors of mirrors can be used to focus some of that light to heat water to steam. This steam can be used to turn a turbine, which can power a generator to produce electricity.

Most of our energy needs are met by burning fossil fuels such as coal, oil, gasoline, and natural gas. The chemical energy stored in these substances is released by burning these fuels. When fossil fuels burn, they combine with oxygen in the air and produce heat and light.

Fossil fuels are not renewable. When they are used up, they are gone forever. However, renewable energy sources such as wind, sun, geothermal, biomass and water power are renewable. They can be used over and over to generate the energy to run our society.

Tremendous amounts of renewable energy are available. For example, the solar energy that falls on just the road surfaces in the United States is equal to the entire energy needs of the country. Although there are sufficient amounts of renewable energy, we must improve our methods of collecting, concentrating, and converting renewable energy into useful forms.

Sources and Savings of Energy

The United States has large reserves of coal, natural gas, and crude oil, which is used to make gasoline. However, the United States uses the energy of millions of barrels of crude oil every day, and it must import about half its crude oil from other countries.

Burning fossil fuels (oil, coal, gasoline, and natural gas) produces carbon dioxide gas. Carbon dioxide is one of the main greenhouse gases that may be contributing to global climate change. In addition, burning coal and gasoline can produce pollution molecules that contribute to smog and acid rain.

Using renewable energy sources such as solar, wind, water, biomass, and geothermal could help reduce pollution, prevent increases in global climate change, and decrease acid rain. Nuclear energy also has these advantages, but it requires storing radioactive wastes generated by nuclear power plants. Currently, renewable energy produces only a small portion of the energy needs of the United States. However, as technology improves, renewable energy should become less expensive and more common.

Hydropower (water power) is the least expensive way to produce electricity. The sun causes water to evaporate. The evaporated water falls to the earth as rain or snow and fills lakes. Hydropower uses water stored in lakes behind dams. As water flows through a dam, the falling water turns turbines that run generators to produce electricity.

Currently, geothermal energy (heat inside the Earth), biomass (energy from plants), solar energy (light from concentrated sunlight), and wind are being used to generate electricity. For example, in California there are more than sixteen thousand (16,000) wind turbines that generate enough power to supply a city the size of San Francisco with electricity.

In addition to producing more energy, we can also help meet our energy needs through conservation. Conservation means using less energy more efficiently.

Cooling and Heating

Cooling and heating are opposite processes. Cooling is the removal of heat energy from an object or space and heating is the addition of heat energy to an object or space. We use these opposite processes a great deal in our daily lives. For example, in the kitchen we use the cooling provided by a refrigerator to keep food cold. We also use the heat from a stove to cook food.

Nearly 75 percent of the energy used by the average family household in the United States goes for cooling and heating purposes. Air conditioning and refrigeration are the major cooling requirements of a home, while water and space heating are the most important heating requirements.

Solar Energy

The energy of sunlight powers our biosphere (air, water, land, and life on the earth's surface). About 50% of the solar energy striking the Earth is converted to heat that warms our planet and drives the winds. About 30% of the solar energy is reflected directly back into space. The water cycle (evaporation of water followed by rain or snow) is powered by about 20 percent of the solar energy.

Some of the sunlight that reaches the Earth is used by plants in photosynthesis. Plants containing chlorophyll use photosynthesis to change sunlight to energy. Since these green plants form the base of the food chain, all plants and animals depend on solar energy for their survival.

When the sun is overhead, about 1,000 watts of solar power strike 1 square meter (10.8 square feet) of the Earth's surface. Using solar cells, this solar energy can be converted to electricity. However, because sunlight cannot be converted completely to electricity, it takes at least a square meter of area to gather enough sunlight to run a 100-watt light bulb.

Solar energy is still more expensive than other methods of generating electricity. However, the cost of solar electricity has greatly decreased since the first solar cells were developed in 1954.

It has been proposed that panels of solar cells on satellites in orbit above the Earth could convert solar energy to electricity twenty-four hours a day. These huge solar power satellites could convert electrical energy to microwaves and then beam these microwaves to Earth. At the Earth's surface, tremendous fields covered with antennas could convert the microwave energy back to electricity.

It would take thousands of astronauts many years to build such a complicated system. However, there are many practical examples of solar energy already in use by people today. These uses include solar energy being used for heating water, heating and cooling buildings, producing electricity from solar cells, and using rain and snow from the water cycle to power electrical generators at dams.

Energy from Biomass

Fossil fuels, which include petroleum, natural gas, and coal, supply nearly 90% of the energy needs of the United States and other industrialized nations. Because of the high demand for these nonrenewable energy resources, they are rapidly being consumed. Some estimates suggest there is only a 50-year supply of oil and natural gas remaining on Earth. Coal supplies are expected to last between 350 and 3,000 years.

We must find other sources of energy to meet the increasing fuel demands of modern society. Important alternate sources of energy include solar, wind, biomass, hydroelectric, geothermal, nuclear, and tidal energy.

One of the benefits of using alternative sources of energy is that many of them are "clean", meaning that they do not cause pollution. Also, many alternative energy sources are renewable energy sources. They are replaced naturally, such as is the case with the plant life used in biomass energy sources, or are readily available, such as is the case with sun and wind power. In addition to being cleaner fuels and more sustainable, the use of renewable forms of energy will allow us to stretch out our current supply of fossil fuels so they will last longer.

Plants are the most important biomass energy source. Plant material can be burned directly, as with wood, or it can be converted into a fuel by other means. We'll learn how water can be heated by composting grass, how a peanut burns, and how corn syrup can be made into ethyl alcohol in our experiments for this section.

Lesson 2: Advanced Alternative Energy

Solar Energy

This is the kind of energy most people think of when you mention alternative energy, and for good reason! Without the sun, nothing you see around you could be here. Plants have known forever how to take the sun's energy and turn it into usable stuff, so why can't we?

There are three different ways to conduct heat energy: conduction, convention, and radiation. When I sit on a cold bench, I *conduct* heat to the bench through touch. Wind chill factor is a form of *convective* heat transfer, and requires a fluid (the wind, in this case) to move the energy (heat) around. *Radiant* heat explains how the sun can warm the earth through the vacuum of space. The sun doesn't need to touch (conductive) the Earth or even share in the same fluid atmosphere to transfer the energy (convective). It warms us up through radiation, or light.

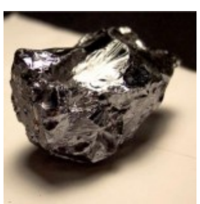
Solar energy, or solar power, refers to collecting the sun's energy and storing it for another use, like driving a car. The sun blasts 174 x 10^{15} Watts (which is 174,000,000,000,000,000 Watts) of energy through radiation to the Earth, but only 70% of that amount actually makes it to the surface. And since the surface of the Earth is mostly water, both in ocean and cloud form, only a small fraction of the total amount of energy makes it to land.

A solar cell converts sunlight straight into electricity. Most satellites are powered by large solar panel arrays in space, as sunlight is cheap and readily available out there.

While solar cells seem new and modern today, the first ones were created in the 1880s, but were a mere 1% efficient. (Today, they get as high as 40% in the lab, but only about 20% efficient in actual use.) A solar cell's efficiency is a measure of how much energy from the sun that the cell converts into electrical energy.

The big leap in technology came in the 1950s when semiconductors were experimented with at Bell Labs.

Today, engineers design space satellites armed with solar panel arrays which continually rotate to track the position of the sun. Solar panels on homes, however, are stationary and rely on the Earth's rotation to guide their path.



How does a solar cell work?

Solar cells are usually made of silicon. Sunlight is made of packets of energy called photons (covered in Unit 9). When photons hit the silicon, one of three things can happen: the photons can pass straight through the silicon if they have a low enough energy; they can get reflected off the surface; or (and this is the fun part) they get absorbed and the electrons in the silicon get knocked out of their shell.

Once knocked out of orbit, the free electrons start flowing through the silicon to create electricity. The solar cells are structured in such a way as to keep the electricity flowing only in one direction. The electron flow created is DC current (more on this in Unit 10).

The solar cells you can buy from stores require huge amounts of energy in creating the solar cell, which is the primary downside. You need high temperatures, big vacuum pumps, and lots of people to make a set of solar cells. However, if we focus just on the physics of the solar cell, then we can easily create our own solar battery and other solar cell projects using household items. While these cells won't look as spiffy as the ones from the store, they still produce electricity from sunlight.

But how does the silicon *do* that?

Semiconductors are the secret to making solar cells. A semiconductor is a material that is part conductor and part insulator, meaning that electricity can flow freely or not, depending on how you structure it. There are lots of different kinds of semiconductors, including copper and silicon.

In semiconductors, there's a gap (called the *bandgap*) that's like a giant chasm between the free electrons (electrons knocked out of its shell) and bound electrons (electrons attached to an atom). Electrons can be either free or attached, but it costs a certain amount of energy to go either way (like a toll both).

When sunlight hits the semiconductor material in the solar cell, some of the electrons get enough energy to jump the gap and get knocked out of their shell to become free electrons. The free electrons zip through the material and create a flow of electrons. When the sun goes down, there's no source of energy for electrons to get knocked out of orbit, so they stay put until sunrise.

Wind and Water Power

Believe it or not, most of the electricity you use comes from moving magnets around coils of wire! Wind turbines spin big coils of wire around very powerful magnets (or very powerful magnets around big coils of wire) by capturing the flow.

Here's how it works: when a propeller is placed in a moving fluid (like the water from your sink), the propeller turns. If you attach the propeller to a motor shaft, the motor will rotate, which has coils of wire and magnets inside. The faster the shaft turns, the more the magnets create an electrical current.

The electricity to power your computer, your lights, your air conditioning, your radio or whatever, comes from spinning magnets or wires! (Refer to Unit 11 for more detail about how moving magnets create electricity.)

Does it really matter what angle the solar cell makes with the incoming sunlight? If so, does it matter *much*? When the sun moves across the sky, solar cells on a house receive different amounts of sunlight. You’re going to find out exactly how much this varies by building your own solar vehicles.

Battery-Free Radios?

A crystal radio is among the simplest of radio receivers—there’s no battery or power source, and nearly no moving parts. The source of power comes directly from the radio waves themselves.

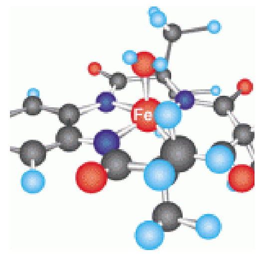
The crystal radio turns the radio signal directly into a signal that the human ear can detect. Your crystal radio detects the AM band that has been traveling from stations (transmitters) thousands of miles away.

After working with the electromagnetic spectrum in Unit 9 where we played with frequency and wavelengths of light, you'll find that you've got all the basics for picking up AM radio stations using simple equipment from Radio Shack.

The radio is made up of a tuning coil (magnet wire wrapped around a toilet paper tube), a detector (germanium diode) and crystal earphones, and an antenna wire.

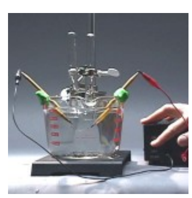
One of the biggest challenges with detecting low-power radio waves is that there is no amplifier on the radio to boost the signal strength. You'll soon figure out that you need to find the quietest spot in your house away from any transmitters (and loud noises) that might interfere with the reception when you build one of these. One of things you'll have to do is to figure out the best antenna length to produce the clearest, strongest radio signal in your crystal radio.

Energy from Molecular Bonds



We're going to use electricity to split the water molecule (H_2O) into hydrogen and oxygen atoms. Molecules can also be split chemically or by getting hit by a fast-moving particle. When you recombine the hydrogen and oxygen, energy is produced—enough to power a small car.

If you guessed that this has to do with electricity and chemistry, you're right! But you might wonder how they work together. Back in 1800, William Nicholson and Johann Ritter were the first ones to split water into hydrogen and oxygen using electrolysis. (Soon afterward, Ritter went on to figure out electroplating.) They added energy in the form of an electric current into a cup of water and captured the bubbles forming into two separate cups, one for hydrogen and other for oxygen.



It takes energy to split a water molecule. (On the flip side, when you combine oxygen and hydrogen together, it makes water and a puff of energy. That's what a fuel cell does.)

Back to splitting the water molecule—as the electricity zips through your wires, the water molecule breaks apart into smaller pieces: hydrogen ions (positively charged hydrogen) and oxygen ions (negatively charged oxygen). Remember that a battery has a plus and a minus charge to it, and that positive and negative attract each other.

So, the positive hydrogen ions zip over to the negative terminal and form tiny bubbles right on the wire. Same thing happens on the positive battery wire. After a bit of time, the ions form a larger gas bubble.

If you stick a cup over each wire, you can capture the bubbles and when you're ready, ignite each to verify which is which. We covered the basics of electrolysis in Unit 8 you will see how to store the energy and use it to power a small car in your experiments.

Energy from Food

The basic idea of electrochemistry is that charged atoms (ions) can be electrically directed from one place to the other.

If we have a glass of water and dump in a handful of salt, the NaCl (salt) molecule splits into Na^+ and Cl^-.

When we plunk in one positive electrode and one negative electrode and crank up the power, we find that opposites attract: Na^+ zooms over to the negative electrode and Cl^- zips over to the positive. The ions [charged atoms Na (sodium) and Cl (chlorine) in this case] are attracted to the opposite electrode and there is current in the solution.

Electrochemistry studies chemical reactions that generate a voltage and vice versa (when a voltage drives a chemical reaction), called oxidation and reduction (redox) reactions. When electrons are transferred between molecules, it's a redox process.

Fruit batteries use electrolytes (solution containing free ions, like salt water or lemon juice) to generate a voltage. Think of electrolytes as a material that dissolves in water to make a solution that conducts electricity.

Fruit batteries also need electrodes made of conductive material, like metal. Metals are conductors not because electricity passes *through* them, but because they contain electrons that can move (covered in Unit 10). Think of the metal wire like a hose full of water. The water can move through the hose. An insulator would be like a hose full of cement—no charge can move through it.

One of the biggest challenges with fruit batteries is reading an average voltage. Due to the nature of the experiment, the voltage can vary as much as ±30%. Does it really matter which fruit we use to power a LED? If so, does it matter *much*? That's what we're going to discover!

BEAM Robots

This is one of the coolest applications of renewable energy to come about in recent years. BEAM stands for **b**iology, **e**lectronics, **a**esthetics, and **m**echanics. It basically refers to a class of robots that, instead of having complicated brains, rely on nervous-system type of sensors to interact with their world.

Some BEAM robots skitter, dance, flash, jump, roll, or walk, and most are solar powered. The result is a fast-responding robot made of old cell phone parts that can fit inside your hand. We'll be making a few different types so you can get a good handle on this type of programming-free, battery-free robotics.

