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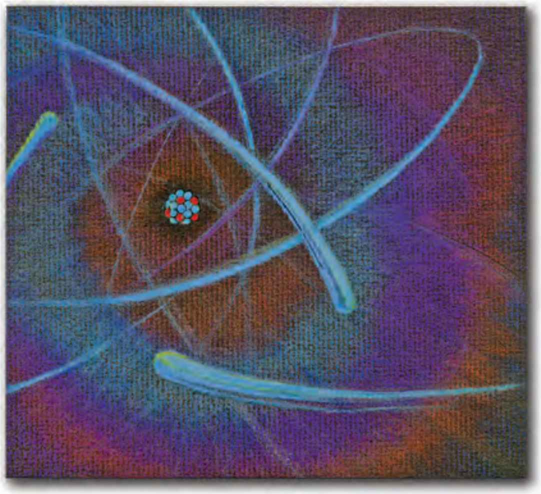
U.S. DEPARTMENT OF ENERGY
Office of Nuclear Energy



The Harnessed Atom

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Lesson 1

ENERGY BASICS

Introduction

This lesson will look at the states and forms of energy. Next we will look at where energy comes from. Finally, we'll explore how the way we live is tied to our energy supply and what that means for the future.

TOPICS:

- **States of energy**
  - Potential
  - Kinetic
- **Forms of energy**
  - Mechanical
  - Chemical
  - Nuclear
  - Electrical
  - Radiant
  - Energy from gravity
  - Thermal
- **Energy sources**
  - Primary and secondary sources
  - Renewable vs non-renewable
  - Conversion
  - Conservation
- **Environmental effects**
  - Greenhouse effect
  - Climate change
- **Future sources**

What is energy?

Energy is the ability to do work. But what does that really mean?

You might think of work as cleaning your room, cutting the grass, or studying for a test. And all these require energy.

To a scientist, "work" means something more exact. **Work** is causing a change. It can be a change in position, like standing up or moving clothes from the floor to the laundry basket. It can be a change in temperature, like heating water for a cup of tea. Or it can be a change in form, like the water in tea changing from liquid to steam. All of these things are work and require energy.

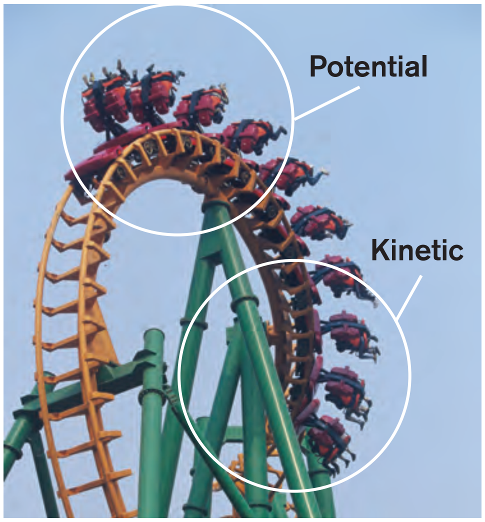
We use energy all the time. Whenever work is done, energy is used. All activities involve energy.

We need energy to

- power our factories and businesses
- heat and light our homes and schools
- run our appliances and machines
- stay alive and keep our bodies moving
- build and fuel our cars, trucks, planes, and ships
- run television and videos
- power our phones, computers, music, and games
- make our clothes
- and do everything else that we do

What are the states of energy?

We can divide energy into two basic states: potential energy and kinetic energy. **Potential energy** is stored energy that is waiting to be used. **Kinetic energy** is energy of motion. A roller coaster at the top of the track has potential energy. When the roller coaster speeds down the track, the potential energy is changed into kinetic energy. Heat, light, and motion all indicate that kinetic energy is doing work. Potential energy is often harder to detect. It must be changed into kinetic energy before we can use it.

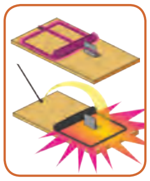


Potential energy is stored energy. Kinetic energy is energy of motion.

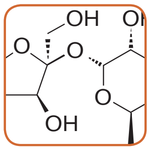
What are the forms of energy?

There are many forms of potential and kinetic energy. These include mechanical, chemical, thermal, electrical, radiant, and nuclear energy, as well as the energy of gravity.

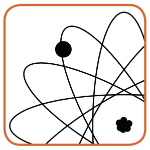
- **Mechanical energy** is the energy that moves objects by applying a force. It can be kinetic – the motion of a snapping mousetrap. Or it can be potential – the tension in a set mousetrap.



- **Chemical energy** is the energy released when the chemical bonds of a material change. Wood stores chemical energy that is released when it burns.



- **Nuclear energy** is the energy stored in the center (nucleus) of an atom. It's the energy that holds the center together. The energy can be released when the center splits apart or when centers fuse together.

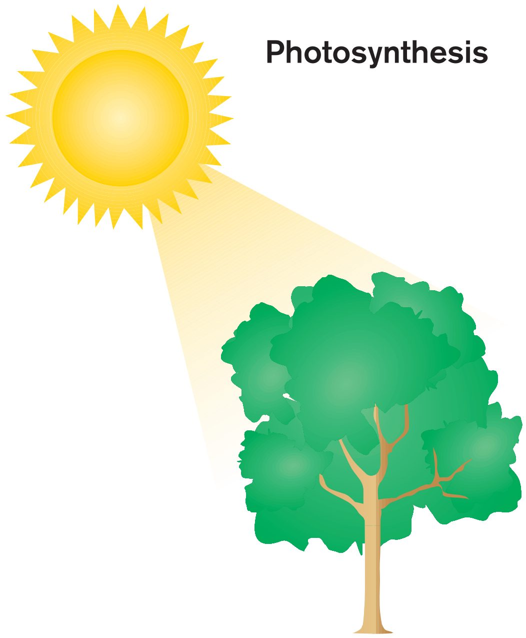


- **Electrical energy** is the flow of tiny charged particles called electrons. Electrons move through a conductor, such as a copper wire.

- **Radiant energy** is energy traveling as waves. It includes visible light, radio waves, x-rays, and gamma rays. The Sun's energy comes to us in this form.

- **Energy from gravity** is the energy of position or place. The potential energy of water held behind a dam is changed to kinetic energy when it is allowed to flow downhill.

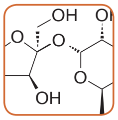
- **Thermal energy** is heat energy. We use it to cook meals, to manufacture products, and to generate electricity.



Plants use photosynthesis to store energy from the Sun. In the process of photosynthesis, plants convert radiant energy from the Sun into chemical energy in the form of sugar or starch.

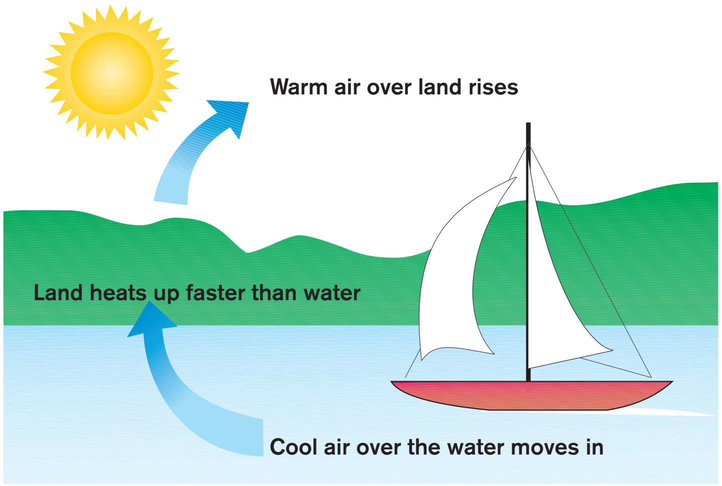
Where does energy come from?

Much of the Earth's energy comes from the Sun in the form of radiant energy. Plants convert this energy to chemical energy by a process called **photosynthesis**. This chemical energy is stored in the form of sugars and starches, which provide energy for the plant as well as people and animals that eat the plant. When we burn plants such as trees, stored chemical energy is converted and released in the form of heat (thermal energy) and light (radiant energy), which we call fire.

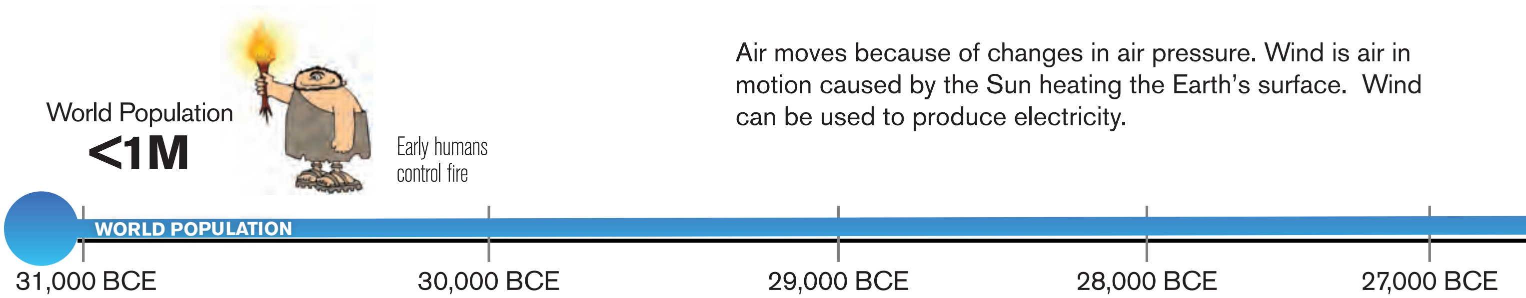


Biomass is the name for materials from plants and animals that have chemical energy stored in them. The energy in biomass originally came from the Sun. A biomass fuel we all know is wood for fireplaces and wood stoves. Other examples are crops such as corn and switchgrass, manure, garbage, and methane gas from landfills. By burning biomass, we release its stored chemical energy as thermal and radiant energy. We also can convert it to liquid fuel, such as **ethanol** and **biodiesel**. Biomass fuels provided about 4.6 percent of the energy used in the United States in 2012.

Radiant energy from the Sun's rays make some parts of the Earth warmer than others. Air surrounding these warmer surfaces is heated, which causes it to rise. Cooler air then flows in to replace the heated air that has risen. We call this flow of air **wind**.



Air moves because of changes in air pressure. Wind is air in motion caused by the Sun heating the Earth's surface. Wind can be used to produce electricity.

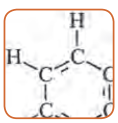


Radiant energy from the Sun also causes water to evaporate into water vapor. The water vapor rises into the upper atmosphere

where it forms clouds and rain. This is called the **water cycle**. The tremendous energy in storms and winds is actually caused by the Sun's radiant energy.

When it rains, the water flows down rivers. The energy in moving water can turn a watermill or turbine to make **hydropower**.

About 300 million years ago, countless plants and animals died and were slowly



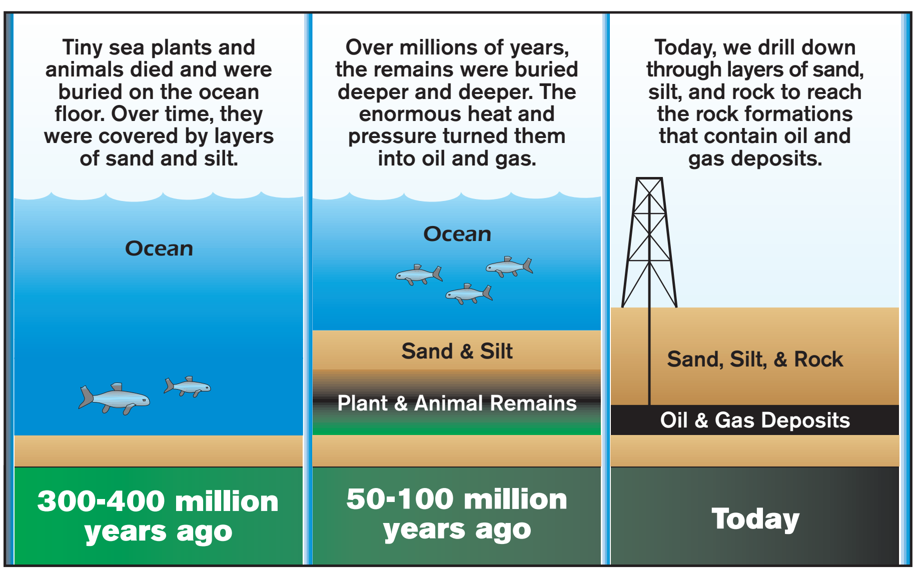
buried beneath layers and layers of dirt and sand. Heat and pressure from these layers concentrated the chemical energy stored in them, slowly changing them to the **fossil fuels** oil, coal, and natural gas.

What is primary energy?

Primary energy is energy found in nature before we convert it to do work. Primary energy sources are

- **Solar energy** (sunlight)
- **Water power** (flowing water)
- **Wind energy** (moving air caused by the Sun heating the atmosphere)
- **Biomass** (plants)
- **Tidal energy** (the effect of the gravity of the Moon and Sun on the oceans)
- **Nuclear energy** (energy from inside uranium and plutonium)
- **Geothermal energy** (heat from inside the Earth)
- **Fossil fuel energy** (coal, natural gas, oil). We consider fossil fuels to be primary energy sources even though they originally took their energy from the Sun and stored it as chemical energy

Petroleum and Natural Gas Formation



Petroleum was formed millions of years ago from the remains of plants and animals under heat and pressure.

WORLD POPULATION

26,000 BCE | 25,000 BCE | 24,000 BCE | 23,000 BCE

What are secondary energy sources?

There are also **secondary energy sources** that are produced by using primary energy. Electricity is a secondary source that can be produced from any of the primary sources listed. Ethanol is a secondary energy source made from biomass.

What are renewable and non-renewable energy sources?

We can further divide the primary and secondary energy sources we use into renewable and non-renewable sources. **Renewable** sources can be continuously replaced. Day after day the Sun shines, the wind blows, plants grow, and rivers flow. We use renewable energy sources in our wood stoves, to make electricity, and to make alcohol and biodiesel fuel for cars. **Non-renewable** sources cannot be replaced. The supplies of coal, oil, natural gas, and uranium are limited. When we use up these resources, they will be gone. In the United States, most of the energy we now use comes from non-renewable sources. We use them to make electricity, heat our homes, move our cars, and to manufacture goods.

How do we convert energy from one form to another?

The **law of conservation of energy** says that energy can change from one form into another, but it cannot be created or destroyed. In fact, when we say that we use energy, we really mean that we convert and harness it to do the work we need to do.

Energy is converted in hundreds of ways. For example, burning gasoline to power cars is an energy conversion process we rely on. The chemical energy in gasoline is converted to thermal energy, which is then converted to mechanical energy that makes the car move.

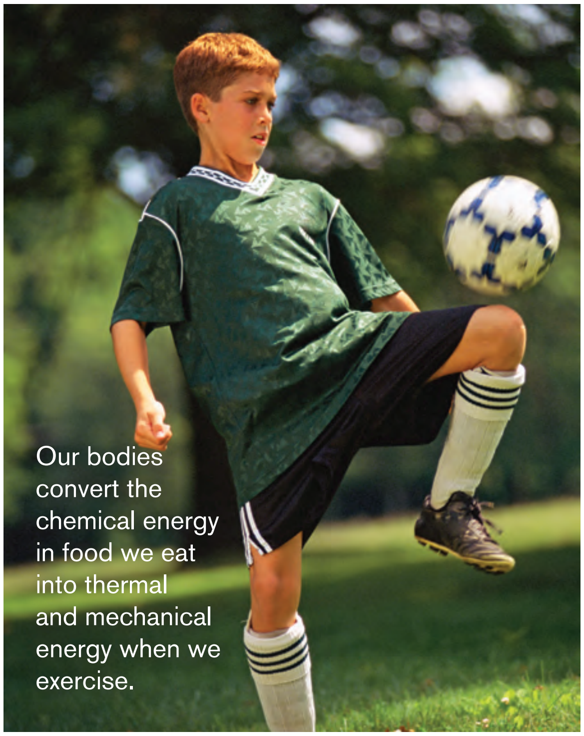
Think about it...

Renewable energy sources are constantly being replaced. Having an energy **supply** we can use now and also count on into the future is important.

But right now there are limitations to using renewable energy. First, there is the **intermittent** nature of the sources. The wind does not always blow, the Sun does not shine at night, and dry spells reduce the flow of rivers for hydropower. Second, the high cost of some of the technologies used for harnessing renewable energy drives up the cost of energy from these sources. Third, there are costs for getting power from renewables to customers.

There are also impacts on the environment. For example, hydropower does not produce carbon dioxide like burning fossil fuels, but building a dam does alter the area where it is built. This may affect plants and animals.

22,000 BCE 21,000 BCE 20,000 BCE



Our bodies convert the chemical energy in food we eat into thermal and mechanical energy when we exercise.

The mechanical energy has been converted to kinetic energy. When we use the brakes to stop a car, that kinetic energy is converted by friction back to heat, or thermal energy.

Our bodies are also powered by converting energy. We must convert the energy in food into other forms of energy, such as mechanical energy so we can move, or thermal energy to maintain body temperature. When we exercise, we also produce a lot of heat energy. You can feel this heat because when you work hard you get hot. Your body converts the chemical energy in your food into mechanical energy, but some is lost as wasted heat.

What is efficiency?

Each time we convert energy from one form to another, we lose some of it, often as heat. We must constantly put more energy into machines or they will run down. A machine or system that converts energy without wasting much is very **efficient**. In fact, most energy conversion processes are not very efficient. As a result, energy is lost to the environment. Only about 25 percent of the energy we use in our bodies or automobiles is converted into mechanical energy. The rest is lost as heat. When a conversion process wastes a lot of energy, it is called **inefficient**.

The first law of thermodynamics explains why...	Energy changes from one form to another, but it can't be created or destroyed.
The second law of thermodynamics explains why...	Every time energy is converted from one form to another, there is less energy available to do useful work.

When we do not convert energy efficiently, it costs money and wastes valuable resources. This is why people today are

Think about it...

An incandescent light bulb gets very hot. A fluorescent bulb gets warm. An LED light stays cool. Which do you think is most efficient in converting electricity into light?

WORLD POPULATION

19,000 BCE — 18,000 BCE — 17,000 BCE — 16,000 BCE looking for ways to save energy by carefully using our energy resources and by trying to convert energy as efficiently as possible.

How can we save energy?

Wasting less energy is called **conservation**. Although conservation is not an energy source, we can use it to make non-renewable energy sources last longer into the future. We can all practice conservation by being careful about how much energy we use. Some things we can do are

- Carpooling
- Driving less, walking, and biking
- Using public transportation, like subways and buses
- Setting the thermostats in our homes, schools, and work places to reduce waste
- Reducing, reusing, and recycling things instead of throwing them away
- Turning off lights and appliances when they are not being used
- Insulating our homes
- Using energy-saving light bulbs
- Unplugging chargers for our phones and music players when we are not using them

Because conserving energy has become more important, manufacturers are making more efficient machines. Choosing cars that are more efficient helps. Also, families can purchase appliances that have good energy efficiency ratings.

What are some environmental impacts of our energy use?

If you've ever been to a greenhouse, you know it's a place to grow plants, even in winter. Usually a greenhouse looks like a glass building. The glass lets the radiant energy from the Sun in, but as the light passes through the glass, its wavelengths get longer and cannot pass easily back out of the glass. The radiant energy is trapped as heat.

Some gases in the atmosphere trap heat in much the same way as a layer of glass. They are called **greenhouse gases**. The rise in temperature that results is called the **greenhouse effect**.

Sunlight enters the Earth's atmosphere. The land, water, and atmosphere absorb the radiant energy. Some of the energy reflects back through the atmosphere to space, but some is trapped in the atmosphere by greenhouse gases. Increasing the amount of greenhouse gases in the atmosphere traps more heat, causing temperatures to rise. Global warming is a planet-wide rise in temperature. Rising

Recycling is one thing that families can do to help save energy.

temperatures may cause changes in rainfall, the strength of storms, melting polar ice, and rising sea levels. This is called **climate change**.

Greenhouse gases occur both naturally and as the result of human activity. Some of the major greenhouse gases are

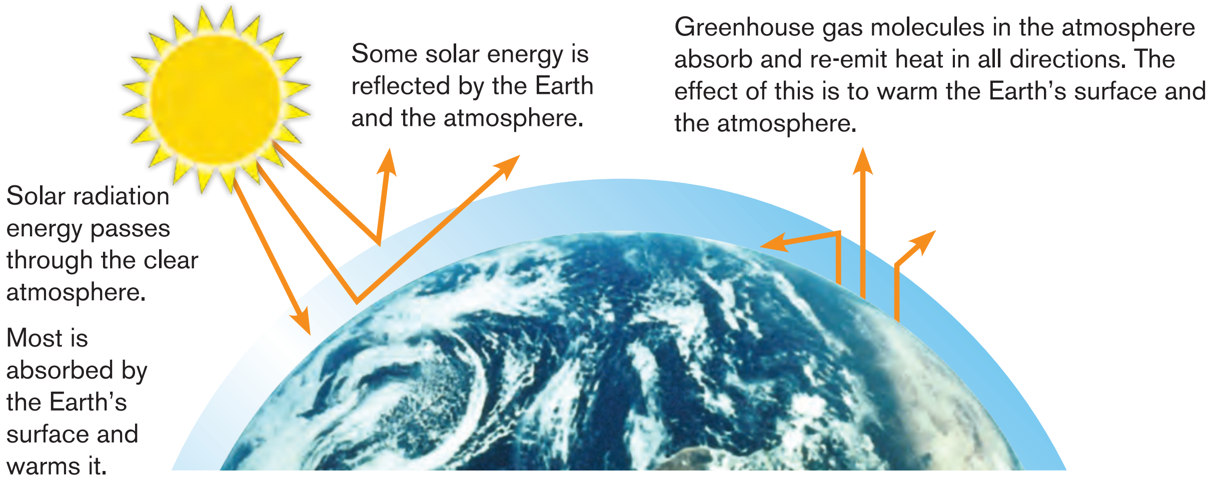
- **Carbon dioxide (CO_2)** – released when we burn oil, coal, and natural gas. It also comes from biomass and volcanoes.
- **Methane (CH_4)** – comes from landfills, coal mines, oil and natural gas operations, and agriculture.
- **Nitrous oxide (N_2O)** – comes from the use of nitrogen fertilizers and burning fossil fuels.

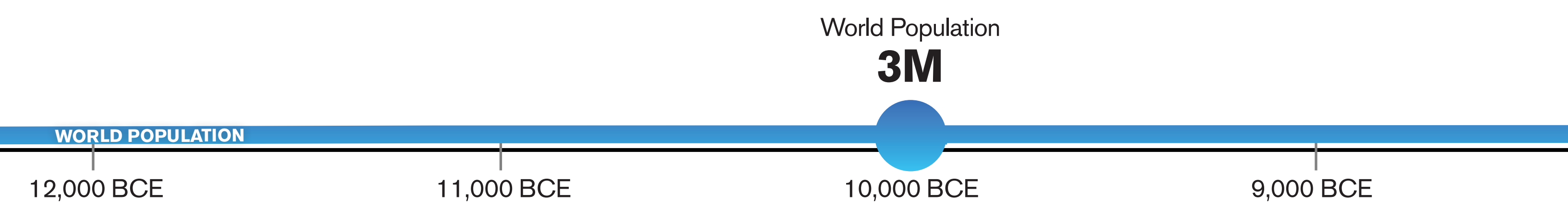
Each way we produce energy affects our environment in some way. Think about the effects of

- Mining coal and uranium
- Drilling for oil
- Fracturing underground rock for natural gas and geothermal wells
- Damming rivers for hydropower
- Cutting trees
- Placing turbines in the sea for tidal power
- Using large tracts of land for wind or solar farms
- Disposing of wastes from burning coal or from nuclear power plants

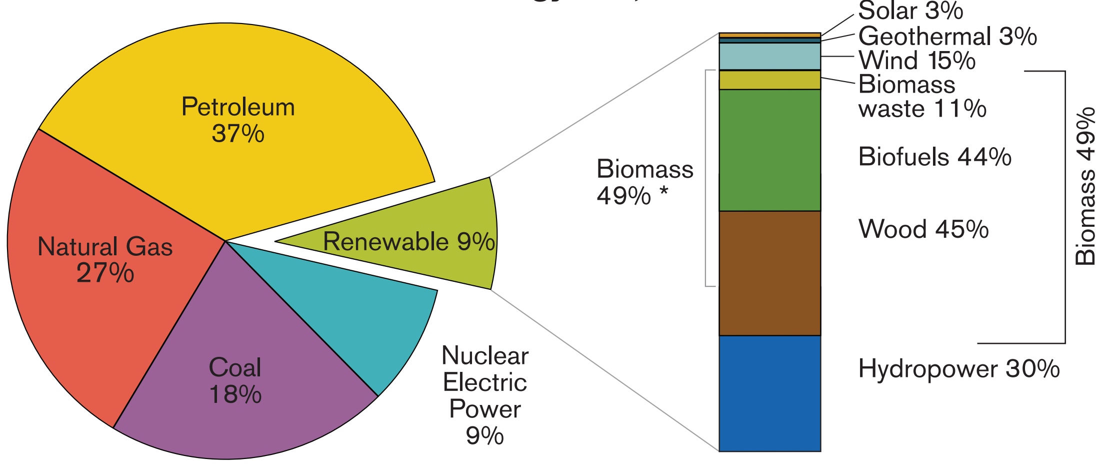
It is important for us to use our energy resources wisely and protect the environment.

The Greenhouse Effect





Our Total Energy Use, 2012



Note: Sum of biomass components does not equal 53% due to independent rounding.
Source: U.S. Energy Information Administration, Monthly Energy Review, Table 10.1 (April 2013), preliminary 2012 data.

About 91 percent of the energy used in the United States in 2012 came from non-renewable sources. Renewable sources provided about 9 percent.

Which energy sources will we use?

More and more, people are becoming aware of how crucial energy is to our way of life. There is also a growing awareness that we will need to make some changes in the energy sources we rely on and about how we use energy. Most people think we will need to use many different energy sources. But our choices are complicated.

We'll have to think about

- The available supply of each resource and where it is located. For example, we buy almost half of our oil from other countries. For our national security, many people want us to be able to produce the energy we need from U.S. sources.
- The cost of the energy we need.
- Which resources can provide enough of the energy we need.

Farmers harness oxen to plow fields

- The impact on the environment from obtaining the energy resource.
- The impact on the environment from using the resource.
- Choosing energy sources that work best in different parts of the country.

During our lifetime, the ways we use and supply our energy will change. We will need to use energy more wisely and protect the environment better.

1859 CE First oil production well drilled in Pennsylvania

1826 CE John Ericson builds hot-air engine powered by the sun

1803 CE Steam locomotive invented

1787 CE Steamboat invented

1785 CE First water-powered fabric loom invented

1698 CE First steam pump invented

1300 CE Hopi Indians use coal for heating, cooking, and firing pottery. Anasazi Indians build cliff dwellings with southern exposures for solar heating

1100 CE Windmills introduced in Europe

644 CE First vertical axis windmill used in Iran

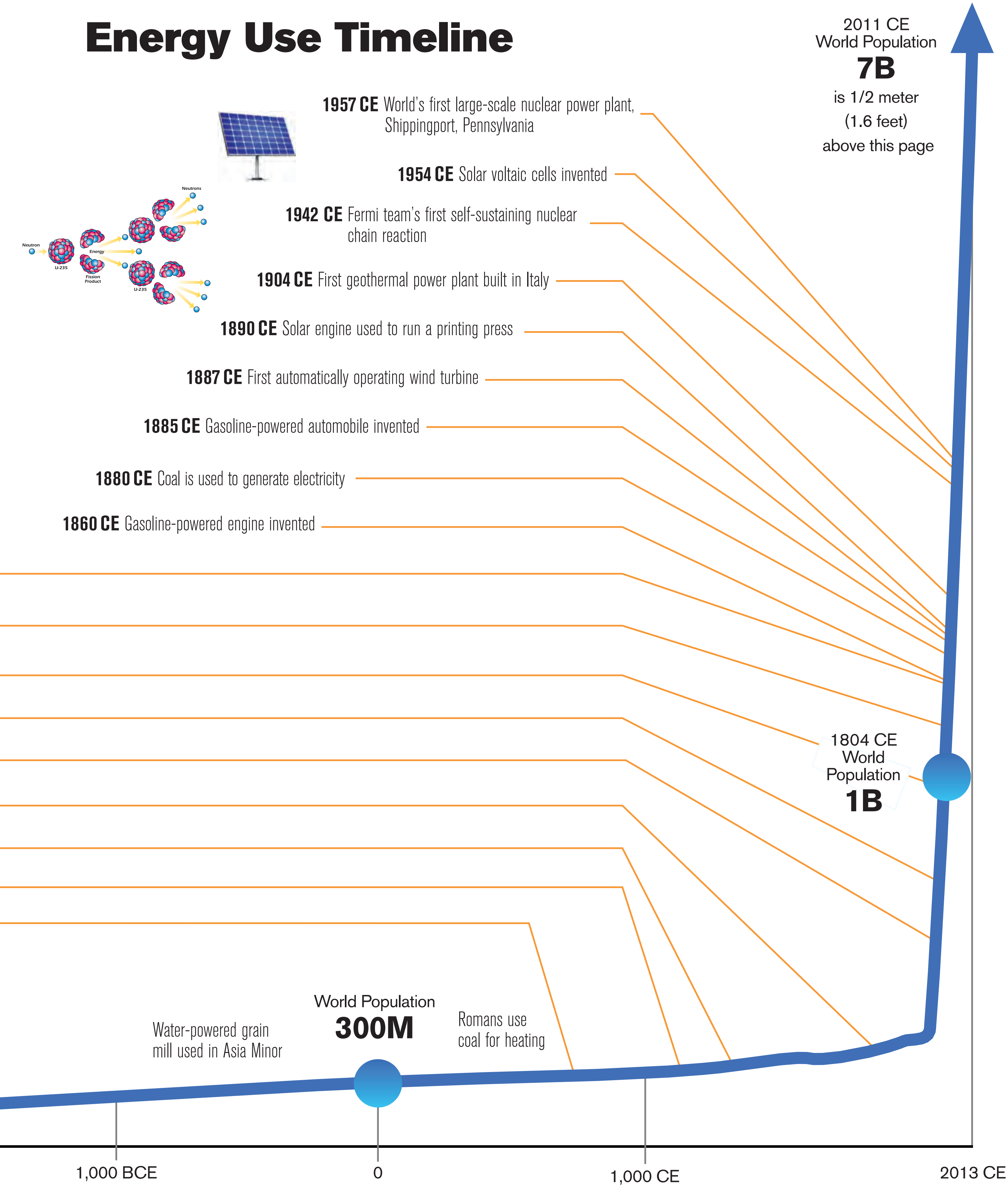
Hot springs used for bathing, cooking, and heating by Romans, Japanese, and others

World Population
85M

WORLD POPULATION

4,000 BCE | 3,000 BCE | 2,000 BCE

Energy Use Timeline



Summary

Energy is the ability to do work.

There are two basic states of energy — potential and kinetic. Potential energy is stored energy. Kinetic energy is energy in motion.

There are many forms of potential and kinetic energy, including mechanical, chemical, thermal, electrical, radiant, nuclear, and the energy of gravity.

The primary sources we use today are fossil fuel energy, nuclear energy, geothermal energy, solar energy, and tidal energy. All these can be used to make electricity, a secondary source of energy.

Energy sources can be divided into renewable and non-renewable sources. Non-renewable sources cannot be replaced. Renewable sources can be replaced.

We can convert energy from one form to another, but we cannot create or destroy energy.

Saving energy is called conservation. Although conservation is not an energy source, we can use it to extend the time non-renewable sources will be available.

There are environmental impacts from the use of all energy sources. One impact is from greenhouse gases, which most scientists believe are contributing to climate change. Mining, drilling, and building dams affect the land and water. There can be spills that affect the oceans and wildlife.

Meeting our energy needs during your lifetime will be different than in the past.

Lesson 2

ELECTRICITY BASICS

Introduction

It's difficult to imagine life without convenient electricity. You just flip a switch or plug in an appliance, and it's there. But how did it get there? Many steps go into providing the reliable electricity we take for granted.

In this lesson, we will take a closer look at electricity. We will follow the path of electricity from the fuel source to the home, including the power plant and the electric power grid. We'll explore the role of electric utilities in the generation, transmission, and distribution of electricity.

TOPICS:

- **Basics of electricity**
- **Generating electricity**
  - Similarities of power plants
- **Distributing electricity**
  - Generation
  - Transmission
  - Distribution
  - Power grids
  - Smart grids
- **Utilities**
  - Cost of electricity
  - Regulation
  - Deregulation
- **Planning for the future**

What is electricity?

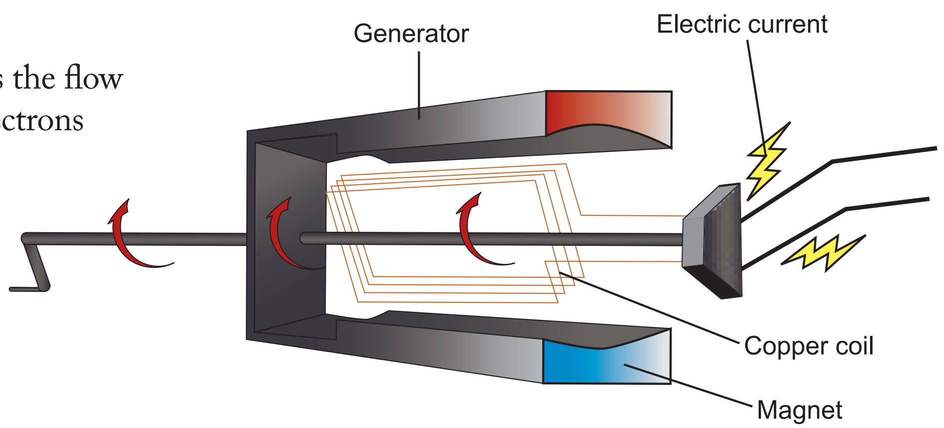
Of all the forms of energy, **electricity** is the one we rely on most in our day-to-day lives. In fact, we are so accustomed to using electrical energy that we tend to take it for granted – until service stops and everything comes to a halt.

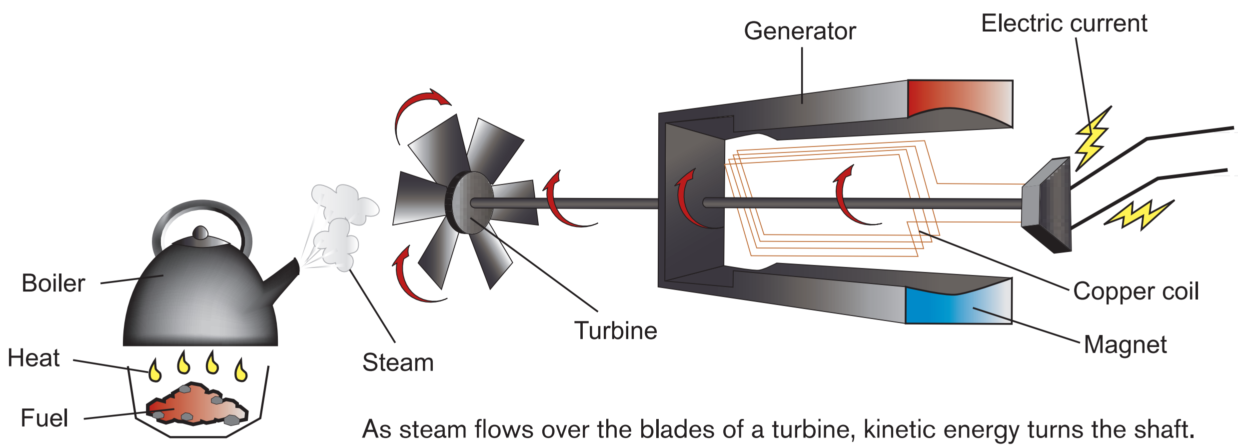
Electricity is our most versatile and adaptable form of energy. We use it at home, at school, and at work to run numerous machines and to heat and light buildings.

To scientists, electricity is the flow of tiny particles called electrons that have an electrical charge. Sometimes you see it in the sky as lightning or experience it as static electricity when your hair is attracted to a comb or when there is a crackling sound as you take off your sweater.

How is electricity produced?

To produce a steady flow of electricity, we use a generator. A generator is a coil of copper wire that spins inside a magnetic field. This produces a flow of electrons through the coil of wire.





As steam flows over the blades of a turbine, kinetic energy turns the shaft.

Where is electricity produced?

Electricity is generally produced at a power plant by converting one of the primary sources of energy into electricity.

What energy sources do we use to make electricity?

In the United States, the sources we use to make electricity are fossil fuels (coal, oil, or natural gas), uranium, or falling water. We also use solar power, wind, biomass, and geothermal sources.

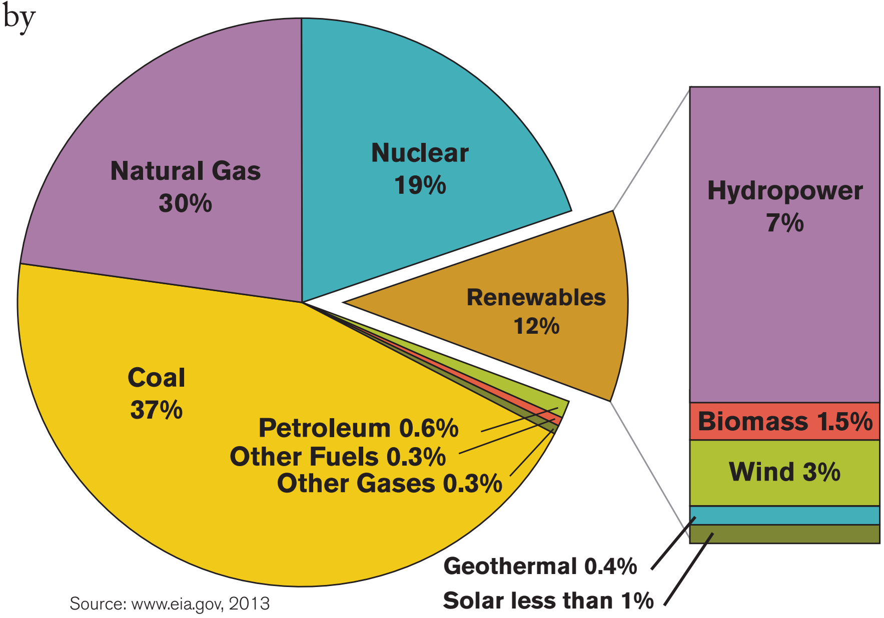
Most power plants are similar in several important ways. They generate electricity by heating water to produce **steam**. The steam is then directed against the blades of a **turbine**, making it spin much like the way air makes a windmill's blades spin. The turbine turns the generator and produces electricity.

Who makes electricity?

Companies that sell electricity to customers are called **utilities**. A utility provides something useful or essential to the public, like electric power, natural gas, or water.

Because a utility provides an essential service to its customers, it has special duties. For instance, an electric utility must be able to supply all the electrical needs of its customers. A utility can't promise to deliver its product in two weeks the way some other

Fuels Used to Make Our Electricity



Source: www.eia.gov, 2013

companies can. Electricity must be ready for use all the time. This means there must be generating plants, fuel, and enough power lines to provide service at any instant. The supply must be reliable. The cost must be reasonable.

To make sure these conditions are met, State and local governments **regulate** utilities. When governments regulate, they make sure the utility provides good services at prices that are fair to customers and the utility. In return, the utility is allowed to be the only one in its area. In some areas of the country, **deregulation** now allows customers to choose which company they buy their electricity from the same way they can select a phone or internet company. However, State public utility commissions still regulate rates for customers, approve sites for generation facilities, and enforce State environmental regulations.

How do we get electricity to the place where we use it?

The electricity produced in the generator is sent out over wires to homes, schools, hospitals, farms, offices, and factories. Getting it there is not a simple job.

One way to think about how electricity is distributed is to imagine water being pumped through pipes. The water flows from high pressure at the pump down the pipes toward the lower pressure at your home. With electricity, this "pressure" difference is called **voltage**.

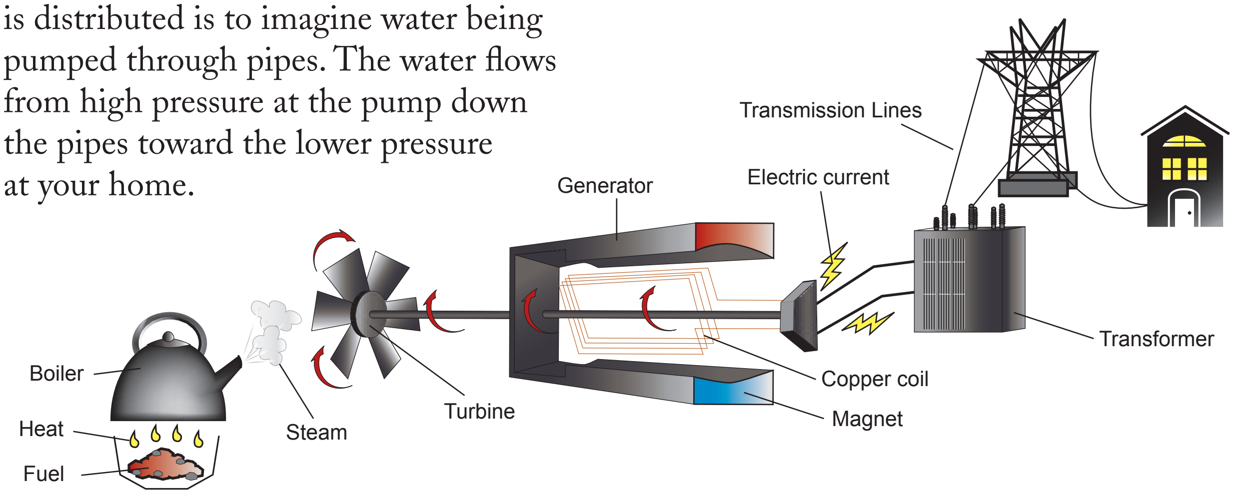
There are three main steps in getting electricity to customers:

- **Generation** – using a source of energy to produce electricity
- **Transmission** – using high voltage lines from the power plant to distribute electricity to areas that may be far from the power plant
- **Distribution** – using lower voltage lines, **substations**, and transformers to deliver electricity to local customers

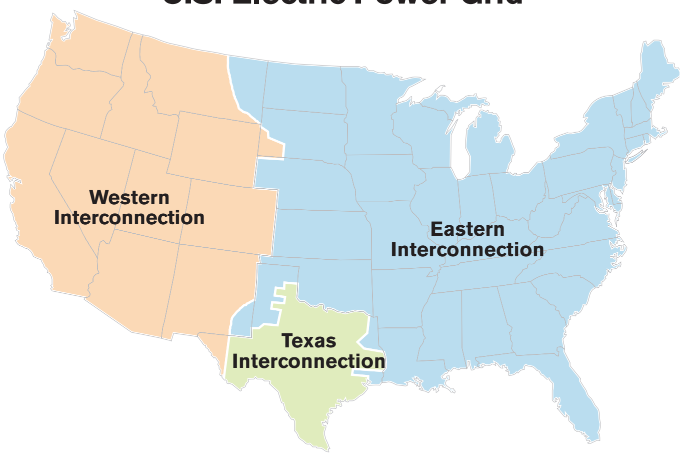
At one time, almost all of the electricity used in the United States came from companies that owned the power plants, transmission lines, and distribution systems. Today, some companies are involved in generation, transmission, and distribution, while other companies are involved in only one aspect of the industry.

What is the power grid?

To get electricity to everyone who needs it, utilities send large amounts of electrical power over long distances. This is done through a network of transmission lines called the **power grid**. At the power plant, the voltage from the



The Main Interconnections of the U.S. Electric Power Grid



The national power grid connects the 48 continental U.S. States. Alaska and Hawaii have their own grids.

generator is increased to transmit it more efficiently. The high-voltage current is then sent through the power grid to a substation where it is transformed to lower voltages for distribution to homes, schools, and industries.

Over the years, transmission networks have evolved into three major power grids in the 48 connected States. These networks allow electricity to transfer from one part of the grid to another. The three networks are the

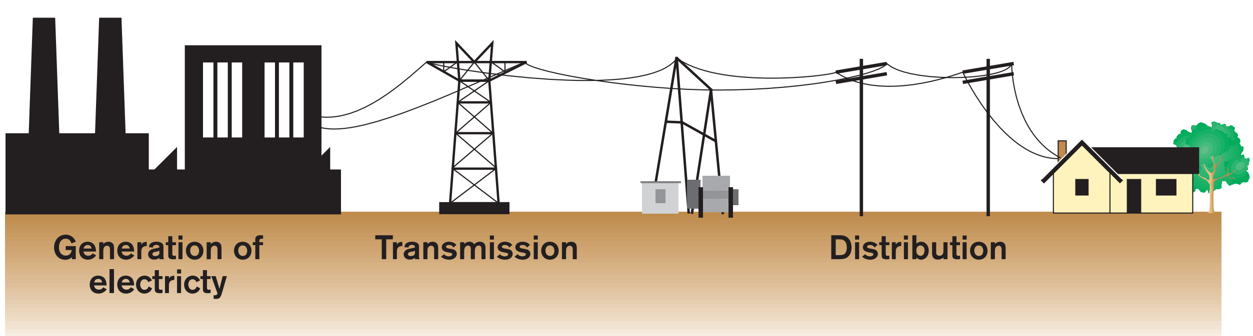
- Eastern Interconnection
- Western Interconnection
- Texas Interconnection

These interconnections between utilities allow them to meet changing energy demands. For example, a utility that has a power shortage can buy electricity from a utility that has a surplus. It also allows small companies or even individuals to sell the electricity they generate to others. This is important because it helps us use intermittent energy sources like hydropower, wind, and solar power. It also means that if a company or even a family generates more electricity than it can use, the electricity can be sold so it isn't wasted.

What is the "smart grid"?

To make sure electricity is there when customers need it, utilities are investing in **smart grid** equipment. This wireless equipment lets the utility know what is

The Power Grid



Electricity is distributed to homes and industry through a power grid.

The smart grid communicates with other wireless equipment the way smart phones do.

happening in real time. It helps the utility find and fix problems like damaged power lines quickly. A smart grid can also tell the power company when more electricity is needed to meet demand. This helps utilities be more efficient. It also helps customers choose to use more electricity at times when power rates are cheaper.

Why do we have to pay for electricity?

The electric industry must build power plants, run them, buy fuel for the plants, string wires or bury them underground to every home and business, and pay workers to do all the jobs that must be done. As you can imagine, all that takes a lot of money.

Meters measure a customer's use of electricity so that bills are accurate.

Customers pay the utility for the electricity that they use. Meters keep track of how much electricity travels from a power company's wires into our homes, businesses, schools, and factories. The company either sends a worker to read the meter or newer meters send a signal through the power lines to the power company that shows how much each customer has used. Then the power company sends each user a bill.

How do utilities plan for the future?

Because an electric utility must serve the needs of the public, the people who manage it must plan carefully so they can produce enough electricity. Decisions made today must predict the public's need for electricity in the future. These decisions can be difficult. It takes from 5 to 15 years to build a new fossil fuel or nuclear plant. It also takes time to build a power plant that uses renewable energy, like a dam, solar project, or a wind farm. Because it can take so long, utilities must act on predictions of what customers will need in the future.

Summary

Electricity is our most versatile form of energy. Electricity is created by the flow of tiny particles called electrons that have an electrical charge.

At power plants, electricity is produced by converting an energy source into electricity. In the United States, the sources include fossil fuels, uranium, and water power. We also use solar power, wind, biomass, and geothermal energy.

Most U.S. power plants generate electricity by heating water to produce steam and then use steam to turn the blades of a turbine attached to a generator.

Companies that sell electricity are called utilities. Utilities are often regulated so that our electricity supply is steady and costs are fair.

There are three main steps in getting electricity to customers – generation, transmission, and distribution. Electricity is sent through the power grid to customers. Customers pay for the electricity they use. New smart grid systems help utilities track the demand for electricity and operate efficiently.

Lesson 3

ATOMS AND ISOTOPES

Introduction

You've probably heard people refer to nuclear energy as "atomic energy." Why? Nuclear energy is the energy that is stored in the bonds of atoms, inside the nucleus. Nuclear power plants are designed to capture this energy as heat and convert it to electricity. In this lesson, we will look closely at what atoms are and how atoms store energy.

TOPICS:

- **Matter**
  - Molecules
  - Elements
  - Chemical reaction
  - Periodic Table
- **The atom**
  - Parts of an atom
  - Isotopes
  - Unstable isotopes
- **Scientists and discoveries**

What are molecules, elements, and atoms?

To understand nuclear energy, it is important to first understand **atoms**, which are the building blocks of **matter**.

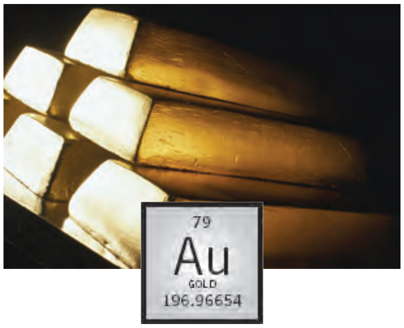
What do you suppose would happen if you took a lump of salt and began to break it up into smaller and smaller pieces? Sooner or later you would get pieces so small that you wouldn't be able to see them. The smallest piece that is still salt is called a **molecule**. Everything is made of molecules – sugar, salt, tables, chairs, and even the cells of your own body. However, all molecules are not alike. A molecule of sugar is different from a molecule of salt. But that is not the whole story.

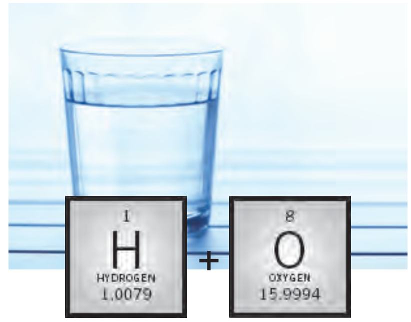
What is an atom?

Molecules are made of even smaller parts, which are called atoms. An atom is the smallest part of any element that has all the properties of that element. Atoms are so small that it takes millions of them to make a speck of dust.

Image Credit: Jon Reis

A molecule consists of two or more atoms bonded together. In the model built here, the black spheres represent carbon atoms. The connectors that join the spheres represent the chemical bonds.





Today, we know that at least 92 different kinds of atoms occur in nature. More kinds of atoms have been made by scientists. Each of these different kinds of atoms is a unique **element**.

Combining atoms of different elements – or atoms of the same element – forms molecules. The kind of molecule depends on which atoms combine. This combining is called a **chemical reaction**. In chemical reactions, atoms do not change. Instead, they combine with or separate from other atoms.

For example, gold is an element. A bar of pure gold contains only atoms of one element: gold. On the other hand, table salt is a combination of more than one kind of atom. It is made of atoms grouped into molecules. A molecule of table salt has one atom of the element sodium and one atom of the element chlorine. Another familiar example is water. A molecule of water has two atoms of hydrogen and one atom of oxygen. That is why chemists call water H_2O.

Atoms are the basic building blocks of everything in the universe. They are the smallest particles of matter that still have all of the properties of an element.

Think about it...

The word "atom" comes to us from a Greek philosopher named Democritus. Around 420 BCE, Democritus wondered, "What is the smallest piece you could cut something like a piece of gold into?" Although he did not have a laboratory, he realized that at some point, the gold would become too small to cut any more. He called the smallest piece *atomos*, which means "indivisible," or "cannot be cut." He proposed that all matter was made of these infinitely small particles that cling together in different combinations to make things. Democritus couldn't see atoms. But he understood that they must exist.

In 1803, English chemist John Dalton began to question ideas about structure of matter. He proposed an atomic theory that said

- Elements are made of very small particles–atoms
- For each element, all the atoms have the same size, mass, and properties
- Atoms cannot be divided, created, or destroyed
- Atoms combine to form chemical compounds
- In chemical reactions, the atoms in a compound rearrange or separate

Dalton performed experiments and found that matter seemed to consist of 35 elements that he could identify.

What are the parts of an atom?

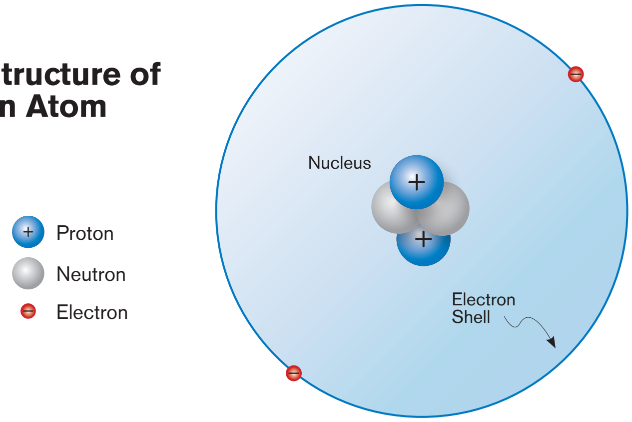
As small as atoms are, they are made of even smaller particles. There are three basic particles in most atoms – protons, neutrons, and electrons.

Protons carry a positive electrical charge (+). **Neutrons** have no electrical charge. Protons and neutrons together make a dense bundle at the center of an atom. This bundle is called the **nucleus**.

Electrons have a negative electrical charge (-) and move around the nucleus. They are extremely small compared to the other parts of an atom. Normally, an atom has the same number of protons and electrons. If the positively charged protons and the negatively charged electrons are equal in number, they balance each other. As a result, the atom has no electrical charge.

We use the number of protons in an atom to identify it. For instance, an atom of oxygen has 8 protons in its nucleus. Carbon has 6, iron 26, gold 79, lead 82, uranium 92, and so on.

Structure of an Atom



The Rutherford-Bohr model provides a simple representation of the structure of an atom. Modern physics theory places the movement of electrons in a cloud of possible orbits around the nucleus.

How was the periodic table developed?

Imagine discovering a few pieces of a jigsaw puzzle, but not knowing what the picture on the puzzle was supposed to look like, or even if it would make a picture. Now imagine that jigsaw puzzles had not been invented yet. Could you solve it?

That's similar to the challenge that scientists in the 1800s faced. They had discovered chemical elements but did not know how, or if, they fit together. Many elements were missing. No one had ever tried to make a chart that organized the information. But science is a process of organizing what we know to help us make sense of it all.

Building on what was being learned about atomic structure, Dmitri Mendeleev began sorting the known elements into categories. His sorting became the foundation of the

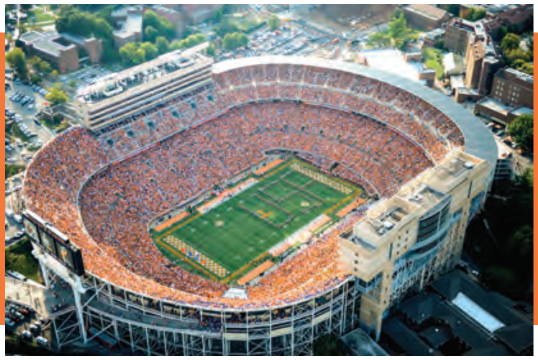


Image Credit: University of Tennessee

If you could enlarge an atom to the size of a stadium, its nucleus would be about the size of a grape on the mid-field stripe. Electrons would be smaller than grains of salt whirling around the upper deck. And the rest of the stadium would be empty space.

Periodic Table of the Elements

1 → Atomic Number
H
1.00794 → Atomic Weight
Hydrogen

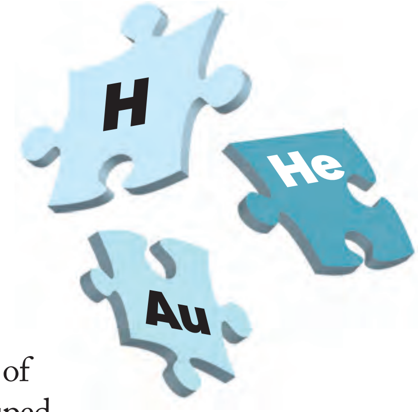
1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1 **H** 1.00794 Hydrogen																	2 **He** 4.002602 Helium
3 **Li** 6.941 Lithium	4 **Be** 9.012182 Beryllium											5 **B** 10.811 Boron	6 **C** 12.0107 Carbon	7 **N** 14.0067 Nitrogen	8 **O** 15.9994 Oxygen	9 **F** 18.9984032 Fluorine	10 **Ne** 20.1797 Neon
11 **Na** 22.98976 Sodium	12 **Mg** 24.3050 Magnesium											13 **Al** 26.9815386 Aluminum	14 **Si** 28.0855 Silicon	15 **P** 30.973762 Phosphorus	16 **S** 32.065 Sulfur	17 **Cl** 35.453 Chlorine	18 **Ar** 39.948 Argon
19 **K** 39.0983 Potassium	20 **Ca** 40.078 Calcium	21 **Sc** 44.955912 Scandium	22 **Ti** 47.867 Titanium	23 **V** 50.9415 Vanadium	24 **Cr** 51.9961 Chromium	25 **Mn** 54.938045 Manganese	26 **Fe** 55.845 Iron	27 **Co** 58.933195 Cobalt	28 **Ni** 58.6934 Nickel	29 **Cu** 63.546 Copper	30 **Zn** 65.38 Zinc	31 **Ga** 69.723 Gallium	32 **Ge** 72.64 Germanium	33 **As** 74.92160 Arsenic	34 **Se** 78.96 Selenium	35 **Br** 79.904 Bromine	36 **Kr** 83.798 Krypton
37 **Rb** 85.4678 Rubidium	38 **Sr** 87.62 Strontium	39 **Y** 88.90585 Yttrium	40 **Zr** 91.224 Zirconium	41 **Nb** 92.90638 Niobium	42 **Mo** 95.96 Molybdenum	43 **Tc** [98] Technetium	44 **Ru** 101.07 Ruthenium	45 **Rh** 102.90550 Rhodium	46 **Pd** 106.42 Palladium	47 **Ag** 107.8682 Silver	48 **Cd** 112.411 Cadmium	49 **In** 114.818 Indium	50 **Sn** 118.710 Tin	51 **Sb** 121.760 Antimony	52 **Te** 127.60 Tellurium	53 **I** 126.90447 Iodine	54 **Xe** 131.293 Xenon
55 **Cs** 132.9054519 Cesium	56 **Ba** 137.327 Barium	57-71 See Below Lanthanides	72 **Hf** 178.49 Hafnium	73 **Ta** 180.94788 Tantalum	74 **W** 183.84 Tungsten	75 **Re** 186.207 Rhenium	76 **Os** 190.23 Osmium	77 **Ir** 192.217 Iridium	78 **Pt** 195.084 Platinum	79 **Au** 196.966569 Gold	80 **Hg** 200.59 Mercury	81 **Tl** 204.3833 Thallium	82 **Pb** 207.2 Lead	83 **Bi** 208.98040 Bismuth	84 **Po** [209] Polonium	85 **At** [210] Astatine	86 **Rn** [222] Radon
87 **Fr** [223] Francium	88 **Ra** [226] Radium	89-103 See Below Actinides	104 **Rf** [267] Rutherfordium	105 **Db** [268] Dubnium	106 **Sg** [271] Seaborgium	107 **Bh** [272] Bohrium	108 **Hs** [270] Hassium	109 **Mt** [276] Meitnerium	110 **Ds** [281] Darmstadium	111 **Rg** [280] Roentgenium	112 **Cn** [285] Copernicium	113 **Uut** [284] Ununtrium	114 **Fl** [289] Flerovium	115 **Uup** [288] Ununpentium	116 **Lv** [293] Livermorium	117 **Uus** [294] Ununseptium	118 **Uuo** [294] Ununoctium

Lanthanides	57 **La** 138.90547 Lanthanum	58 **Ce** 140.116 Cerium	59 **Pr** 140.90765 Praseodymium	60 **Nd** 144.242 Neodymium	61 **Pm** [145] Promethium	62 **Sm** 150.36 Samarium	63 **Eu** 151.964 Europium	64 **Gd** 157.25 Gadolinium	65 **Tb** 158.92535 Terbium	66 **Dy** 162.5 Dysprosium	67 **Ho** 164.93032 Holmium	68 **Er** 167.259 Erbium	69 **Tm** 168.93421 Thulium	70 **Yb** 173.054 Ytterbium	71 **Lu** 174.9668 Lutetium
Actinides	89 **Ac** [227] Actinium	90 **Th** 232.03806 Thorium	91 **Pa** 231.03588 Protactinium	92 **U** 238.02891 Uranium	93 **Np** [237] Neptunium	94 **Pu** [244] Plutonium	95 **Am** [243] Americium	96 **Cm** [247] Curium	97 **Bk** [247] Berkelium	98 **Cf** [251] Californium	99 **Es** [252] Einsteinium	100 **Fm** [257] Fermium	101 **Md** [258] Mendelevium	102 **No** [259] Nobelium	103 **Lr** [262] Lawrencium

Alkali Metals	Alkaline Earth Metals	Basic Metal	Halogen	Noble Gas	Non Metal	Rare Earth	Semi Metal	Transition Metal

The Periodic Table of the Elements tells the names, symbols, and number of protons in each element. It also shows the relationships among the elements. Elements are placed on the table in order of their atomic number and are arranged by their properties.

Periodic Table. By 1869, he had grouped elements by common properties. For example, elements with the smallest relative atomic mass went into the far left column. As he learned more about the chemical properties of the elements, Mendeleev grouped together metals, gases, and non-metals. His later tables even left gaps where Mendeleev suspected an element was missing, but he didn't know what it was yet. By the early 1890s, he and others had identified about 80 elements.



Today the Periodic Table includes 118 elements. Most occur in nature. But those with an atomic number higher than 92 (uranium) were made by scientists. In the future, the Periodic Table will likely continue to change based on new discoveries.

What is an isotope?

The nucleus in every atom of an element always has the same number of protons. For example, oxygen always has eight protons. However, the number of neutrons may vary. The different numbers of neutrons determine **isotopes** of the element.

To show which isotope of an element we are talking about, we total the number of protons and neutrons. Then we write the sum after the chemical symbol for the element. For example, in the nucleus of one isotope of uranium there are 92 protons and 143 neutrons. We refer to it as uranium-235 or U-235 (92 + 143 = 235). A second isotope of uranium, which contains three additional neutrons, is uranium-238 or U-238 (92 + 146 = 238).

The isotopes of an element have the same chemical properties, but they may differ in their nuclear properties.

What are stable and unstable isotopes?

Some proton-neutron combinations are more **stable** than others. Those that are stable do not change. Those that are **unstable** will change at some time.

What happens if you pull a rubber band to its limit? It will break, and the energy that was holding it together will be suddenly released.

As you just learned, the isotopes of an element have different numbers of neutrons in their centers. Some of these isotopes are like rubber bands that are stretched too far. We call these elements unstable isotopes. They break and change instantly to a different energy level.

Isotopes of an element are kind of like siblings in a family. Although siblings share many genetic characteristics, each child is unique.

Scientists observe that the elements do this to become more stable. Everything in the universe seeks these lower, more stable energy levels.

When a stretched rubber band breaks, you can't see its energy, but you can see the effect on the rubber band, which shoots across the room.

Sometimes similar things happen when unstable isotopes break down and new bonds are formed. Energy is released. And although all atoms are extremely small, the energy holding together their centers is the strongest force known in nature. It is called **strong force**. When the strong force is broken and a new bond is formed, the energy that is released is vast.

How was the energy of atoms discovered?

As scientists from around the world continued their experiments, they realized that the atom held large amounts of energy. In 1895, German physicist Wilhelm Roentgen discovered that an invisible energy was given off by an electrical current inside a vacuum tube. He called this unknown energy an "x ray" because it had no name. In 1896, French physicist Henri Becquerel observed that uranium gave off a similar energy. French chemist Marie Curie studied these "uranium rays" and discovered what they were: radioactivity. She realized that the energy came from within the atom itself.

In 1904, British physicist Ernest Rutherford recognized that, "If it were ever possible to control the rate of disintegration of radio elements, an enormous amount of energy could be obtained from a small amount of matter." The following year, Albert Einstein proposed his famous theory about the relationship between energy and matter: $E=mc^2$ which means "energy equals mass times the speed of light squared." This is a huge number. If correct, it confirmed that a vast amount of energy was contained within the atom.

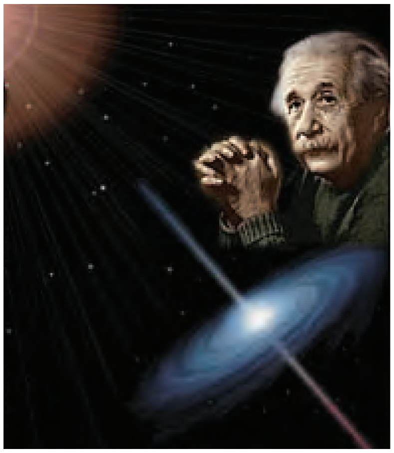


Image Credit: NASA

Scientists released energy from the nucleus by splitting atoms about 20 years later. Experiments by Italian Enrico Fermi and a team of scientists surprised everyone, even Fermi himself. When he bombarded uranium with neutrons, he expected it to become heavier. Instead, the resulting elements were lighter in mass. German scientists Otto Hahn and Fritz Strassman also fired neutrons into uranium and were surprised to find lighter elements, like barium, in the leftover materials. Hahn and Strassman worked with Lise Meitner, from Austria. She observed that in her experiments, the mass of lighter elements almost, but not quite, equalled the total of the uranium mass. Meitner used Albert Einstein's equation $E=mc^2$ to show that lost mass had changed into energy.

Summary

Atoms are the smallest units of matter that have all the properties of an element. Atoms combine to form molecules. Atoms are composed of smaller particles known as protons, neutrons, and electrons.

Protons have a positive electrical charge, neutrons have no electrical charge, and electrons have a negative electrical charge. Protons and neutrons together form the nucleus or central mass of the atom. Electrons move around the nucleus.

The nucleus of each atom of a specific element contains the same number of protons, but the number of neutrons may vary. Isotopes of an element are identified by adding the number of protons and neutrons together and writing the sum next to the chemical symbol for the element.

Stable isotopes do not change. Unstable isotopes will change at some time.

The energy that holds the nucleus of an atom together is the strongest force known in nature.

The Periodic Table of the Elements gives the names, symbols, and number of protons for each element.

Many scientists have contributed to our knowledge of elements and atoms. They have come from many countries and have included both men and women. Some have been honored by having elements named after them.

Lesson 4

IONIZING RADIATION

Introduction

In the last lesson, we learned that unstable isotopes emit energy as they become more stable. This energy is known as radiation. This lesson will explore forms of radiation, where radiation is found, how we detect and measure radiation, what sources of radiation people are exposed to, whether radiation is harmful, and how we can limit our exposure.

TOPICS:

- **Types of radiation**
  - Non-ionizing
  - Ionizing
- **Forms of ionizing radiation**
  - Alpha particles
  - Beta particles
  - Gamma rays
- **Radiation**
  - Decay chain
  - Half life
  - Dose
- **Radiation Measurements**
- **Sources of radiation**
- **Average exposure**

What is radiation?

Radiation is energy moving through space in the form of waves and particles. Radiation is everywhere – in, around, and above the world we live in. It is a natural energy force that surrounds us. It is a part of our natural world that has been here since the birth of our planet.

Radiation can be described as **non-ionizing** or **ionizing**. Non-ionizing radiation does not have enough energy to knock electrons from atoms as it strikes them. Sunlight, radio waves, and cell phone signals are examples of non-ionizing radiation. However, it can still cause harm, like when you get a sunburn.

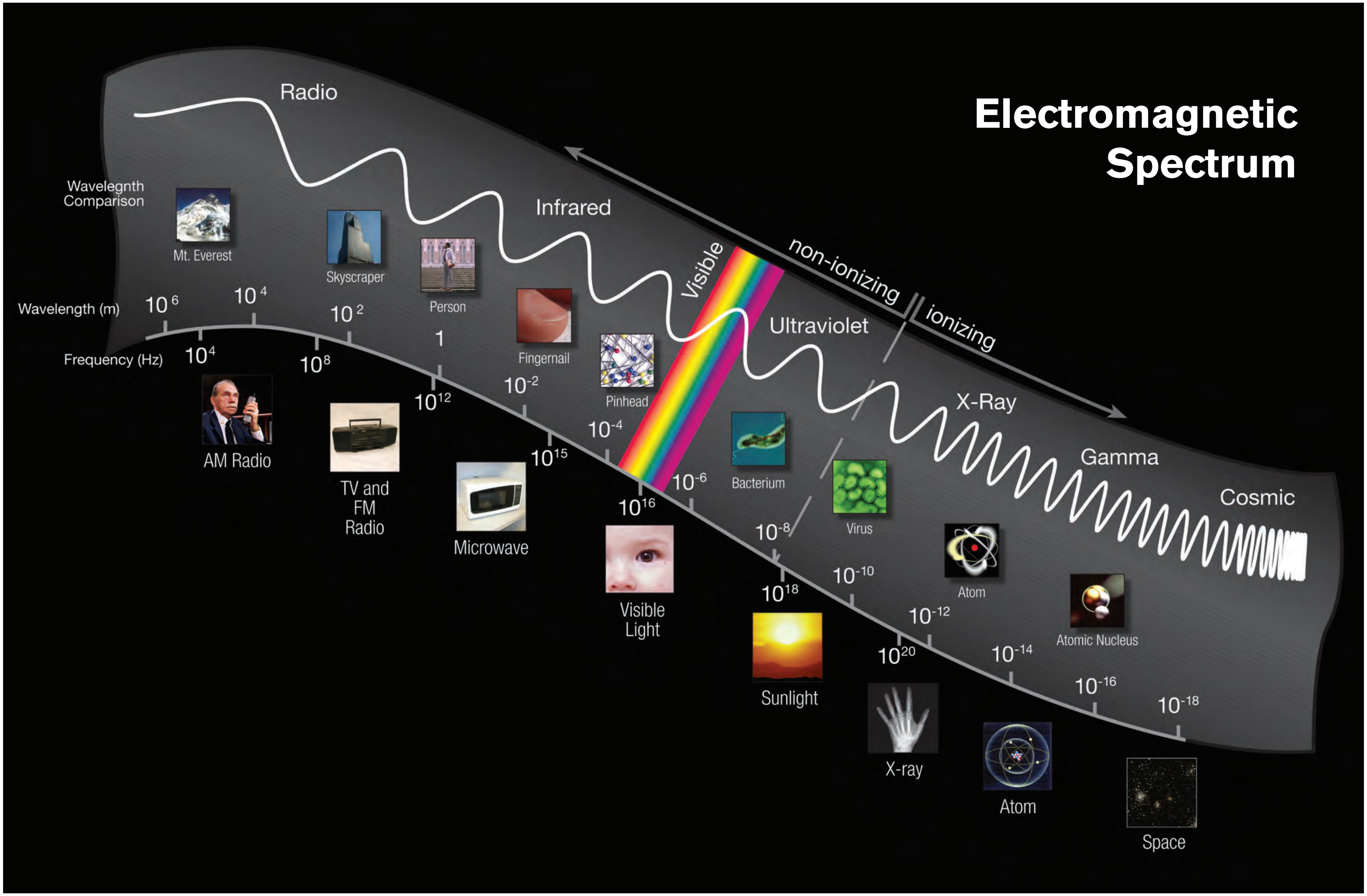
Ionizing radiation is the type of radiation most people think of when they hear the word *radiation*. **Ionizing radiation** can knock electrons from an atom, creating electrically charged particles called **ions**.

Because we cannot see, feel, hear, smell, or taste ionizing radiation, no one knew it existed until 1895. But it was here all along. Since its discovery, radiation has been one of the most thoroughly studied subjects in modern science. Scientists have found important uses for ionizing radiation. They have also studied its effects on human health.

What are the forms of ionizing radiation?

Ionizing radiation includes the **alpha** and **beta particles** and **gamma rays** emitted from radioactive materials. Cosmic radiation that reaches the Earth from outer space is ionizing. Ionizing x-ray radiation is produced by x-ray machines.

Gamma rays, x-rays, and cosmic rays are waves of pure energy, without mass or charge. They appear at the high frequency (high energy) end of what we call the **electromagnetic spectrum**.



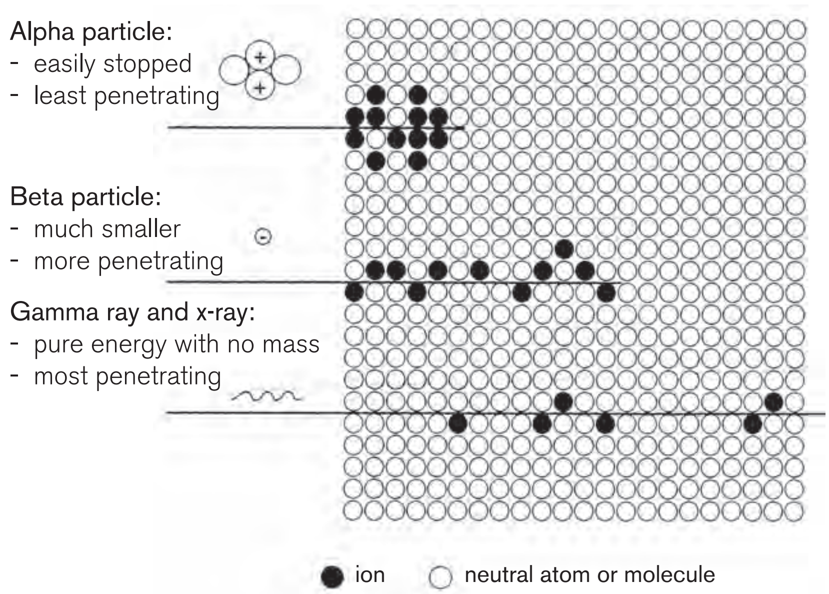
X-rays, gamma rays, and cosmic rays are waves of pure energy. They are part of the electromagnetic spectrum that also includes radio waves, visible light, and ultraviolet light. Because they are higher energy and frequency, they can knock electrons off molecules and cause them to become "ionized."

The spectrum also includes non-ionizing radiation (radio and television waves, microwaves, light, etc.) at the lower frequency (lower energy) end.

How does ionizing radiation deposit energy?

Because it can knock electrons from the atoms and molecules in its path, ionizing radiation can cause chemical changes in living cells. However, the types of ionizing radiation are different in how much they penetrate and deposit energy through ionization.

Types of Ionizing Radiation



Alpha, beta, and gamma are ionizing radiation. The distance each can travel is limited by how it interacts with other atoms.

Alpha particles are relatively large and carry a double positive charge (++). They are not very penetrating and a piece of paper or your skin can stop them. They travel only a few centimeters but deposit all their energies along their short paths. In delicate tissue, alpha can do a large amount of damage.

Beta particles (electrons) are much smaller than alpha particles. They carry a single negative charge (-). They are more penetrating than alpha particles, but thin aluminum metal can stop them. They can travel several meters but deposit less energy at any one point along their paths than alpha particles.

Gamma rays are waves of energy without mass or electrical charge. They can travel 10 meters or more in air. This is a long distance compared to alpha or beta particles. However, gamma rays deposit less energy along their paths. Lead, water, and concrete stop gamma radiation.

Where does radiation come from?

Some unstable isotopes become more stable by emitting or shooting out energy rays similar to x-rays. Others may emit particles from their nuclei and change into different elements. The rays and particles unstable isotopes shoot out are **radiation**. Substances that give off radiation in this way are **radioactive**.

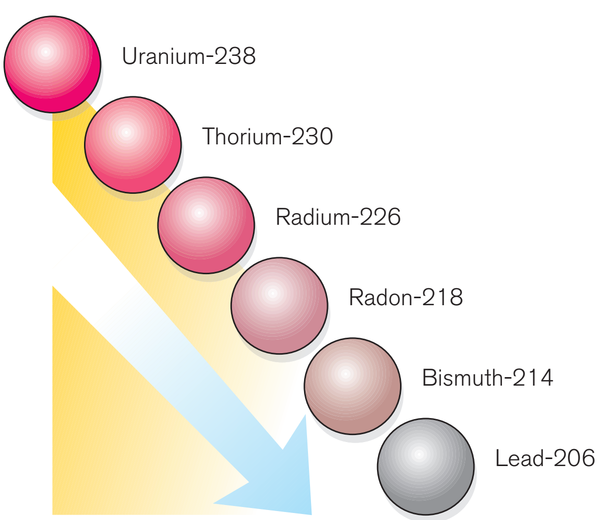
Radioactive decay is the process of isotopes emitting particles or rays from an atom's nucleus to become more stable. An unstable isotope will eventually decay into a stable element. However, this process may take many steps and a long time. These steps are called a **decay chain**. For example, the isotope uranium-238 transforms into more than 15 different isotopes before it becomes stable lead-206.

What is half-life?

Radioisotopes decay at random, and it is impossible to guess which one will decay next. Yet, in a group of atoms, we can see a pattern. We describe this pattern by using the term **half-life**. The amount of time it takes for a given isotope to lose half of its radioactivity is known as its half-life.
If a radioisotope has a half-life of 14 days, half of its atoms will have decayed within 14 days. In 14 more days, half of that remaining half will decay, and so on.

Some isotopes may change in the next second, some in the next hour, some tomorrow, and some next year. Other isotopes will not decay for thousands of years. Half-lives range from fractions of a second to several billion years.

Decay Chain



Uranium slowly decays to lead. It happens in a chain of events called a decay chain. Here are some of the steps in the uranium decay chain. The half-life of uranium-238 is 4.5 billion years.

Half-lives of Some Radioactive Isotopes	
Americium-241	432.7 years
Fluorine-18	109.7 minutes
Carbon-14	5,715 years
Hydrogen-3 (tritium)	12.32 years
Iodine-131	8 days
Iridium-191	4.9 seconds
Krypton-85	10.7 years
Technetium-99m	6.01 hours
Uranium-235	700 million years

Technetium-99m and fluorine-18 are useful in medical diagnosis because of their short half-lives.

What is radiation dose?

To measure how different amounts of ionizing radiation affect people, we use the term **radiation dose**. When you take medicine, the effects of a dose depend on the type of medicine, the amount of the medicine you take, the period of time in which the medicine is taken, and how your own body responds. Two aspirin may cure your headache. Twenty aspirin in a week may cure ten headaches. But 20 aspirin taken all at once could do serious damage.

Another example to think about is your exposure to the non-ionizing radiation from the Sun's rays. If you spend a short time in the Sun each day, or limit your exposure by wearing sunscreen and clothing, your skin will get less damage than if you spend an entire day on the beach in just your bathing suit (ouch!).

People who work with radiation limit their extra radiation exposure as much as possible. Your dentist may step out of the room during your x-ray, for example. To minimize dose, workers can apply the rule of **time, distance, shielding:**

- *Decrease* the time of exposure
- *Increase* the distance from a source of radiation
- *Increase* shielding with dense material like lead or concrete

Because we cannot detect radiation with our senses and because exposure to too much radiation is harmful, we use a special symbol to warn us when radioactive materials are present. We put the symbol on packages of radioactive materials when we ship them by truck, train, plane, or ship. We also put the symbol on doors to rooms or areas where we use or store radioactive materials. You have probably seen the symbol if you have had an x-ray.

How do we measure radiation?

Scientists use different units to measure radiation depending on what they want to measure. If a friend asks how far it is from school to your home, you can answer the question several different ways. For instance, you may live a half mile away, but you also live 2,640 feet from school, 804 meters, or an 18-minute walk away. It's the same with measuring radiation.

The unit most often used to measure ionizing radiation in the United States is **millirem (mrem)**. The international unit is **millisievert (mSv)**. Both measure the risk that the ionizing radiation will cause tissue damage in a person. One millisievert equals one hundred millirem (1 mSv = 100 millrem).

We use the curie (Ci) or becquerel (Bq) to measure the amount of radioactivity in a substance. We use the rad or gray (Gy) to talk about the energy in radiation absorbed by a person.

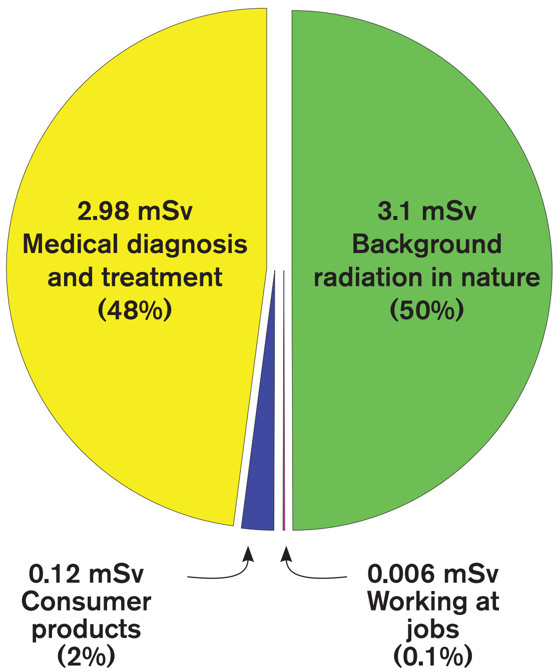
What does radiation do?

Scientists have studied the effects of radiation for almost a century. High doses are well understood. If an exposure is very high and happens quickly, it is dangerous. Radiation exposures of over 1,000 millisieverts (100,000 millirems) cause radiation sickness. Very high exposures over 5,000 millisieverts (500,000 millirem) received all at once usually cause death. Fortunately, exposures this high are extremely rare.

Measurements of Radiation

What is measured	Traditional unit	International Unit (SI)
Total amount of radioactivity contained in a source	curie (Ci)	becquerel (Bq) 37 billion Bq = 1 Ci
Radiation dose absorbed by a person (amount of energy deposited in human tissue)	rad (radiation absorbed dose)	gray (Gy) 1 Gy = 100 rad
Biological effect of exposure to radiation (dose equivalent)	rem (radiation equivalent man) or millirem (mrem)	sievert (Sv) or millisievert (mSv) 1 Sv = 0.l rem 1 mSv = 100 mrem

Where Our Exposure to Ionizing Radiation Comes From



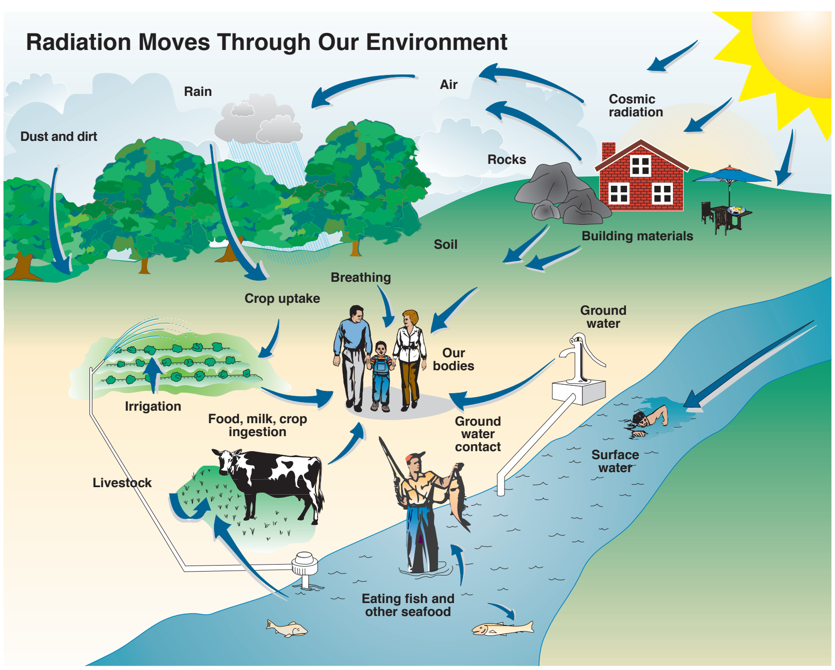
Adapted from NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States, March 2009.

People who work in industry or medicine are permitted to receive up to 50 millisievert (5,000 millirems) a year. It takes 10 times this amount received all at once before doctors can detect any harmful effects on a person.

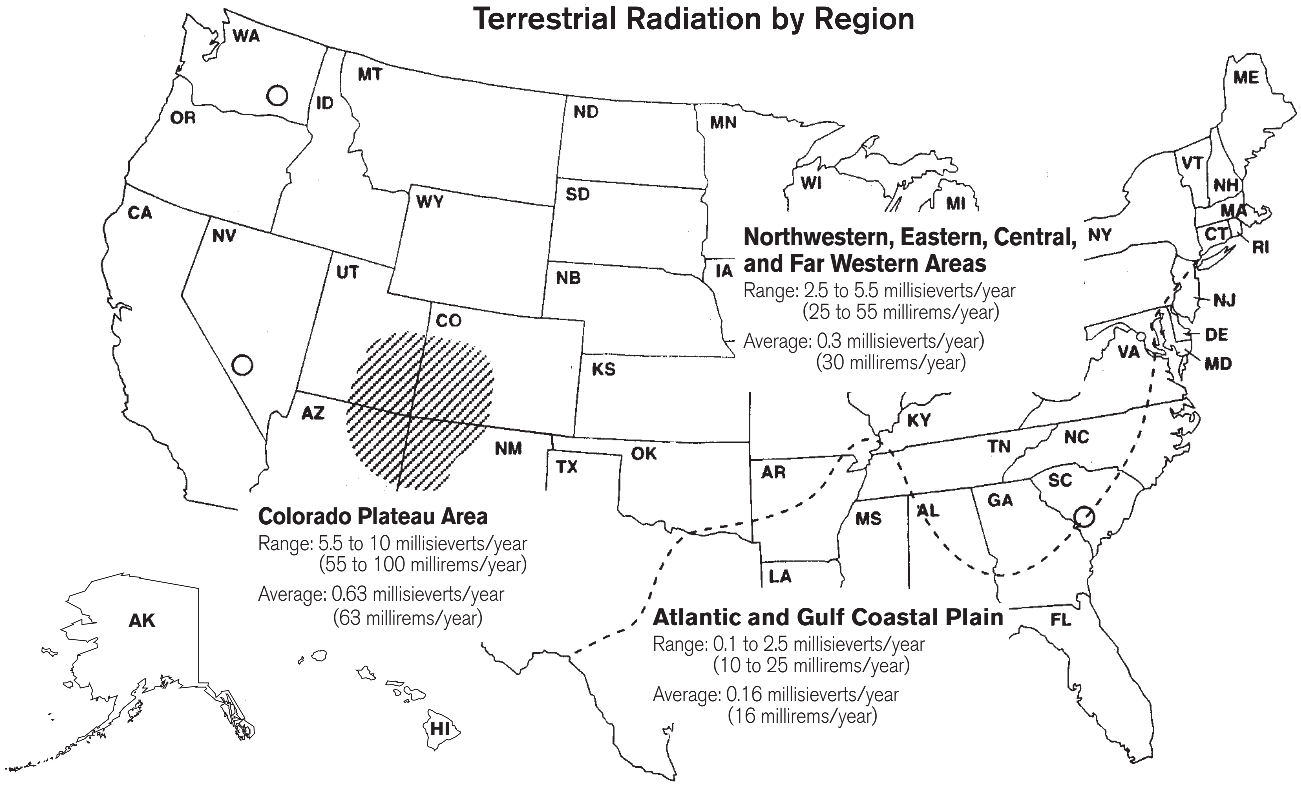
Some scientists believe that any amount of radiation may have a harmful effect. However, most scientists believe that low levels do not have much effect on people. If radiation exposure is low, or the radiation is received over a long period of time, the body repairs any damage. Even so, sometimes the body makes an incorrect repair. If this happens, there is a possibility of a delayed effect that doesn't show up for years. Cancer can be one delayed effect.

Where does our exposure to radiation come from?

In the United States, the average person receives about 6.2 millisievert (620 millirem) a year. About half of this is from natural radiation and half is from medical procedures.



Everything around us exposes us to small amounts of radiation.



The average yearly dose of ionizing radiation in the United States is increasing. That's because we use radiation much more often as a tool in medicine. As imaging technology improves, doctors are using x-rays and computed tomography (CT) scans more often for diagnosis. Doctors are also using radiation to treat diseases such as cancer.

What is background radiation?

Let's look more closely at where we find radiation. Everything in the world is radioactive and always has been. The ocean we swim in, the mountains we climb, the air we breathe, the foods we eat, and the water we drink all expose us to small amounts of radiation from nature. This is because there are unstable isotopes that emit ionizing radiation everywhere on Earth.

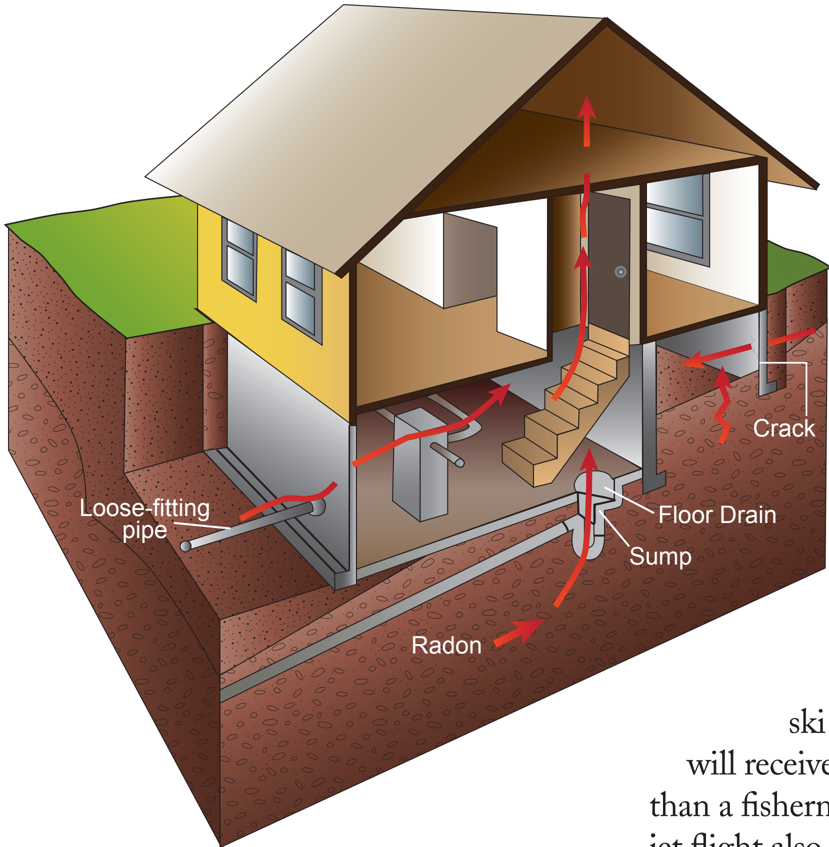
The main natural sources of radiation are

- **Terrestrial radiation** from the rocks and soils around us
- **Cosmic radiation** from space
- **Radon** in the atmosphere
- **Internal radiation,** the radioactive elements in our bodies, mainly from what we eat or drink

The sum of our exposure from these sources is called **background radiation**.

What is terrestrial radiation?

Terrestrial radiation is background radiation that comes from the Earth. About 7 percent of natural background radiation is terrestrial radiation that comes from elements like potassium, uranium, and thorium. Most soils around the world contain at least small amounts of these elements. These elements constantly decay and emit radiation.



Radon gas travels from the soil up into buildings.

The average dose to a person in the United States from terrestrial sources is about 0.2 millisievert (200 millirem) per year. However, average exposure varies throughout the country, taking into account soils and the populations of different regions. For example, on the coastal plains of the Atlantic and Gulf regions, the average annual dose is lower than it is in the mountains in the western United States.

What is space radiation?

Space radiation comes from solar particles and cosmic rays from outer space. It accounts for about 11 percent of the total dose you get from background radiation. This radiation is filtered by the Earth's atmosphere, so the elevation where you live affects your exposure from space radiation. How close you live to the equator also affects your dose. In Honolulu (at sea level and near the equator), the average annual dose from space radiation is 0.26 millisievert (26 millirem). In Denver, (farther from the equator and higher altitude) the dose is 0.52 millisievert (52 millirem). This means a ski instructor at a mountain resort will receive more background radiation than a fisherman at sea level. Taking a jet flight also results in exposure to space radiation. However, there is no evidence of increased radiation health effects for people who live at high altitudes or for people, like airline pilots, who fly often.

What is radon?

Radon is a radioactive gas that comes from the natural decay of uranium found in nearly all soils and water. It has no color, odor, or taste. It can get into our buildings through cracks in the foundation. When this happens, it can build up indoors. Radon gas can damage lung tissue if we breathe too much of it. Simple tests can help you check a building or home for high radon levels.

What is internal radiation?

Natural radiation is also found in plants, animals, and people. After all, living things are made entirely of atoms of the elements from Earth, including such elements as potassium and carbon. Some are radioactive. The radiation we receive from elements inside our bodies is called **internal radiation**. Americans get about 2.68 millisieverts (268 millirems) of radiation each year from the food we eat, what we drink, and elements we breathe in. Of course, this number varies depending on what we eat or drink, where it is grown, and how much we eat. However, all foods contain some radioactive elements, and certain foods – bananas and Brazil nuts, for example – contain higher amounts than other foods. These are not harmful, and potassium and carbon are essential for our health.

What are some human-made sources of radiation?

We get additional radiation from products that use radiation. You already know that almost half of our average annual exposure to radiation (48 percent) comes from medical uses like x-rays, CT scans, and treatments for cancer that use radiation. But human-made sources include consumer products, such as smoke detectors.

Other human-made sources are related to technology. We get a trace amount of radiation from the nuclear power industry (0.1 percent of our exposure). It also comes from naturally occurring radiation in coal, ash, and smoke from coal-fired power plants. Other examples include increased terrestrial radiation from disturbing soils during construction or road building and fertilizers made from phosphates. Building materials, such as bricks and stone, also emit natural background radiation. So our homes, schools, factories, and businesses are all sources of background radiation.

Summary

Radiation is energy moving through space in the form of waves and particles. It is a part of natural world and has been since the beginning of our planet. It can be described as non-ionizing (low energy) or ionizing (high energy). Some important forms of ionizing radiation are alpha and beta particles, gamma rays, and x-rays.

Unstable isotopes change by emitting particles or energy rays in a process called radioactive decay. As an unstable atom decays, it changes to a different element. Eventually, unstable isotopes decay to stable elements. The half-life of an isotope is the amount of time it takes to lose half of its radioactivity by decay.

The main natural sources of ionizing radiation we are exposed to are called background radiation. Background radiation includes

- Terrestrial radiation from the rocks and soils around us
- Solar particles and cosmic radiation from space
- Radon in the atmosphere
- Internal radiation - radioactive materials in our bodies mainly from what we eat, drink, and breathe in

There are also human-made sources of radiation. These include medical uses such as x-rays and CT scans and some products like smoke detectors. The average yearly dose of ionizing radiation for a person in the United States from all sources is 6.2 millisieverts (620 millirems). Half comes from background radiation (50 percent), 48 percent comes from medical uses, and 2 percent comes from consumer products and industry, including making electricity.

Because it can knock electrons from the atoms and molecules in its path, ionizing radiation can cause changes in human tissue. Most scientists believe low levels of exposure to radiation have an insignificant effect on people. If exposure is low or the radiation is received over a long period of time, the body can usually repair itself. However, if an exposure is high enough, it can cause damage. Fortunately, exposures to large amounts are extremely unusual.

People who work with radiation minimize their exposure using the rule of time, distance, and shielding:

- Decrease the length of time of exposure
- Increase the distance from a source
- Increase shielding

Lesson 5

FISSION, CHAIN REACTIONS

Introduction

We have learned how the nuclei of atoms store energy and how unstable atoms decay and release energy. How do nuclear engineers use this knowledge to help them harness energy to make electricity? The answer lies in being able to start a nuclear chain reaction in fuel inside a nuclear power plant and keep it going. In this lesson, we'll look closely at nuclear reactions called fission. We'll also learn how uranium is processed from ore to fuel.

TOPICS:

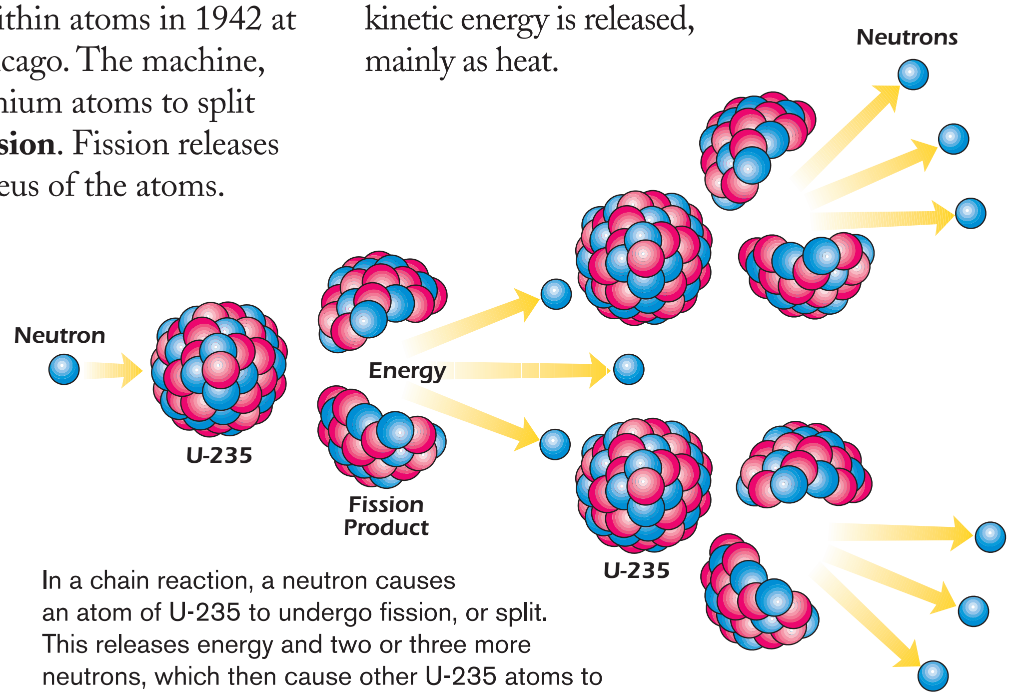
- Fission
- Chain reactions
- Uranium fuel
  - Mining
  - Milling
  - Enrichment
  - Fuel fabrication

What is fission?

When scientists began to understand the forces that bind atoms together, they wondered if a machine could be built to harness this energy. A team of scientists led by Enrico Fermi built a machine to harness the energy within atoms in 1942 at the University of Chicago. The machine, a **reactor**, caused uranium atoms to split in a process called **fission**. Fission releases energy from the nucleus of the atoms.

When a **neutron** strikes the nucleus of uranium-235, the nucleus becomes more unstable, vibrates, and then splits apart. All this takes about a millionth of a second.

When a uranium-235 atom splits apart, many things happen. We end up with two lighter-weight atoms of new elements, which are called **fission products**. Two or three neutrons are released. And an enormous amount of kinetic energy is released, mainly as heat.



In a chain reaction, a neutron causes an atom of U-235 to undergo fission, or split. This releases energy and two or three more neutrons, which then cause other U-235 atoms to split. This continues the reaction.

What is a nuclear chain reaction?

Splitting an atom apart releases a lot of energy, especially considering its size. But splitting one atom does not produce enough heat to be useful. We need to fission millions of atoms to get enough heat to do work.

How can we do that? The answer lies in the two or three neutrons that fly off when the first atom is split. If these neutrons hit other uranium-235 atoms, these atoms also fission, each releasing heat and two or three more neutrons. Under the exactly right conditions, we can get millions of atoms fissioning. When that happens, it gives off enormous heat. This chain of events is called a **nuclear chain reaction**.

Keeping a chain reaction going is actually very difficult. This is because many of the neutrons that fly away from each fission will not hit another uranium atom's nucleus. If more miss than hit, the chain reaction will quickly slow down and stop.

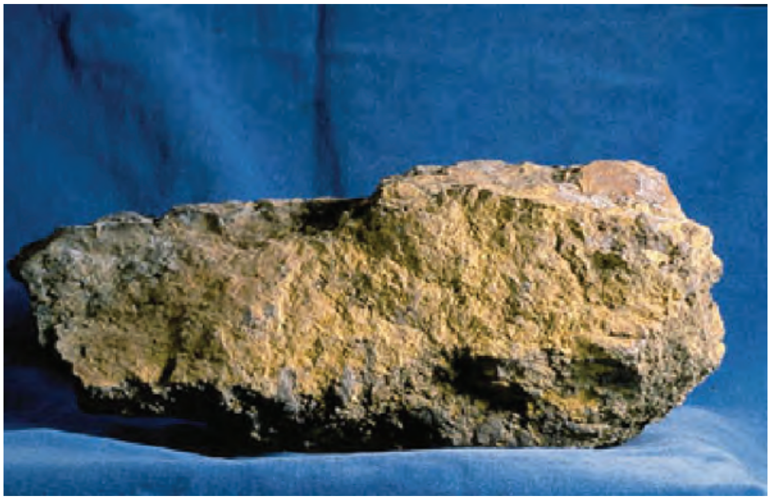
The heat we get from a chain reaction comes from breaking the strong force in the nucleus and forming new bonds. In this process, a tiny amount of mass is converted into energy ($E=mc^2$). As fission products bounce off neighboring atoms, kinetic energy is converted to heat by friction.

What is the fuel at a nuclear power plant?

The fuel at a nuclear power plant is uranium-235. The heat produced by the fissioning of billions of uranium-235 atoms heats water, which produces steam. This steam turns turbines to generate electricity. The major difference between a nuclear power plant and one that burns coal is the way the heat to make steam is produced. The rest of the nuclear power plant is very similar.

Where does uranium come from?

Uranium formed in the supernovae that created our solar system about 4.6 billion years ago. It was part of the material in space that became the Earth. Uranium is a dense metal element that holds a tremendous amount of energy in its nucleus. This element occurs in small amounts all over the world, even in seawater. Rocks that contain uranium are called uranium **ore**. Typically, a ton of uranium ore contains 2 to 4 pounds of uranium. Before we can use uranium to generate electricity, we must mine it, separate it from the ore, and process it. Let's look at the steps in taking uranium from a mineral in the Earth to nuclear fuel.



Uranium is found in rocks and soil around the world. Rock that contains 2 to 4 pounds of uranium per ton is called uranium ore.

How is uranium mined?

Workers can mine uranium ore in much the same way they mine coal, either in deep underground mines or in open-pit surface mines. They can use machines to dig the ore from the Earth. However, today, miners often take uranium from the ground by a process called **in-situ leaching**. Workers drill into the rock and inject solutions that dissolve the uranium from the ore. Then they pump out the solution that contains the dissolved uranium from a second well.

Mining any mineral alters the environment and disturbs the habitat of plants and animals. To minimize damage and to protect the environment, when mining ends, mining companies must replant and restore the land. This process is called **reclamation**. Federal, state, and local agencies enforce mining laws that help protect mine workers and the environment.

What is uranium milling?

If miners remove the ore as rock, the uranium ore is crushed. Crushed ore is put in an acid. The acid dissolves the uranium but not the rock. The solution is dried, leaving a yellow powder called **yellowcake**, which is mostly uranium. The process of removing uranium from the ore is called uranium **milling**.

The leftover rock is known as **mill tailings**. Mill tailings contain other minerals, including the element radium. Radium gives off a radioactive gas called radon. Uranium mill tailings are disposed of by putting them back in the ground and covering them with soil and clay to keep radon in and water out.

The end result of uranium milling is a dry, yellow powder known as yellowcake.

What is enrichment?

Less than 1 percent of the atoms in natural uranium are uranium-235 atoms. Most of the rest of the uranium atoms are uranium-238. However, power plants need uranium that is about 4 percent uranium-235. This means that before it can be made into reactor fuel, we must increase the concentration of uranium-235 in a process called **uranium enrichment**.

How do we enrich uranium?

Isotopes of uranium-238 contain three more neutrons than isotopes of uranium-235. This gives them a tiny bit more mass. This tiny difference in mass makes it possible to separate these two isotopes of uranium. We can make fuel richer in uranium-235.

Before uranium can be enriched, it is purified and combined with fluorine at a conversion plant. This compound is **uranium hexafluoride**, also known by its chemical name, UF_6.

Next, it is shipped to a facility where it is heated to a gas and pumped through barriers that contain extremely tiny holes that act as filters. Because it has about 1 percent less mass, uranium-235 moves through the holes a bit more easily than uranium-238. By the time the gas has gone through thousands of filters, the percentage of uranium-235 has enriched from less than 1 percent to about 4 percent.

Gaseous Diffusion Enrichment

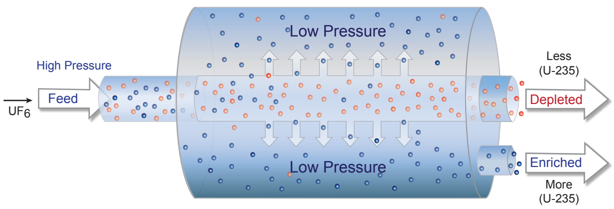


Image Credit: USEC, Inc.

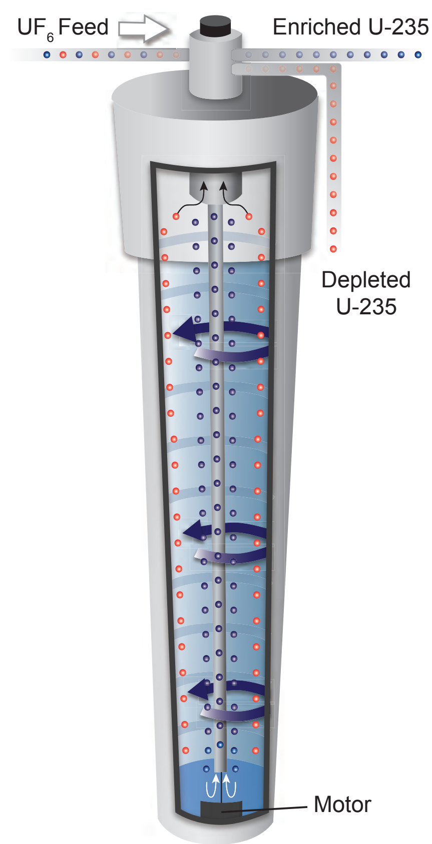
In gaseous diffusion, uranium hexafluoride gas is pumped through many filters called barriers. Each time the gas goes through a filter, the concentration of uranium-235 gets slightly richer.

A more energy-efficient process uses a **centrifuge** to enrich uranium. A centrifuge separates heavier materials from lighter ones by spinning them. UF_6 gas is placed in a cylinder, which then rotates at a very high speed. The rotation makes the heavier uranium-238 molecules move toward the outside wall while the lighter uranium-235 molecules collect near the center. This process is repeated until the percentage of uranium-235 has increased to about 4 percent.

How is the uranium prepared for the reactor?

We can't just put uranium into the reactor the way we pour coal into a furnace. Enriched uranium must be taken to a fuel fabrication plant where it is made into reactor fuel. At the fabrication plant, uranium is pressed into solid, ceramic **fuel pellets**. These fuel pellets can withstand very high temperatures, much like ceramic tiles or oven-proof cookware. Fuel pellets are about 1 centimeter (3/8 inch) in diameter and about 2 centimeters (3/4 inch) long. Workers stack fuel pellets in fuel rods. Then they bundle fuel rods together as fuel assemblies.

Centrifuge Enrichment

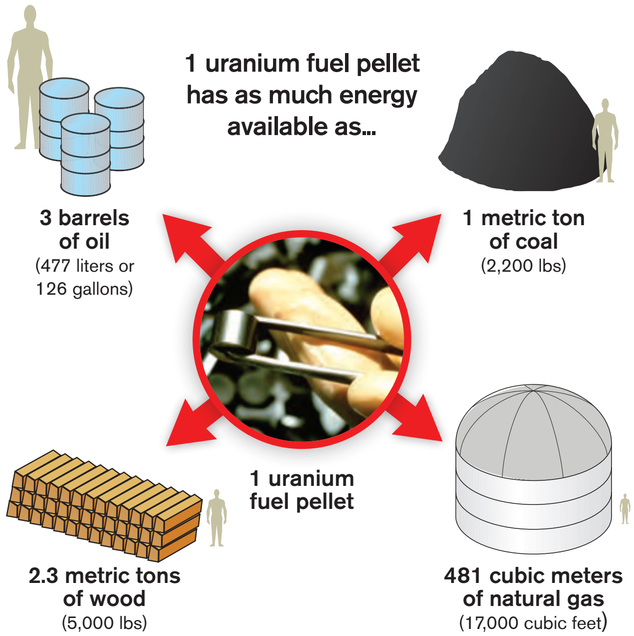


Centrifuge enriches fuel by spinning uranium hexafluoride. Heavier uranium-238 moves toward cylinder walls. Uranium-235 collects near the center.

How much energy is in uranium fuel?

Energy in uranium is extremely concentrated. A uranium fuel pellet weighs less than 14 grams (0.5 ounce), which is less than an empty aluminum soft drink can. Each pellet can release as much energy as 477 liters (126 gallons) of oil, 1 metric ton (2,200 pounds) of coal, or 2.3 metric tons (5,000 pounds) of wood. This means that there is a very large amount of energy available to generate heat and make electricity.

Fuel Equivalents



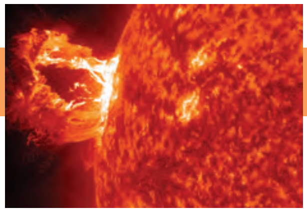
Fuels have different energy content. Less uranium is required to produce electricity.

Each fuel rod holds about 200 fuel pellets and is about 4 meters long. A single fuel rod does not contain enough uranium-235 for a fission chain reaction. So, depending on the design of the power plant where they will be used, 63 to 264 fuel rods are bundled together in a fuel assembly. A reactor core has 200 to 800 fuel assemblies. Nuclear plants replace one-third of their fuel assemblies about every two years as the uranium-235 gets used up.

Fuel Pellets **Fuel Rods** **Fuel Assemblies**

Workers stack uranium fuel pellets inside fuel rods and group the fuel rods in fuel assemblies.

Think about it...



Fission gives off energy when the heaviest elements are split. Another kind of reaction, **fusion**, gives off energy when the lightest elements are combined, or fused together.

When two hydrogen atoms fuse to form a helium atom, a huge amount of energy is released. Thanks to the pioneering work of Albert Einstein, the formula $E = mc^2$ tells us exactly how much energy the fusion reaction releases.

Fuel used for fusion is abundant and can be taken from sea water. But there are huge challenges to harnessing this power. The greatest challenge is how to heat the hydrogen fuel to 100 million degrees Celsius (180 million degrees Fahrenheit) and confine it long enough for fusion to occur. So far, scientists have been able to maintain a controlled, continuous fusion reaction for only fractions of a second.

Summary

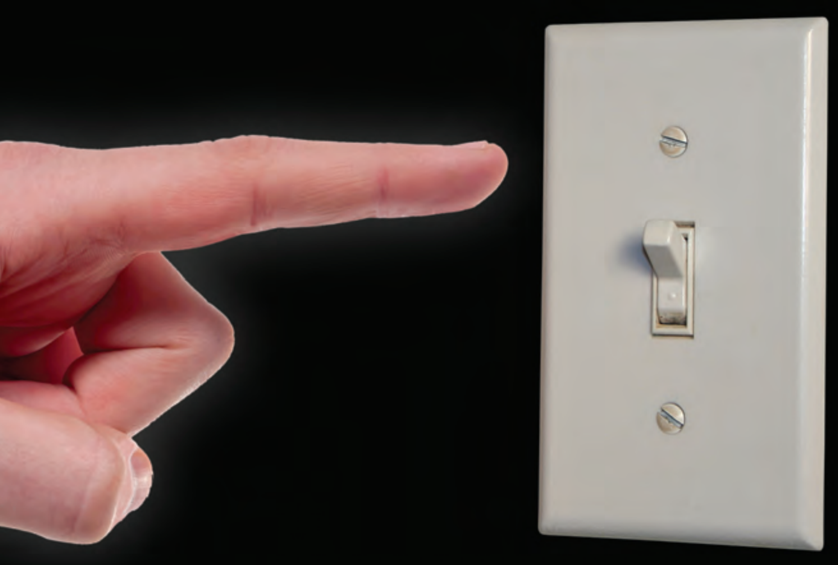
Fission occurs when a neutron strikes the nucleus of a uranium-235 atom, causing the atom to split apart. Two new lighter- weight atoms, two or three neutrons, and a lot of energy — mostly as heat — are released. If the neutrons that were released hit other uranium-235 atoms, these atoms may fission. This way, millions of atoms can be made to fission. This sequence of events is called a nuclear chain reaction.

The fuel for nuclear power plants is uranium, a dense metal found in rocks and soil around the world. Rock that contains 2 to 4 pounds of uranium per ton is known as uranium ore. Uranium is mined, milled, converted to a gas, enriched, and then made into solid ceramic pellets that are stacked in fuel rods that are bundled together as fuel assemblies.

Less than 1 percent of the atoms in uranium are uranium-235. But power plants need uranium that is about 4 percent uranium-235. The uranium enrichment process raises the concentration of uranium-235 based on the fact that uranium-238 atoms have a tiny bit more mass than uranium-235 atoms. We enrich uranium by using gaseous diffusion or by using centrifuges.

In addition to fission, or splitting atoms of heavy elements, scientists are learning how to control another type of nuclear reaction called fusion. Fusion occurs when light atoms of hydrogen join together (or fuse) to create helium and release a large amount of energy. So far, scientists have been able to maintain a controlled, continuous fusion reaction for only fractions of a second.

ATOMS TO ELECTRICITY



Introduction

Most power plants make electricity by boiling water to make steam that turns a turbine. A nuclear power plant works this way, too. At a nuclear power plant, splitting atoms produce the heat to boil the water.

TOPICS:

Inside the reactor
- Heat
- Pressure
- Steam

Fission control
- Fuel assemblies
- Control rods
- Coolant
- Pressure vessel

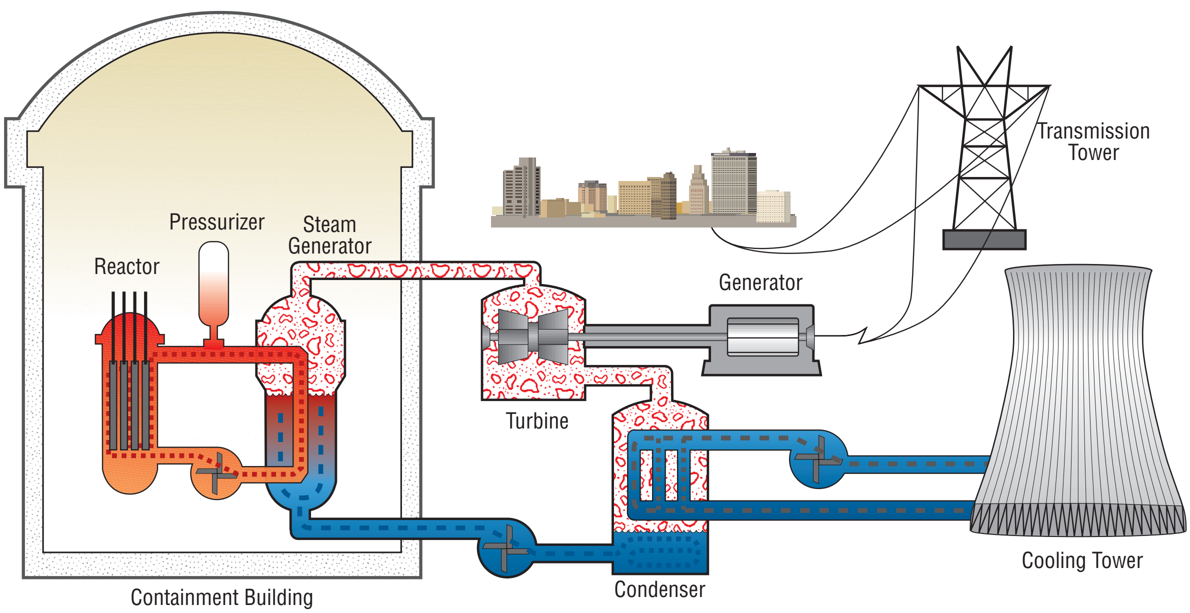
Electricity generation
- Turbine
- Generator
- Condenser
- Cooling tower

How does splitting atoms produce electricity?

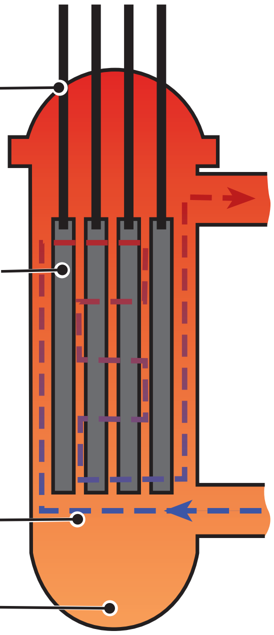
A nuclear power plant is built to produce electricity. But splitting atoms, or fission, does *not* produce electricity directly. Splitting atoms produces heat. At a power plant, heat energy is converted to mechanical energy that is then converted to electrical energy.

How is the electricity produced?

The heat from fission turns water into steam. The mechanical energy from steam pressure turns a **turbine**. This spins a generator, which produces electricity. The way heat energy is changed into electrical energy in a nuclear power plant is the same as in a coal power plant.



A **nuclear reactor** is basically a machine that heats water. Like other large power plants, nuclear plants have specialized pipes, electrical equipment, and buildings. They are built to extremely high standards so that they will work reliably and produce electricity that customers need.



The fuel assemblies, control rods, and coolant make up the reactor's core. The core is surrounded by a massive steel pressure vessel.

Utilities use two different types of nuclear reactors in the United States. One is the **pressurized water reactor**, and the other is the **boiling water reactor**. Both use ordinary water and work in a similar way. In this lesson, we use a pressurized water reactor to explain the science of how nuclear power plants work.

Where does fission take place?

Fission takes place in the fuel sealed inside the **core** of a nuclear reactor.

Uranium **fuel assemblies** form the core of the reactor. A reactor core has 200 to 800 fuel assemblies, depending on its design. Because uranium has so much energy, the fuel in the core lasts about three to five years. To maintain the plant, utility workers turn off the reactor about every 2 years and replace one-third of the fuel, rather than changing it all at once. This helps to schedule regular maintenance on the plant and keeps the power supply steady.

What are control rods?

The **control rods** help regulate, or control, the rate of fission. Control rods are made of **cadmium** or **boron** metal. They slide in and out of the reactor core and act like sponges for neutrons.

When control rods are inserted in the fuel, they absorb neutrons. Keeping control rods in the fuel prevents a fission chain reaction. Pulling the control rods out of the fuel allows the reaction to begin.

Who controls the control rods?

Highly trained operators work in the control room. They monitor the reactor with the help of computers and sensors. The operators in the control room are the "brain" of the power plant. To start the reactor, they slowly pull the control rods out of the core. Without the control rods to absorb neutrons, fission begins and produces heat.

Nuclear power plant operators use computers and sensors in the control room to monitor the reactor.

Operators monitor the temperature in the reactor closely. As the temperature in the core rises, they adjust the reactor to keep the rate of fission constant so the temperature stays at about 315° C (600° F). If there is any sudden change in temperature or pressure, the reactor automatically shuts down by sliding all the control rods into the fuel. It takes only seconds to stop the nuclear chain reaction.

What is the coolant and moderator?

Water is the reactor's **coolant**. Water circulates around the fuel to transfer heat from the core. Water also keeps the core from getting too hot.

Just as it is easier to catch a ball that is thrown softly, neutrons are more likely to be captured and cause fission when they are not moving too fast.

Water serves another purpose in a reactor. It is also a **moderator**. Passing through water slows the neutrons down, or "moderates" their speed. This helps make fission possible.

It is easier for uranium-235 atoms to capture neutrons when they are moving more slowly. Using water to slow the neutrons down allows enough neutrons to be captured by the uranium fuel for a chain reaction to occur.

What is a pressure vessel?

The reactor is surrounded by a huge steel **pressure vessel**. Its walls are over 20 cm (7.87 inches) thick, and it weighs more than 300,000 kg (331 tons). It is filled with the coolant water that protects the reactor core by removing heat. Pressure vessels are machined to the highest standards. Every square centimeter is x-rayed to make sure there are no hidden defects inside the metal. The steel vessel can withstand very high temperatures and pressure.

The reactor pressure vessel is cast from solid steel 20 cm (9 inches) thick.

The entire reactor system is surrounded by a **containment building** made of thick concrete that is reinforced with steel. This building protects the reactor from problems outside, and it protects the environment in case of a problem in the reactor.

The reactor is surrounded by a massive concrete and steel reinforced containment building 2 to 3 meters (6 to 10 feet) thick. This picture shows the two containment buildings for reactors at St. Lucie plant in Florida.

What is heat transfer?

The science of how heat moves is called **thermodynamics**. The laws of thermodynamics show that when heat is added to a system, some of the heat moves, or transfers, to the systems around it. Heat moves from hotter systems to cooler ones. This scientific law helps us understand how we move the heat energy produced inside the reactor.

When you pour hot cocoa into a mug, the mug quickly becomes warm. This is because heat always flows from hotter materials to colder ones.

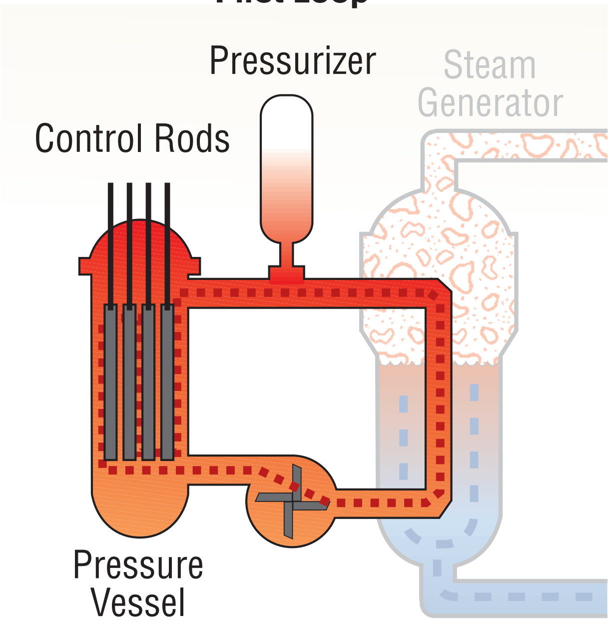
How does the heat make steam?

Heat moves from the hot fuel to the cooler water that surrounds it. The water gets hot. Normally, water boils when it reaches 100° C (212° F). When water boils, it turns into steam. Steam is water in the form of a gas rather than a liquid. Gases take up more volume than liquids.

Engineers design a pressurized water reactor so that there is not space for the hot water to turn into steam. The heated water builds up **pressure** because it cannot expand. Power plant operators use this pressure to heat water to 315° C (600° F) and keep it a liquid. Higher temperatures make the system more energy efficient.

The power plant has three separate loops of piping. Water in one loop does not mix with water in the other loops. However, the heat transfers from one loop to another. How?

First Loop



The huge blades of the turbine are spun by steam. The turbines are attached to the generators. Generators convert the mechanical energy of the spinning turbines into electricity by rapidly spinning a coil of wire inside a magnetic field.

In a pressurized water reactor, superheated water in the first loop flows through tubes in the steam generator, making them very hot. Heat energy is transferred as water in the second loop touches these hot tubes. This causes the water in the second loop to boil, building pressure as the water expands from liquid to vapor. The steam pressure provides mechanical energy that can be used to do work.

How does the steam drive turbines to make electricity?

Steam pressure blows across the blades of the turbine and spins it. A turbine works like a pinwheel with many blades. The spinning turbine is attached to a **generator**. The generator changes the mechanical energy of the spinning turbine into electrical energy.

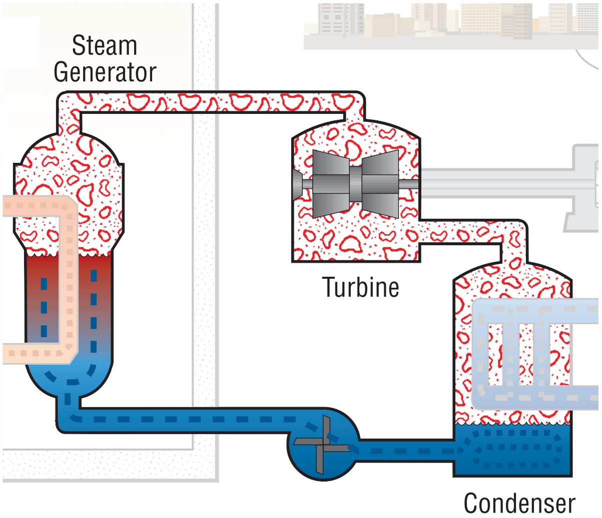
A generator at a large power plant is about twice the size of a school bus. It can produce enough electricity to supply a city of half a million people.

The generator works by rotating a coil of wire inside a magnetic field. This causes electrons to move in the wire.

What happens after steam spins the turbine?

As steam turns the blades of the turbine, it loses much of its mechanical energy. The temperature and pressure drop. Before it can be used again, the steam must be cooled back into water. Then it can be pumped back through the second loop to be re-heated and turned back to steam to build up pressure, starting the cycle again.

Second Loop



How does the condenser work?

Cooling the steam back into water is the purpose of the third loop. It starts with the **condenser**, which is located below the turbine. In the condenser, steam from the second loop flows over tubes filled with cool water from a lake, river or ocean. The steam transfers its heat to the third loop. The water does not mix. Only the heat is transferred.

A glass of ice water in the summer is a model of how a condenser works. If you pour ice water into a glass, beads of water form on the outside. The glass seems to be sweating. What is going on? We know water does not leak through the glass. The drops have come from water vapor in the air. Heat energy from the warm air has moved to the cold glass. Water vapor in the air condenses into liquid when it loses heat energy.

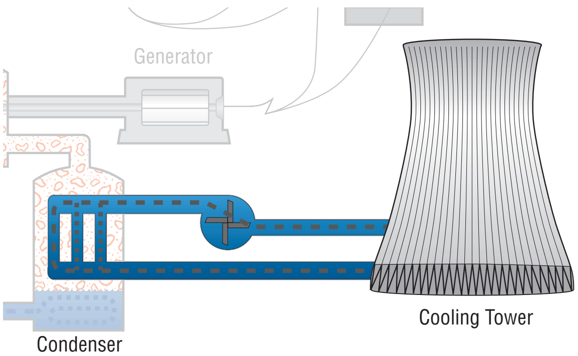
Why do we remove the heat from the water in the third loop?

Warmer water might harm fish or plant life if it were put back into the lake. So power plant operators cool the water to protect the environment. Laws require water to be within 2.8° C (5° F) of the lake's normal temperature before it is released. Therefore, some nuclear and coal power plants use cooling towers to get rid of waste heat.

How does the cooling tower work?

At 200 meters (656 feet) high, a **cooling tower** is usually the power plant's tallest structure. It is a giant, hollow concrete cylinder. It sits on legs that allow air to flow up under it. Inside the tower, warm lake water from the third loop is sprayed in the air and trickles down through the stair-stepped layers of the interior.

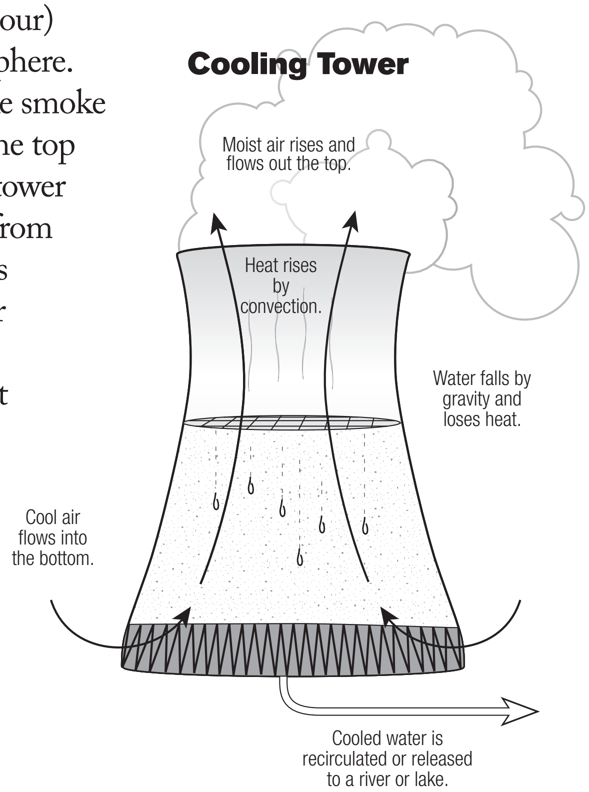
Third Loop



Heat transfers from the water into the air. Some of the water evaporates. The warm, moist air rises inside the tower. This pulls in cool air from the bottom. A natural draft begins to flow up and out of the top of the tower. The water is collected at the bottom of the cooling tower and used again in the third loop. Water that evaporates is replaced with more water from the river.

Heat and moisture leave the top of the tower at about 16 km per hour (10 miles per hour) into the atmosphere. What looks like smoke coming from the top of the cooling tower is really vapor from lake water. This water has never been near the reactor. It is not radioactive.

Cooling Tower



Summary

The way nuclear power plants produce heat energy through fission is unique. However, the way heat energy is changed into electrical energy is basically the same as in a coal power plant.

At a nuclear power plant, fission takes place in the reactor. A reactor has four main parts:

- uranium fuel assemblies
- control rods
- water (the coolant and moderator)
- pressure vessel

The fuel assemblies, control rods, and coolant/moderator make up the reactor's core. The core is surrounded by the pressure vessel. The entire reactor system is within the huge containment building.

The reactor has separate loops of piping that use water to move heat energy. Water in these loops never mixes together. However, heat energy moves from one loop to another.

In a pressurized water reactor, the first loop carries water that has been heated to a very high temperature in the reactor to the steam-generator. In the steam generator, heat energy from the first loop transfers to the second loop.

The second loop carries the heat energy as steam to the turbines and spins the turbine's blades. The turbines are attached to the generators, which change the mechanical energy of the spinning turbine into electricity. From the turbines, water in the second loop goes to the condenser. In the condenser, steam in the second loop is cooled when some of its remaining heat transfers to the water in the third loop. When it is cooled, the steam changes from a gas back into liquid water.

The third loop contains cooling water drawn from the river or lake. Because heated water could harm the environment, water in the third loop is pumped to the cooling tower where heat is removed. Some of the water evaporates and leaves the cooling tower as water vapor. Most is used again in the third loop.

Lesson 7

WASTE FROM NUCLEAR POWER PLANTS

Introduction

This lesson takes a look at the waste from electricity production at nuclear power plants. It considers the different types of waste generated, as well as how we deal with each type of waste.

TOPICS:

- Waste
- Types of radioactive waste
  - Low-level waste
  - High-level waste
- Disposal
- Transporting waste
- Reprocessing
- Waste isolation
- Decommissioning

What is waste?

In our day-to-day living, we make a lot of trash. Think of how much garbage your family collects in one week. Think of how much trash you have from just one visit to a fast-food restaurant. It probably includes wrappers, bags, straws, drink containers, and leftover food. Industries also have trash each time they do or make something. These leftovers are called **by-products** or **wastes**.

What is nuclear waste?

Like all industries, nuclear power plants produce wastes. One of the main concerns about nuclear power plants is getting rid of the wastes safely.

The problem with wastes at nuclear plants is not the amount they make, which is quite small in comparison with the amount of waste from other industries. The problem is that some nuclear power plant wastes are radioactive. This means that disposing of the waste requires special care to protect workers, the public, and the environment.

If all the electricity you used in your lifetime was generated by nuclear power plants, your share of the highly radioactive waste would fit in a soda can.

How do we decide the way to dispose of waste?

When you finish your lunch in the school cafeteria, do you just throw your tray and everything on it in a pile for someone else to deal with later? Probably not. There is a place for your tray, another place to sort dishes, and a bin for the silverware. Your trash goes in the garbage can, and there might even be separate places to put recyclables and compost. Why are there so many ways to get rid of what is left after lunch? Because it is best to handle different wastes in different ways.

It is the same with wastes from a nuclear power plant. There is a special way for disposing of each type of waste. The way it is disposed of depends on

- How radioactive the waste is
- The half-life of the waste
- The physical and chemical form of the waste

What is low-level waste?

In the United States, most low-level radioactive wastes comes from hospitals, research labs, industry, and nuclear power plants. **Low-level waste** includes items that have become contaminated with radioactive material. This waste includes shoe covers, mops, water and air filters, cleaning rags, lab supplies, broken tools, gloves, and used protective clothing. Doctors perform 100 million medical procedures each year that use radiation or radioactive materials, and many of these produce low-level waste.

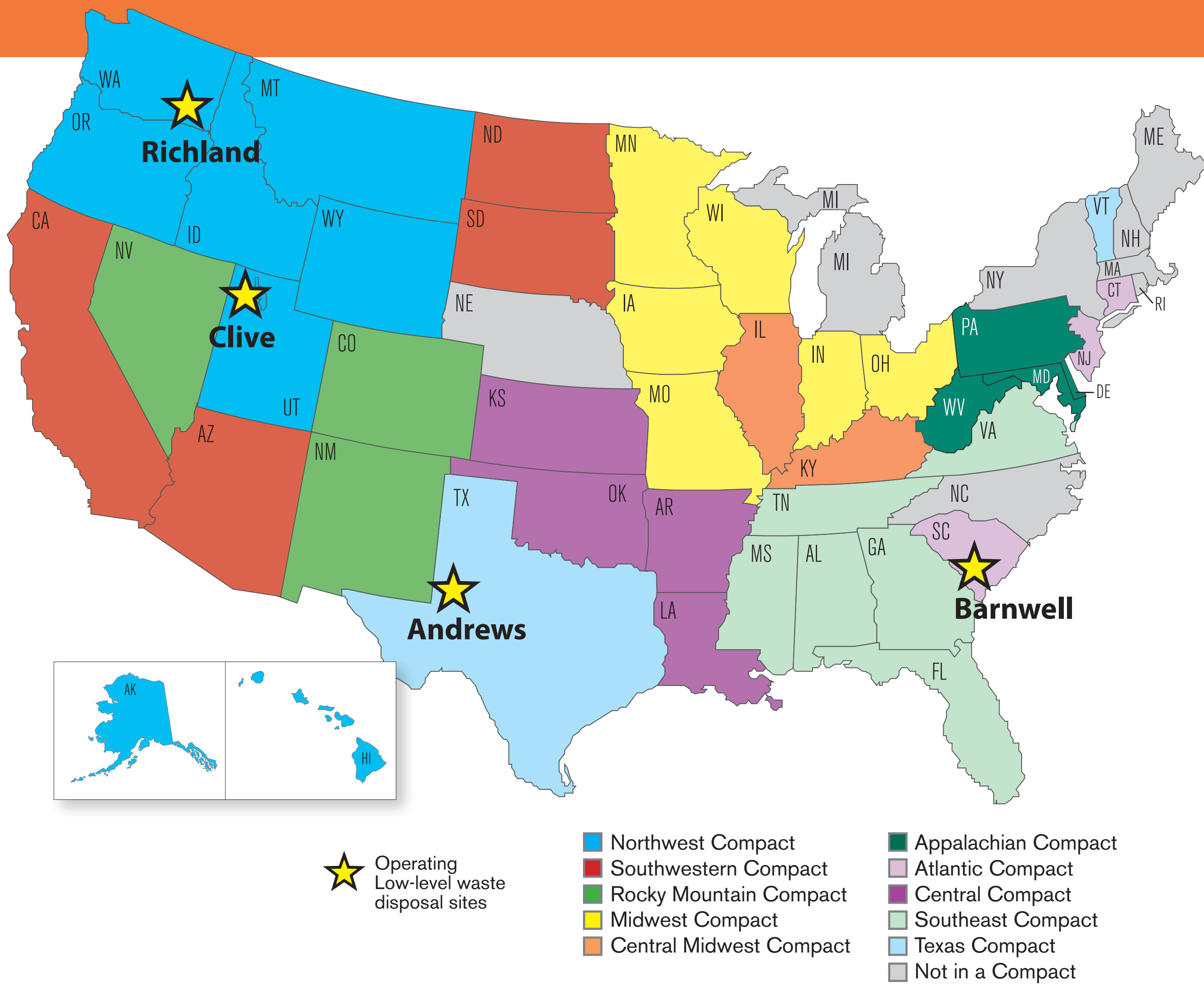
Many companies also use radioactive materials and have low-level waste to dispose of. These companies

- Make smoke detectors
- Make instruments used to inspect for defects in highways, pipelines, and aircraft
- Test and develop 80 percent of our new drugs
- Make supplies for medical procedures that use radiation or radioactive materials
- Make electricity at nuclear power plants

How do we dispose of low-level waste?

Low-level radioactive waste is sealed in containers and shipped to a licensed disposal site. The containers are put in the ground and covered with soil. Then a "cap" of soil and clay is put over the site. The cap keeps the site dry. The site is monitored with sensors that can detect radiation. Workers and regulatory agencies also regularly check radiation levels at open and filled trenches and around the site boundary.

Low-level radioactive waste is stored in containers and covered with soil.



What is a low-level waste compact?

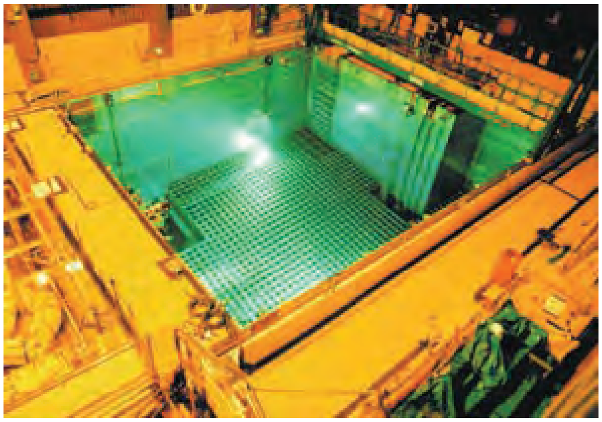
By law, each State is responsible for disposal of low-level waste from industries, hospitals, utilities and research institutions within its borders.

Instead of every State building its own site, most States have joined **low-level waste compacts**. They have legal agreements to share the cost of disposing of their low-level waste at one site in the compact.

Where are low-level waste disposal sites?

Four States have licensed disposal sites. They have agreements with compacts or States not in a compact to accept and dispose of low-level wastes. Private companies operate the sites and charge a fee for waste disposal. The sites are located at

- Barnwell, South Carolina
- Richland, Washington
- Clive, Utah
- Andrews, Texas



A spent fuel pool allows spent fuel to cool and also shields workers from radiation.

What is high-level waste?

High-level waste is the highly radioactive by-product produced inside a nuclear reactor. It can be either

- **Spent fuel** (used fuel), or
- Waste materials remaining after spent fuel is recycled

Every two years, about one third of the fuel assemblies in the reactor are replaced with new ones. Fuel that is removed from the reactor is called spent fuel. Spent fuel can be considered high-level radioactive waste.

If spent fuel is recycled, then the waste that is left over is also considered high-level waste.

How is spent fuel stored?

Spent fuel produces a lot of heat during the first year as radioactivity decays. The utility stores it near the reactor in a pool of water called the **spent fuel pool**. The pool is typically 12 meters (40 feet) deep. Here, the water cools the spent fuel and also shields the radiation. During storage, spent fuel becomes less radioactive through radioactive decay. After one year, 99 percent of the radioactivity decays away. But it still remains radioactive for thousands of years.

Some utilities use **dry cask storage** for spent fuel that has already been cooled in the spent fuel pool. The casks are typically steel cylinders that are either welded or bolted closed. The steel cylinder provides a leak-tight containment for spent fuel. More steel, concrete, or other material surrounds each cylinder to provide radiation shielding.

These dry storage casks hold spent nuclear fuel assemblies that have cooled for at least one year.

How will we transport the waste?

Eventually, utilities will ship spent fuel assemblies to a central storage site or a permanent repository. The utility will ship spent fuel in special spent fuel shipping casks.

If you play a musical instrument in band, you probably take it to school in a case to keep it safe. The purpose of spent fuel shipping cask is similar to the purpose of an instrument case. Both are specially made to protect their contents. A spent fuel shipping cask must also protect people and the environment from the radiation given off by the fuel it holds. Engineers design spent fuel shipping casks with heavy shielding and thick walls that prevent radiation in the spent fuel assemblies from getting into the environment.

Transportation specialists carefully plan and manage fuel shipments for safety and security.

A spent fuel shipping cask must be strong enough to withstand even the worst transportation accidents. To be sure they work as they are supposed to, scientists and engineers have performed crash tests with these casks. They used high-speed cameras to study what would happen to the casks in a very serious accident. The tests included slamming a truck and cask into a concrete barrier at over 113 kilometers (70 miles) an hour, burning casks in jet fuel, sinking them underwater, dropping them from a crane onto a steel spike, and crashing a high speed train into a cask on a trailer. In all of the tests, the casks protected their contents, even though the trucks and trains were destroyed.

What is reprocessing?

Some parts of the spent fuel can be recycled and used again as reactor fuel. This is called **reprocessing**. Spent fuel is taken out of a reactor when there is not enough uranium-235 to power a chain reaction. However, it is still 95.6 percent unused uranium, including 1 percent uranium-235. It also contains **plutonium** produced by the reaction. Both uranium-235 and plutonium can be recycled to make new reactor fuel.

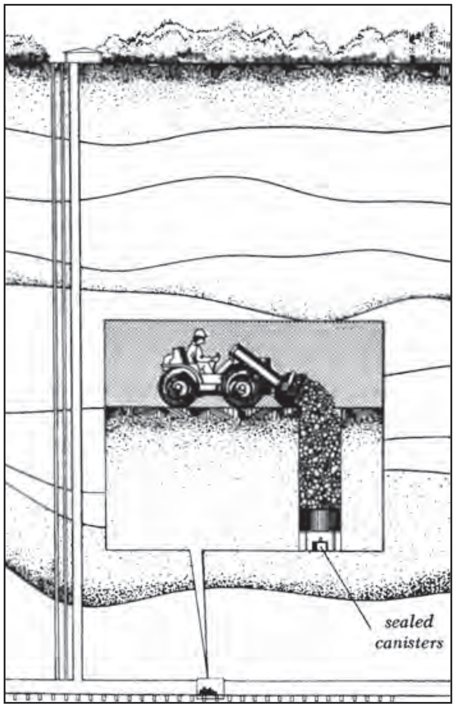
At present, the United States has decided not to do nuclear fuel recycling. One reason is that a by-product of reprocessing is plutonium, and safeguards must be taken because the plutonium could be used to make weapons. Another reason is that reprocessing is expensive.

If we do not reprocess spent fuel, then it will be treated as high-level waste. If we do reprocess spent fuel, there will still be some high-level waste that requires disposal.

How can we isolate high-level waste for thousands of years?

Nuclear technicians can seal high-level waste in heavy metal canisters and then store them deep underground in a **geologic repository** drilled into a dry, stable rock formation. In 1982, U.S. Congress passed the Nuclear Waste Policy Act. This law called for a deep geologic repository to safely store or dispose of high-level radioactive waste. This geologic repository would be as much as 1 kilometer (.6 mile) underground with tunnels for storing waste. The Act required nuclear power plants to pay a fee for the cost of the waste repository.

In the years since it passed, there have been a number of changes to the Act. Yucca Mountain, in Nevada, was chosen by Congress as a site for a repository. In 2010, work at that site was stopped. Today, utilities store spent fuel at power plants as other solutions are being evaluated.



This drawing shows how spent fuel and high-level waste could be isolated 1,000 to 3,000 feet beneath the surface of the Earth in a geologic repository.

What happens to a nuclear power plant when it closes?

A license to operate a nuclear power plant lasts for 40 years. After that, the utility company can ask to renew its license for 20 years longer, or it can shut down the plant and **decommission** it.

During the years nuclear power plants produce electricity, many parts become radioactive. When the plant closes, the radioactivity begins to decrease through the process of radioactive decay. With each passing year, materials at the reactor become less radioactive. This means it becomes easier to **dismantle** after 10 or more years because the level of radioactivity is lower.

What is the nuclear fuel cycle?

All of the steps involved in using uranium to make electricity are known as the **nuclear fuel cycle**. The fuel cycle begins with mining uranium ore and ends with nuclear waste disposal. The fuel cycle includes all the steps to refine the uranium, enrich the concentration of uranium-235, manufacture fuel, use it in a reactor, store the spent fuel, and recycle or dispose of the waste. People who have jobs in nuclear energy carefully manage each step in the fuel cycle to protect the public and the environment.

Summary

Like all industries, nuclear power plants produce wastes. Some of the wastes are radioactive and require special methods of disposal. The way we dispose of radioactive waste depends on

- How radioactive the waste is
- The half-life of the waste
- The physical and chemical form of the waste

Waste that has been contaminated with radioactive material at hospitals, research labs, industry, and power plants is called low-level waste. Most of the radioactive waste from a nuclear power plant is low-level. Usually it is sealed in steel drums and buried at licensed low-level waste disposal sites.

Nuclear fuel is removed from the reactor when it can no longer support fission efficiently. This spent fuel from power plants can be considered high-level waste. Spent fuel is stored in water in spent fuel pools near the reactor where it cools and undergoes radioactive decay. After a year or two in the spent fuel pool, spent fuel can be removed from the pool and stored in dry casks.

The United States has not made a final decision about how to permanently dispose of high-level waste. The usable parts of spent fuel can be recycled through a process called reprocessing, but the United States is not currently reprocessing spent fuel. High-level waste requires permanent isolation because it remains radioactive for thousands of years. Spent fuel and high-level waste left after reprocessing need to be isolated deep beneath the Earth's surface in a geologic repository.

CONCERNS

Introduction

Nuclear energy is one of our three largest sources of electricity. It is important for us to make sure nuclear power plants are safe and reliable. In decisions to build and operate a nuclear power plant, safety and security are essential concerns. Learning from past accidents, understanding this energy source, and protecting against risk are important in our energy mix.

TOPICS:

- **Safety at nuclear power plants**
  - Design features
  - Engineering safety
  - Barriers and backups
  - Regulations
- **Security**
- **Accidents**
  - Three Mile Island
  - Chernobyl
  - Fukushima
- **Learning from accidents**
- **Informed decisions**
  - Risk and benefits
  - Utility costs
  - Tradeoffs

What concerns do people have about nuclear power plant safety?

Safety must be the primary concern when we plan, build, and operate a nuclear power plant. The main questions people have about nuclear power plant safety center around radiation because the fuel in a reactor becomes very radioactive. Nuclear power plants release very little radiation as they make electricity. However, if an accident released a large amount of radiation, it would be serious.

Safety includes protecting people who work at the nuclear power plant as well as the people living nearby. It also includes protecting the environment and the power plant itself from damage. Safety is every employee's responsibility. Working at a nuclear power plant is one of the safest jobs in industry. Each year, the injury rate is lower in the nuclear power industry than other jobs, even office work like finance and real estate.

Preventing accidents is the focus when people design, build, and operate nuclear power plants. As a result, nuclear power

Nuclear power plants have safety systems that are inspected by workers and regulators.

plants in the United States have been very reliable and have a record for operating safely. However, the record is not perfect. There have been accidents at nuclear power plants in the past.

Each way that we have of producing electricity has its own safety concerns. For this reason, each type of power plant—coal, nuclear, hydro, gas, solar, wind—has special **design features** to protect people and the environment. The safety requirements for nuclear power plants are the strictest.

Regulators inspect the way nuclear power plants are operated and maintained.

What keeps U.S. nuclear plants safe?

Nuclear engineers focus on safety when they design reactor systems. Scientists, **engineers**, **architects**, and **regulators** all work together as they plan plants. They use the natural properties of the fuel and fission for a safe design. Then they add **engineered safety systems** that protect against failure. Around this, they build strong **barriers** to keep radioactive material inside the plant. To make sure that the plant is run properly, operators take years of special training and tests.

The **Nuclear Regulatory Commission** – the **NRC** – must grant a license to the power plant before it can operate. Then NRC experts conduct regular inspections to make sure the plant runs safely and that the utility performs proper maintenance. Each nuclear power plant has an NRC inspector assigned to work at the power plant as his or her full time job.

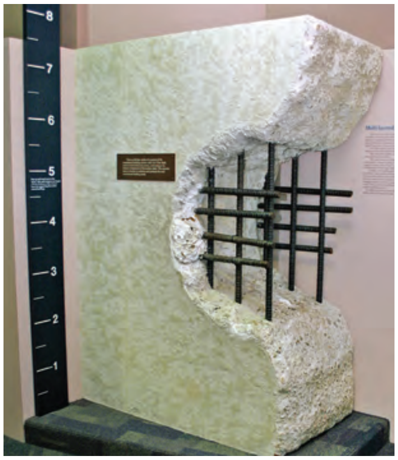
Design safety. The physics of a nuclear power plant design help keep it safe. The characteristics of the fuel, the coolant, and the chain reaction itself **safeguard** against accidents. Fuel in a reactor is concentrated just enough to keep the reaction going. It is too diluted to explode like a bomb.

As fuel gets hotter, the chain reaction slows down. This property naturally helps limit the rate of fission.

The water used as a coolant is also necessary for a chain reaction. If cooling water is lost from around the fuel, the chain reaction will stop and the heat from the fuel will drop to 1.5 percent within an hour. Although the remaining heat would damage the reactor, the fission reaction would not keep going.

Nuclear power plants are built to withstand hazards like tornadoes.

Engineered safety. Every safety-related system in a nuclear plant has **backup** systems. For example, designers include backup pumps to circulate water in the reactor if the main pumps should ever quit working. There are also more backup pumps just in case the first backups should fail. There are also backup cooling systems, instruments, and electric power systems.



The containment building around a reactor is built from concrete reinforced with steel like the exhibit shown here.

Safety barriers. Utilities build nuclear power plants to withstand all environmental hazards, including tornadoes, hurricanes, fires, floods, and earthquakes. Engineers design for safety in the event of an earthquake, even for plants located in areas of moderate or low earthquake activity.

The containment building that houses the reactor works as a barrier that keeps radiation inside, away from the environment. Other barriers also hold in radiation. Uranium fuel is in solid ceramic form that does not rust or dissolve. It can withstand very high temperatures. The ceramic fuel is sealed inside metal fuel rods that make up the core. A massive steel pressure vessel surrounds this reactor core. All of these barriers keep radiation in the reactor and out of the environment.

In late March 2011, scientists at Cook Nuclear Power Plant in Michigan took measurements of the radiation around their site. They recorded a level of 0.05 millirem (mrem). The graphic below shows how this level compares to other naturally occurring and human-made radiation that Americans are exposed to each year.

0.08 MREM
smoke detector

1–2 MREM
watching TV

10 MREM
chest X-ray

30 MREM
cosmic rays
(average for most of U.S.)

What regulations apply to U.S. nuclear power plants?

Regulations require utilities to develop detailed plans to prepare for emergencies. The utility must immediately notify the public, the **NRC**, and State and local governments if a problem occurs. The utility must also have plans for evacuating people who live nearby. Emergency officials, plant employees, firefighters, rescue teams, and police teams regularly practice putting the plans into action to be ready to respond to accidents.

Isn't even a small amount of radiation harmful?

Some people are concerned about low levels of radioactivity released by nuclear power plants generating electricity. As you learned in Lesson 4, everyone receives natural and human-made radiation all the time.

U.S. nuclear power plants add about 0.0001 millisievert (0.01 millirem) a year to the radiation received by people living within 50 miles of a nuclear power plant. Most scientists agree that this is insignificant when compared to the 6.2 millisievert (620 millirem) of total radiation the average American receives each year.

What about the radioactivity from spent fuel?

When reactor operators take fuel out of the reactor, it is very radioactive. It must be handled carefully and shielded to protect workers. Today, spent fuel (used fuel) is stored securely at power plants under water in spent fuel pools or in dry casks. This keeps radiation away from workers and people living near the plant. In the future, we will use **permanent disposal** to isolate high-level radioactive waste for thousands of years.

Can terrorists use nuclear power plant fuel to make nuclear bombs?

No. The uranium fuel used in nuclear power plants will not work for a nuclear bomb. It is not enriched enough to explode as a weapon. Some people worry that terrorists might try to steal or hijack a fuel shipment to try to make a "dirty bomb" by using explosives to spread contamination in the environment. Although this would scare people, it would not be very effective. However, nuclear fuel is kept under strict **security** to prevent anyone from getting access to it.

How do nuclear power plants affect other kinds of security?

So far, we have talked about physical safety. Another kind of security involves protecting our economy. The United States depends on energy for every part of our economy. When energy is not available, or the price goes up quickly, it affects every person. We import much of our energy from other countries. Using nuclear energy to make electricity is one way our nation maintains a reliable electricity supply at a reasonable price.

What happened at Three Mile Island?

A 1979 accident at the **Three Mile Island** plant in Pennsylvania was the most serious nuclear power plant accident in the United States. Plant operators mistook readings from the reactor systems and turned off automatic safety systems. This caused the reactor to lose cooling water. The reactor fuel overheated and seriously damaged the core. High levels of radiation were released into the containment building, and the heat ruined the reactor unit.

The protective barriers at the plant kept most radiation inside, but traces of radioactive iodine and xenon gas were released off the plant site. The average radiation exposure to people living in that area was about 0.01 millisievert (1 millirem) from the accident. This is less than the radiation from a chest x-ray, which is about 0.06 millisievert (6 millirem). It's also far less than the natural background radiation in that part of Pennsylvania, which is about 1 to 1.25 millisievert (100 to 125 millirem) per year. There were no serious injuries. However, it took weeks before authorities fully understood what had happened and people living near the plant were concerned that it could be dangerous. It was costly for the utility to clean up the damaged reactor and to replace the electricity it produced.

What about accidents in other countries? What happened at Chernobyl?

In April 1986, there was a very serious accident at a reactor in **Chernobyl**, Ukraine, in the former Soviet Union. Operators were performing unauthorized tests that caused a steam explosion and fire that destroyed the reactor. Two workers died in the accident. Another 28 workers died several months later.

The Chernobyl reactors were an entirely different design than power plants in the United States. Chernobyl reactors did not have containment buildings like the ones required for U.S. power plants. The Chernobyl accident released a large amount of radioactive contamination to areas of Belarus, Ukraine, and other countries in Europe.

Studies by a United Nations scientific committee indicate that there were more than the normal number of cases of thyroid cancer in children near the site. No other increase in cancer or other diseases has been found in 25 years since the accident. However, it is possible that we could see some increase in diseases linked to radiation from Chernobyl in the future.

What happened at Fukushima in Japan?

In March 2011, there was a massive earthquake off the coast of Japan. The earthquake caused a 14 meter (49 foot) **tsunami**, or tidal wave that flooded the coast and killed about 19,000 people and injured 28,000 more. The **Fukushima Dai-Ichi** nuclear power station is on the coast. The plant has six reactors, but three were shut down for regular maintenance. When the earthquake occurred, the three operating reactors automatically shut down and emergency cooling systems came on. However, the earthquake cut off the supply of electricity to the plant, so emergency backup generators started to supply electricity. Then the tsunami flooded over the emergency backup generators. Without electricity, plant operators were not able to keep the reactor and spent fuel cooled. Damage to the nuclear fuel caused explosions of hydrogen gas. There were releases of radiation. People were evacuated from areas around the plant. Some food and water supplies were contaminated, and workers were exposed to radiation. No one died because of the damage to the power plant, but one worker died in the tsunami.

What do these accidents mean for reactor safety?

Whenever there is an accident or problem at a nuclear power plant, experts in the United States and around the world study it to see what we can learn to make our nuclear plants safer. For example, after Three Mile Island, all reactors in the United States had to meet new safety regulations, and the operators had more training. After

In deciding how to make our electricity, we will have to weigh the risks and benefits of using various energy sources.

the earthquake in Japan, the U.S. Nuclear Regulatory Commission analyzed reactors to make sure they could withstand similar natural disasters. The lessons learned led to changes in the safety systems to protect the reactor fuel in case power is cut off at a plant.

How do these concerns affect U.S. energy decision making?

There are good aspects and problems with every energy source. The good aspects are called **benefits**. The problems are called **risks**. Most people feel that the benefits of a reliable energy supply outweigh certain risks. The question is really about how we can better understand and protect against risks when using energy resources like nuclear power.

There is an area of science called **risk assessment** that has been used to study the risks in various industries. Risk assessment can involve detailed mathematical calculations and analysis. For example, to study risk in the nuclear power industry, scientists examine every step, beginning with mining fuel, building and operating power plants, and ending with decommissioning the power plants and disposing of nuclear wastes.

Risk assessment helps us understand the risks involved by comparing them to other situations. It also helps pinpoint ways to make things safer.

How do people make decisions about risks?

Scientists who study human behavior tell us that people are more likely to distrust new or unfamiliar things. When electricity, trains, and automobiles were first developed, some people were too frightened to use them. In more recent times, the same was true with microwave ovens and cell phones.

When given choices, we are most likely to pick things that are familiar. For example, some people refuse to fly in airplanes but will travel in cars, even though statistics show that airplanes are less likely to have accidents. Medical vaccinations, prescription drugs, food preservatives, and cell phones are other examples of new technologies that have changed the way we live, but that also concern some people.

We have grown accustomed to certain hazards even though they are comparatively dangerous. You accept certain risks when you bicycle or skateboard, go sledding or swimming, or participate in sports like football, basketball, soccer, or softball. All of our activities involve risk.

Many of our favorite activities involve risk.

What are the risks and benefits of nuclear energy?

As with all energy sources, nuclear energy has both risks and benefits. Major questions we must consider about the risks and benefits of our energy options are

1. What are the risks of using an energy source to generate electricity?
2. Do the benefits outweigh the risks?
3. What are the risks of not having affordable electricity and the quality of life that goes with it?

These are very difficult questions and there are no simple answers. But these are questions you and other Americans are going to be answering in the future.

Summary

In decisions to design, build, license, and operate nuclear power plants, safety is the primary concern. Engineers design a series of barriers to provide layers of containment to keep radiation from being released during regular operations of a nuclear plant or during an emergency. They design nuclear power plants to withstand natural disasters, including fire, floods, tornadoes, earthquakes, tsunamis, and hurricanes.

The security of nuclear power plants is also part of safety. To ensure safety and security, workers at nuclear power plants spend many hours planning, training, and practicing for emergencies.

Nuclear power plants in the United States have been very reliable and have a record for operating safely. However, the record is not perfect. There have been accidents at nuclear power plants. The most serious ones did not happen in the United States. When there is a problem at a power plant anywhere in the world, experts study what happened to find ways to make plants safer.

One issue in the United States today is how to meet our future electricity demands. All choices involve some risk. In order to make decisions about this issue, it is important to understand risks and benefits. Risk assessment is an area of science that studies and measures risk to help us make decisions.

Being informed about nuclear energy involves defining the concerns people have, gathering the facts, and evaluating the information.

Lesson 9

ENERGY AND YOU

Introduction

The United States depends on a plentiful supply of energy that is available at affordable prices. Why does that matter to you? Energy costs affect your family, your community, and the businesses around you all the time. When you enter the job market, your fresh ideas on clean energy sources, fuel efficiency, and new technologies can keep America the leader in energy innovation and production.

TOPICS:

- Supply and demand
- Energy decisions
  - Energy and the economy
  - Utilities
  - Energy and you
- Your future career options

Do energy decisions affect you?

Yes. Rising energy prices affect everyone – workers, farmers, truck drivers, and restaurant owners. If businesses have to spend more for energy, they may earn less profit. Families feel the pinch when they pay their energy bills. That's why the United States is working to secure our energy supply and meet our demand for energy.

What is supply and demand?

Supply is how much of something is available. **Demand** is how much of it people want. Supply and demand determine the value of things. For example, the supply of oil on the world market determines the price of gasoline. When supply and demand are in balance, we say they are **stable**. Prices don't change much.

If demand is greater than supply, something will change

- Sellers may charge more for their product
- Buyers may be willing to pay more
- Buyers may choose to go without
- Buyers may choose to buy something else

Imagine you and your friends have a bag of gummy bears. The bears are the supply. What if everyone likes the red ones best? Red bears are in demand. When you divide the bears, what do you think will happen?

What do supply and demand have to do with energy?

Energy costs are determined by supply and demand. When energy demand is greater than supply, prices go up. We also know that energy markets are global. This means that what happens in any part of the world affects everyone.

Energy is not like most other things we buy. With energy, it is hard for buyers to simply go without or to choose to buy something else.

How do utilities balance supply and demand?

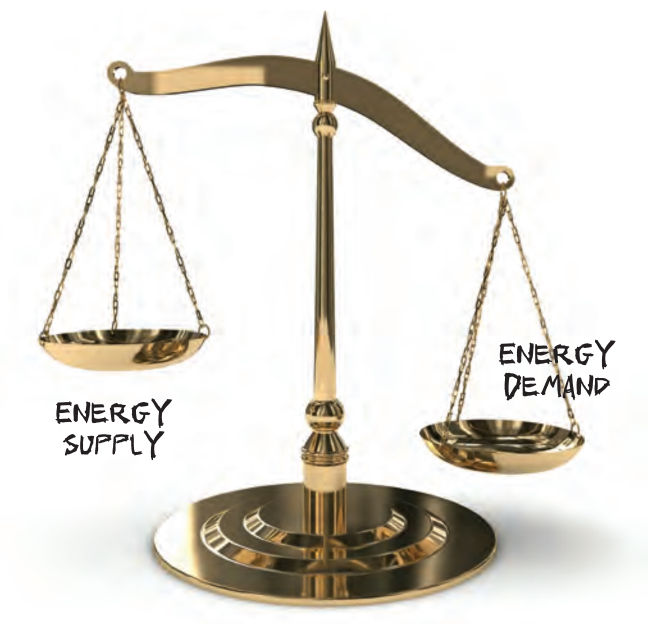
Utilities build power plants to meet our demand for electricity. However, the demand for electricity changes from year to year. Before deciding to build a power plant, utilities consider supply and demand. Because it takes years to build a new power plant, utilities hire people to plan for what their customers will need in future. In planning, they figure the cost of building power plants, including the cost of borrowing money. They estimate the cost of operating the power plant over its entire lifetime. They also base their choice on the cost of the fuel and whether they can get a steady supply.

How can we plan for energy demand in the future?

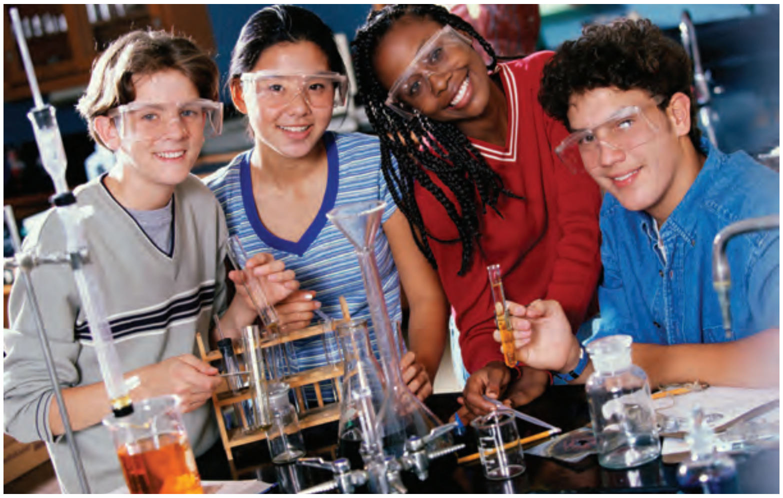
To meet tomorrow's energy demand, we must look carefully at the energy sources we have available. This is called our energy mix. Then we must make choices that will provide clean energy at a reasonable cost.

Current energy research focuses on expanding cleaner sources of electricity, including wind and solar, biomass, nuclear energy, clean coal, and natural gas. The United States is working toward making 80 percent of our electricity from clean energy sources by 2035. Keeping America on the cutting edge of clean energy technology sparks new jobs, new industry, and innovations that keep us safe, healthy, and protect our economy.

For the future, engineers are working on a new generation of smaller, safer, and more



Utilities must plan ahead to meet the future demand for electricity by constructing power plants that help keep supply in balance. Clean energy sources will need to meet most of our demand by 2035.



Skills that you learn in your science and math classes connect to your life outside school. They will also matter for jobs.

No matter what kind of job you want to do when you graduate, you need a strong foundation in computers and math. To take advantage of the career opportunities in your future, you will need to understand how science works and have the skills to use technology for learning more.

efficient nuclear reactors. Nuclear scientists and engineers from around the world are also working together to design a way to generate electricity using nuclear fusion.

A global race is underway to develop cleaner energy technology. Other countries are playing to win, too. To rise to this challenge, we need to tap into the greatest resource we have – your ingenuity.

Why should I think about this now?

Tomorrow's energy careers will require a deep understanding of science, and technology.

What are some jobs in nuclear science?

Your nuclear science career could focus on electricity production, nuclear fuel design, medical research, environmental protection, or even archaeology. Throughout the world, nuclear science is used in industry, medicine, agriculture, and environmental research to provide energy, help save lives, boost productivity, increase food output, and protect resources.

You have many options within those fields. Choosing your career starts with your interests, skills, and talents.

After graduating from high school, you have options that can lead to careers in nuclear science…

- 2-year college degree (called an associate's degree)
- Trade school certificate
- Apprenticeship
- 4-year college degree (called a bachelor's degree)
- Graduate school (called a master's or doctoral degrees)

CareerSnapshot:

Brent - Nuclear Engineering

I work with Advanced Reactor Systems and Safety on nuclear policy and safeguards to prevent spread of hazardous materials. My next assignment will be helping design systems for the next generation of smaller, safer, and more efficient reactors.

Education: I have a bachelor's degree in mechanical engineering and a master's degree in nuclear engineering, and am now finishing a doctorate.

What are some energy jobs that use nuclear science?

Electricity demand is growing around the world. Nuclear energy is a clean energy resource that supplies electrical demand without releasing carbon dioxide into the atmosphere. Nuclear energy also powers satellites, ships, and space laboratories.

Career choices in nuclear energy include

- Reactor operators, who run the systems at a power plant to produce electricity
- Engineers, who design power plants and supervise operations
- Mathematicians and statisticians, who calculate energy costs and future demand
- Nuclear scientists, who explore ways to improve safety and efficiency
- Technologists, who locate natural resources underground

What are some other nuclear science jobs?

As the world's population grows, the need for food is increasing rapidly. Scientists use radiation to develop crops that produce higher yields, eliminate pests without chemicals, and improve food safety. For example, most pasta consumed today is made from a wheat variety developed by using this research. In Africa, radiation helped control the tsetse fly that transmits deadly disease to cattle and people.

Career choices in environmental research and nuclear technology include

- Gamma facility operators, who use radiation to destroy microorganisms like salmonella or *E. coli*.
- Biologists, who conduct experiments to develop new varieties of crops

CareerSnapshot:

Jenna - Nuclear Scientist

I am a food scientist with a specialization in nuclear science. I use radiation techniques to produce higher yield crops and protect livestock from disease. I also look for ways to eliminate pests without the use of traditional chemicals.

Education: I have a bachelor's degree in nuclear science and bachelor's degree in biology.

- Agricultural technicians, who use radiation to destroy disease-causing germs in food and spices
- Research assistants, who help scientists and food engineers collect and analyze data
- Technologists, who study natural resources to help make the most of limited water supplies

What are some nuclear medical science jobs?

Discoveries in nuclear science have dramatically improved people's health. Nuclear medicine benefits over 40,000 patients daily. Doctors rely on x-rays to diagnose broken bones or find tumors without surgery. They use radiation to treat leukemia and other types of cancer. More than half of all medical equipment used in hospitals is sterilized with radiation. Scientists use radioisotopes to develop more than 80 percent of all new drugs.

Career choices in nuclear medicine and biology include

- Health physicists, who assure that people who work with radiation do it safely
- Physicians, who use nuclear medicine to diagnose and treat diseases
- Nuclear medicine technologists, who run tests in hospitals
- X-ray technicians, who work with patients in hospitals

CareerSnapshot:

Anthony - Nuclear Physicist

I do research at a national laboratory on energy and matter. My team is looking at the structure of matter and ways to use energy within the atom's nucleus.

Education: I have a master's degree in physics, which took another 2 years after my bachelor's degree. Most jobs in my field require at least a B.S. in physics or a related area, as well as strong math and writing skills.

CareerSnapshot:

Madison - Radiological Technologist

I assist doctors with x-rays and imaging scans that help diagnose tumors, certain types of cancer, and other diseases.

Education: After high school, I took two years of college courses that led to an associate's degree. My coursework included anatomy, pathology, patient care, radiation physics and protection, and image evaluation.

I WANT A JOB IN NUCLEAR SCIENCE

SCIENCE

Science exercises the mind and teaches logical thinking. It encourages looking at things in different ways.

TECHNOLOGY

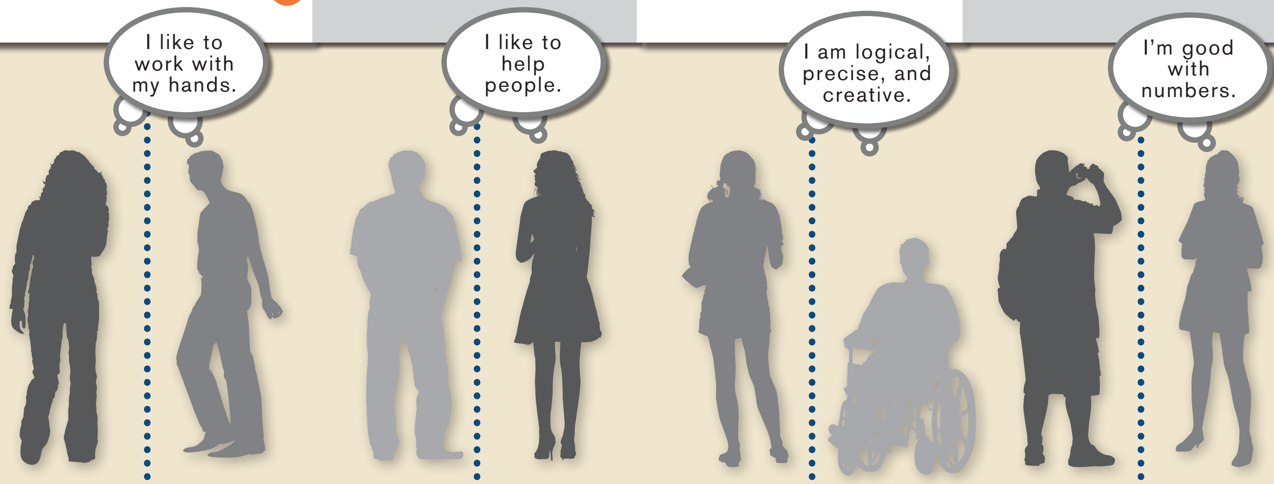
Technology skills increase your ability to use, understand, and change many of the tools you already use, like computers or your cell phone, and to help develop new ones.

ENGINEERING

Engineering uses science and math, and applies them to design, create, or modify nearly any structure, machine, or material.

MATHEMATICS

Math skills give you the ability to identify and analyze patterns and use logic. It develops critical thinking skills and problem-solving skills.



maybe you would be interested in becoming a...

Power Plant Operator, Distributor, or Dispatcher who controls the systems that generate and distribute electric power. Nuclear power reactor operators regularly check power plant equipment to ensure it is working properly.

Requires

High school diploma, technical skills, continuous on-the-job training. College or Navy career is desirable.

Demand

55,900 jobs in 2010 expected to be steady through 2020

Nuclear Medicine Technologist who uses scanners to create images of areas of a patient's body. They prepare radioactive drugs and administer them to patients undergoing scans. Radioactive drugs cause abnormal areas of the body to appear different from normal areas in the images.

Requires

2-year college degree

Demand

21,900 jobs in 2010 with 19% expected increase in positions through 2020

Nuclear Engineer who could help find industrial or medical uses for nuclear energy and radiation. You could also design nuclear power plants. Some nuclear engineers work for NASA, testing space shuttles to ensure safety in orbit and on launch.

Requires

4-year college degree

Demand

19,100 jobs in 2010 with 10% expected increase in positions through 2020

Applied Mathematician who creates models to solve practical problems in fields like business, government, engineering, and the sciences. You could work with a team of engineers and scientists and solve real-world energy problems.

Requires

6- or 4-year college degree

Demand

3,100 jobs in 2010 with 16% expected increase in positions through 2020

What are other careers in nuclear science?

Lots of other careers use nuclear science. Archaeologists and paleontologists use nuclear techniques to determine the age of objects. Crime investigators test evidence using neutron activation analysis. Art experts use nuclear tools like x rays to study paintings to see if they are valuable original art or fakes.

Today's students will be tomorrow's energy decision makers, designers, and workers.

Why does energy science matter to you?

You will be making choices about how we should supply our future energy demands. Learning about the world's energy resources and the science behind how they can be used, will make you a better decision-maker in the future.

Meeting the world's energy demands will take many solutions. A mix of energy supplies is what Americans use now. That mix will change as supply and demand change. Planning for the best future energy mix will require smart scientists, engineers, and inventors working to create new energy options and to conserve what we have. Perhaps you will be one of these people.

Lesson 9 ENERGY AND YOU

Summary

Supply and demand determine the cost of all things, including electricity.

The question we need to answer is how America will supply our demand for electricity. In deciding what type of power plant to build, utilities must consider construction, fuel, and operating costs. The sum of these costs will help them decide how to make electricity in the future.

You and your classmates will be making decisions about how we should meet our future energy demands. Planning the best mix of energy for the future will require smart scientists, engineers, inventors, and citizens. What will you be?

Credits

Cover

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