Simple machines help people relax and stay fit. How many simple machines can you identify in this exercise equipment?

CHAPTER 9

Transportation

The Bikedispenser allows one-way trips to other rental stations.

Better by Design

Hans Schreuder designed the Bikedispenser®

Hans Schreuder, a Dutch industrial designer, wants to encourage more people to use public transportation. Hans and his team noted that a lot of people use a bicycle to travel between their home and a train station. But when they arrive at their destination, they have to use a bus or taxi, both of which are expensive and add to air pollution, to complete their commute. The Bikedispenser is a fully automated public bicycle rental system. It can store 50–100 bicycles in a compact and safe environment at a train or bus station. You rent a bicycle, cycle to work and leave the bicycle in the company parking lot. At the end of the day, you cycle back to the station and return the bicycle to the Bikedispenser. Not only does this reduce the use of polluting buses, but cycling is healthier and often quicker than using public transportation.

Bicycle rental systems can have a positive effect on the environment. What are the environmental advantages and disadvantages?

"We must create better alternatives to those imperfect solutions currently in use, such as cars."

Reading Target

Finding the Main Idea

As you read this chapter, look for the key points, or main ideas, in each part of the chapter. Then look for important details that support each main idea. After you have read the entire chapter, use the Reading Target graphic organizer at the end of the chapter to organize your thoughts about what you have read.

Key Terms

- *automated guided vehicle (AGV)*
- *diesel engine*
- *electric motor*
- *electric vehicle*
- *engine*
- *external combustion engine*
- *fuel cell vehicle*
- *gasoline engine*
- *human-powered vehicle (HPV)*
- *intermodal transport*
- *internal combustion engine*
- *jet engine*
- *mass transit*
- *on-site transportation*
- *recumbent*
- *steam turbine*
- *thrust*
- *transportation*
- *transportation system*
- *turbine*
- *turbofan*
- *turboshaft*

Objectives

After reading this chapter, you will be able to:

- State the advantages and disadvantages of various modes of transportation.
- Explain the principles of various types of engines and motors.
- Describe how industries rely on transportation systems.
- Identify the processes that enable a transportation system to work.
- Explain how transportation technology influences everyday life.
- Discuss the environmental impact of transportation systems.

Useful Web sites:
www.bikedispenser.com/home-english.html
www.youtube.com/watch?v=pcwll9nzEvc

Transportation forms a vital part of our lives, giving us access to education, recreation, jobs, goods, services, and other people. Different transportation systems enable people, packages, and commodities to travel from house to house, from town to town, from country to country, and even from earth to the moon.

Modes of Transportation

Suppose you want to send a package to a friend who lives in a distant city. You might transport the parcel to the post office using your bicycle. From the post office, a truck might take the parcel to the airport. An airplane delivers it to a city across the continent. There, another truck takes it to a central depot for sorting. Finally, a mail carrier might use a bus or mail truck to deliver the parcel to your friend's house. The bicycle, truck, airplane, and bus are individual modes of transportation. Together, they form a transportation system.

You are probably familiar with the millions of miles of public roads, but you might not know about other transportation networks, including the commercially navigable waterways and hundreds of ports on our inland waterways, the Great Lakes, and our coastal regions. You have probably never thought about the millions of miles of pipelines in North America, but they too are part of our transportation system. They transport oil and natural gas.

Land Transportation

Transportation burns much of the world's supply of petroleum. Also, hydrocarbon fuels produce carbon dioxide, a greenhouse gas thought to be the main cause of global climate change. Although regulations for our vehicles have ensured that the vehicles pollute less than they used to, the number of vehicles has increased, and we use the vehicles more often. For example, over 90 percent of workers in North America travel to work by car.

By contrast, most people in the rest of the world use other forms of transportation. See **Figure 9-1**. While we are used to traveling by car, most people in the world cannot afford a car. Walking, cycling, and taking minibuses or trains are their means of getting around.

Even in North America, public transportation can often be the fastest way to travel. When city streets are congested, buses traveling in dedicated bus lanes, metro cars moving underground, and high-speed trains going between major urban centers can all travel at much higher speeds than private vehicles. See **Figure 9-2**. If transportation were public, we would have more people in each vehicle, fewer cars would be on the roads, and traffic jams might be eliminated.

Figure 9-1. Trolley buses are an option in many urban areas. What are the advantages and disadvantages of trolley buses?

Figure 9-2. Many major cities have dedicated bus lanes. How can this help improve traffic flow?

When large numbers of passengers are transported, we call it *mass transit*. Mass transit is a good description because underground systems, such as those in London and Hong Kong, carry millions of passengers each day. Underground systems solve some of the worst traffic problems, especially at rush hour, because weather and street-level congestion do not affect them. They are, however, extremely costly to build. Many mass transit railways include not only underground tracks, but surface and elevated tracks. San Francisco's Bay Area Rapid Transit (BART) includes 19 miles (30 km) of tunnels, 25 miles (40 km) of surface track, and 31 miles (50 km) of elevated track.

Road Transportation

Roads carry an extraordinary variety of motor vehicles. In addition to cars, buses, and many sizes of delivery trucks, they handle fire engines, ambulances, police vehicles, mixer trucks, crane carriers, and garbage trucks, to name only a few types of vehicles.

Tractor-trailers are the most common vehicles for long-distance hauling. See **Figure 9-3**. The tractor part has a cab, an engine, and a transmission with a turntable (or fifth wheel) on top of the rear axle, where it hooks to the trailer. Rules mandate the number of hours tractor-trailer drivers can drive and how much rest or sleep time is necessary. Long-distance trucks are, therefore, often equipped with sleeper cabs, where the drivers can rest while not driving. These are equipped like small apartments, with good sound systems, stoves, refrigerators, storage places, and wash basins. They are air-conditioned and insulated against noise and vibration, so the drivers stay fresh and alert.

Figure 9-3. Many tractor-trailers have a cab equipped like a small apartment.

Rail Transportation

Railroads are part of North America's history and folklore. Today, the Trans-Siberian railroad in Russia is the longest in the world, stretching almost 5780 miles (9300 km), much of that over frozen wasteland. The Orient Express in Europe has been the setting of several films and novels. There are also fictional trains, such as the Hogwarts Express, which transports Harry Potter to Hogwarts Academy.

The diesel-electric system is a common type of fueling system for locomotives, Figure 9-4. However, more systems are starting to use electric trains, because these trains create less air pollution. Electric locomotives are also generally faster than diesels. For example, the Spanish Alta Velocidad Española runs between Madrid and Seville at speeds of up to 300 km per hour. See Figure 9-5. Electric trains pick up their power from overhead power lines or a third rail alongside the ordinary track. Trains make efficient use of fuel because there is not a lot of friction between the steel wheels of the train and the steel rails on which they run. Some special kinds of trains run on unique guides, such as monorails, maglevs, rubber-tired subways, funiculars (cable railways), and cog trains.

Figure 9-4. Diesel-electric locomotives are used in many rail systems. What is the disadvantage of this type of locomotive?

Figure 9-5. The Spanish Alta Velocidad Española is an example of a high-speed electric train. What are the advantages of this type of train?

Figure 9-6. Merchant ships are commonly used to transport cargo over long distances. What are the advantages and disadvantages of this form of transportation?

Water Transportation

For more than 5000 years, people have used ships to travel, trade, and fight in far-off lands. See Figure 9-6. Today, planes have largely replaced ships as people carriers, but every day, thousands of merchant ships ply the seas. These ships vary in size from simple cargo carriers to giant oil tankers. Although they differ in size, all of them have double hulls, which are double steel plates with a space in between, for safety reasons. Most ships use diesel power, although a few use nuclear reactors to make steam to drive turbines. While a ship's advantage lies in the amount of goods it can transport economically, its disadvantage is its slow speed, due to the resistance, or drag, of water on the hull.

Hydrofoils and hovercraft overcome this disadvantage by reducing the drag of water on the hull. When at rest or moving slowly, a hydrofoil looks like any other boat, but when it increases its speed, the entire hull lifts out of the water. The only parts that remain submerged are the rudder and part of its wings, or foils. This lift is made possible by the shape of the foils.

A hovercraft flies a few centimeters above the surface on a cushion of air. This means it is free of friction from the ground or water underneath. In the early days of hovercraft, transportation regulators could not decide whether hovercraft were boats or planes. Hovercraft are used as passenger and cargo ferries and by the military as patrol craft and troop carriers. See Figure 9-7.

The most popular method of transporting goods by sea is container ships. See Figure 9-8. Modern container ships are relatively fast. They can cross the Atlantic Ocean in seven days. Other ships transport loose cargo, such as coal, grain, and mineral ores in holds below deck. Others specialize in transporting mail, cargo, and passengers to smaller communities, which sometimes are not even connected by roads. Cruise ships create a "fun ship" image by transporting vacationers to islands in the Caribbean, the Mediterranean, and the South Seas.

Figure 9-7. Hovercraft fly just above the water's surface on a cushion of air.

Figure 9-8. Containers allow the maximum amount of goods to be stored in the minimum amount of space.

Air Transportation

A huge variety of transportation vehicles fly through the air. We are most familiar with planes. Regularly scheduled passenger planes operate according to timetables, and some companies hire charter planes to fly passengers. See Figure 9-9.

Lift

Why doesn't a heavy airplane drop out of the sky? The principle discovered by Daniel Bernoulli explains how the shape of a plane's wing produces lift and keeps the airplane in the sky. Airplane wings, as shown in Figure 9-10, are designed to be more curved on the top surface. Thus the air travels a larger distance over the wing than below it. The speed of the air above the wing is increased, but the pressure is reduced. Therefore, pressure on the underside of the wing is greater. This pressure difference gives the wing lift and allows the plane to fly.

Figure 9-9. Small passenger planes can move people between both small and large airports.

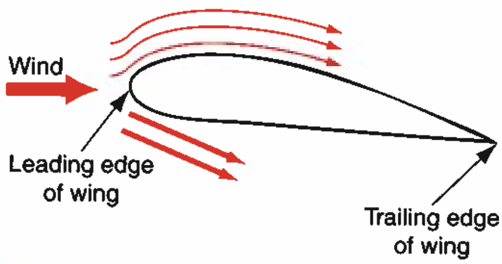


Figure 9-10. Air moving above the wing travels faster than air traveling below the wing. Why does this create lift?

Types of Aircraft

Although airplanes are the most common type of aircraft, many other types are also commonly used. For example, helicopters are often called on to help in rescue operations, such as lifting a pet to safety from the side of a cliff, helping people who are lost in remote areas, or rescuing earthquake survivors. See **Figure 9-11**.

Sports enthusiasts use many other means of air travel, including gliders, hang gliders, parachutes, and ultralight aircraft. See **Figure 9-12**. Gliding is a sport that enables people to experience the exhilaration of flying in a vehicle that looks like a small plane but has no engine. The most common way to launch a glider is to pull it into the air by means of a steel cable connected to a powerful winch, or to be towed into the sky behind another airplane.

Hang gliders are quite different; they do not even need a tow. The riders launch themselves from high places and return to the ground using movements of their bodies to turn and land. Ultralight aircraft are like hang gliders with very small engines. They operate at a maximum speed of 55 knots per hour and fly only between sunrise and sunset.

Other flying vehicles include hot air balloons and blimps. In a hot air balloon, passengers ride in a basket suspended under the balloon. See **Figure 9-13**. A propane heater warms the air inside the balloon, and because air expands as it is warmed, it rises and lifts the balloon up through the cooler outside air.

Blimps are often seen at major sporting events. They are usually used for photography or advertising. Blimps work in a manner similar to a balloon, except that instead of hot air, they are filled with helium, which is lighter than the surrounding air. They also usually have a motor and rudder, which make them more maneuverable than hot air balloons. The strangest aircraft is the ornithopter, an engine-powered vehicle in which the mechanical flapping of its wings creates the thrust and nearly all the lift!

Figure 9-11. Helicopters use rotating blades instead of a fixed wing to give them lift. Why are helicopters suited to rescue missions?

Figure 9-12. This glider has a retractable engine that allows the aircraft to be self-launching. The engine also provides a back-up source of power for those times when it flies too low.

Figure 9-13. Cold air is heavier than warm air. What causes a hot air balloon to rise?

Intermodal Transportation

Airplanes, ships, trains, and trucks all have advantages, but no single system is better than the others. Ships can move the largest loads from country to country. Trains carry large loads efficiently over long distances on land, but they cannot collect and deliver goods to your door or to the store around the corner. The amount of cargo that trucks carry is limited. While planes are the fastest means of travel, the cost of air freight is the highest of any method.

The most cost effective and efficient transportation system is *intermodal transport*, which integrates separate transportation systems through an intermodal chain. The most important development for intermodal transport was a simple one: the container. A container is a box, usually measuring 20′ long, 8′ high, and 8′ wide. Its size has been standardized worldwide, so lifting equipment is available in all ports and rail terminals. Cranes can handle the containers quickly.

Goods are shipped in bulk within the containers, so costs are reduced. The contents are protected from damage and theft, and containers can be stacked to minimize storage space. Freight might be packed in containers and transported by ship, for example, to San Francisco from China.

Each container can be loaded onto a flatbed railcar when it arrives at a port. See **Figure 9-14**. When the railcar arrives at a large city, each container might be loaded onto a tractor-trailer and taken to a warehouse. There the containers are opened and the contents removed. Finally, a forklift truck loads items onto smaller trucks that deliver the items to local stores.

On-Site Transportation

On-site transportation moves people and materials from one place to another in a defined location, such as a warehouse or factory. See **Figure 9-15**. Other examples of sites include gravel pits, shopping malls, airports, and mines. Elevators, escalators, and conveyors move people or materials in a building. Robots in a factory move materials cheaply and

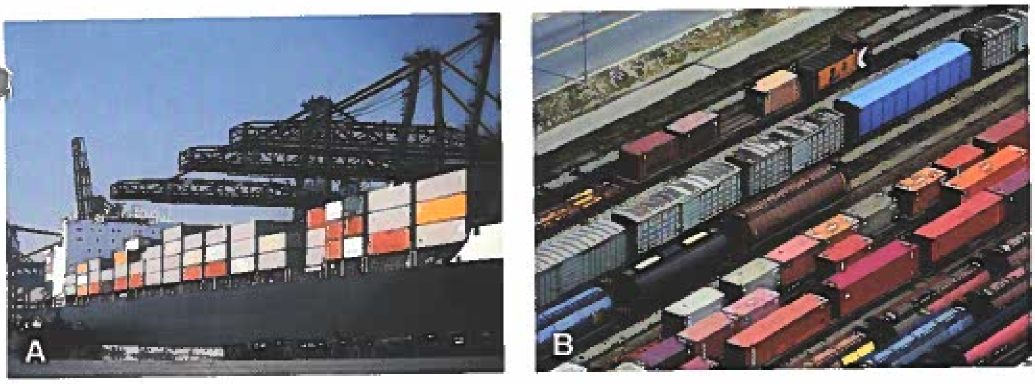


Figure 9-14. Containers are often transported first by boat (A) and then by train (B). What happens to the containers when they reach the train terminal?

quickly from one spot to another. Some are stationary and move parts short distances. Others are *automated guided vehicles (AGVs)*. They follow a set path and transport parts and materials over longer distances. Conveyors, trucks, and pipelines move materials at many sites, including mines, refineries, wells, and construction sites.

Figure 9-15. A forklift truck can move heavy pallets around a warehouse or can load them onto a truck.

Human-Powered Vehicles

A *human-powered vehicle (HPV)* is any vehicle powered solely by one or more humans. Rowboats, canoes, and bicycles are common examples. See **Figure 9-16**. The shape of the bikes you see every day has changed very little in the past 100 years. See **Figure 9-17**. However, there is now a greater choice of materials, including steel, aluminum, carbon fiber composite, and titanium. Top-of-the-line off-road bikes now include features such as hydraulic disk brakes and dual suspension for riding on off-road terrain that has drops, big roots, logs, and other obstacles.

Conventional bicycles and other pedaled vehicles have several disadvantages. A limited amount of downward pressure can be placed on the pedals. Also, as much as 80% of a rider's energy is used just to push away the air in front of the vehicle.

Wind resistance can be reduced in several ways. Making the tubing oval-shaped and hiding parts such as cables within the frame makes all surfaces smoother. A second way is to lower the rider into a *recumbent* position, lying on his or her back or stomach. A third method is to cover the machine and rider by a streamlined shape that resembles an aircraft wing or teardrop. See **Figure 9-18**.

Several cities have bike sharing systems. Bikes can be taken from one location and dropped off at another. See **Figure 9-19**. Many countries, and many cities within the United States, also have dedicated bike paths.

Figure 9-16. Any vehicle that is powered by humans is considered an HPV.

Figure 9-17. Bicycles are among the most common human-powered vehicles. What are the advantages and disadvantages of using a bicycle for transportation?

Math Application

Division of Whole Numbers

In the transportation industry, two important practical concepts are:

- How long will it take the product being shipped to reach its destination?
- How much fuel will be needed, and how much will it cost?

The answers to these questions can be found by division. Division is the reverse of multiplication. It determines how many times one quantity is contained in another. For example, if you ride your bike at 10 miles per hour (mph), how long will it take you to travel 70 miles? To find the answer, divide 70 miles by 10 miles per hour:

$$\frac{70 \text{ miles}}{10 \text{ mph}} = 7 \text{ hours}$$

Math Activity

Calculate the answers to the following questions about practical concerns in transportation and shipping.

1. If a car travels 320 miles on a tank of gasoline and the tank holds 20 gallons, how many miles can the car travel on a gallon of gas?
2. If the total load carried by a container ship is 50,000,000 lbs., and there are 5,000 containers on board, how many pounds does the average container hold?
3. If a space shuttle travels at 18,000 mph and the distance to the moon is 234,000 miles, how long would it take to travel to the moon?

Figure 9-18. Wind resistance is a major force that must be overcome by a cyclist. What three things have been done to these bicycles to lower wind resistance?

Figure 9-19. Bike sharing is a common system in some cities and countries. What are the advantages and disadvantages of bike sharing?

Engines and Motors

Most forms of transportation need engines to make them move. *Engines* are machines made up of many mechanisms. They convert energy into useful work. An engine needs a constant supply of energy to keep it working. The energy may come from burning fuel such as gasoline, diesel, or kerosene. Engines that burn this fuel inside them, such as those used in cars, are called *internal combustion engines*. Internal combustion engines depend on hot, expanding gases for power.

An *external combustion engine* burns its fuel outside the engine. A steam engine is an example of this type of engine. The fuels used as energy sources include coal and oil. External combustion engines heat water or gases to produce power.

Four-Stroke Gasoline Engine

Imagine trying to pedal the family car at 55 mph (90 km/h). The driver and one passenger would have to pump their legs up and down about 60 times a second. Although it is impossible for legs to move that fast, pistons in a gasoline engine slide up and down at this speed. The pistons are like short metal drums moving inside cylindrical holes in a metal block. The power to move the pistons comes from a mixture of air and gasoline. This mixture is ignited by an electric spark. Expanding gases push the pistons down to rotate the crankshaft. The crankshaft then transmits turning power to the drive train. The four-stroke *gasoline engine* is an internal combustion engine. See **Figure 9-20**.

Figure 9-20. The four-stroke gasoline engine is a popular power source for transportation.

In a four-stroke cycle, a piston travels down and up the cylinder four times (down twice and up twice) to produce a complete sequence of events, or cycle. See Figure 9-21. The following is what happens during one complete cycle of the engine:

1. **First Stroke—Intake**

   The intake valve opens. The rotating crankshaft pulls the piston downward. The piston sucks fuel and air into the cylinder.

2. **Second Stroke—Compression**

   The intake valve closes. The crankshaft pushes the piston upward. The air-fuel mixture is squeezed into a small space to make it burn with an explosion. Just before the piston reaches the top of the stroke, the spark plug ignites the mixture.

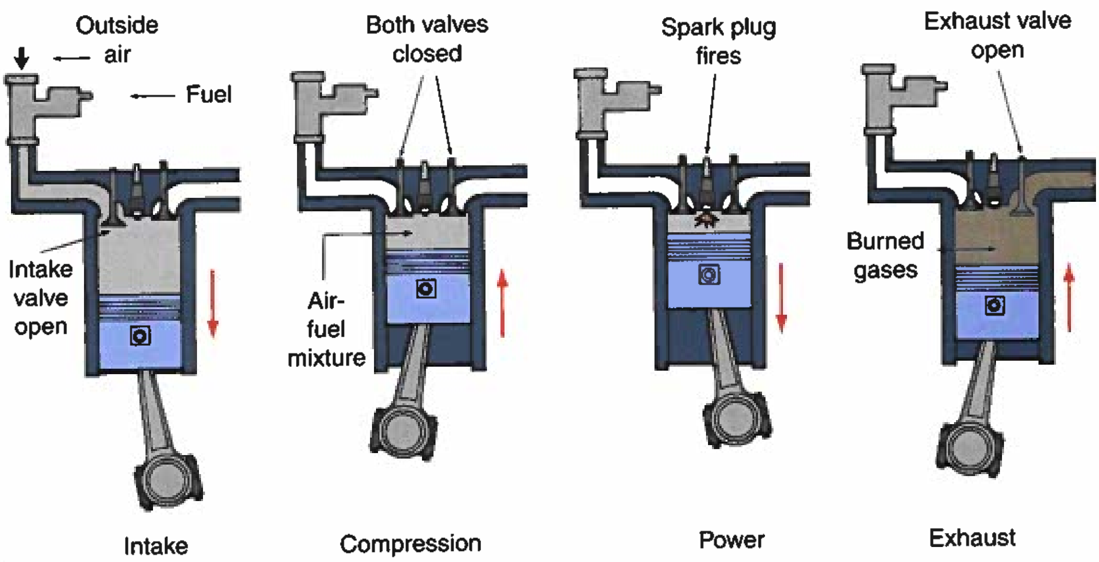


Figure 9-21. The four strokes of a four-stroke gasoline engine.

3. **Third Stroke—Power**

   Both valves are closed, so expanding gases cannot escape. The hot, expanding gases force the piston downward with great force. The piston pushes hard on the crankshaft, making it rotate.

4. **Fourth Stroke—Exhaust**

   At the bottom of the power stroke, the exhaust valve opens. The piston comes up again and pushes the gases from the burned fuel out of the cylinder. The cycle starts over again.

The four-stroke gasoline engine can be used in many different types of vehicles, as shown in **Figure 9-22**. It has the following advantages:

- It adapts easily to speed changes.
- It provides good acceleration.
- It has sufficient power for medium size machines.

However, the gasoline engine also has some disadvantages:

- It is not strong enough for very heavy work.
- It pollutes the air.
- It burns a relatively expensive fuel.

The Four-Stroke Diesel Engine

Diesel fuel is different from gasoline. It contains larger hydrocarbon molecules. This makes it heavier and oilier than gasoline, so it evaporates more slowly. The result is that the fuel can be ignited by pressure alone. So, unlike the gasoline engine, the *diesel engine* does not need a spark to ignite its fuel. It uses the heat from compressed air to ignite the fuel. Pure air is drawn into the cylinders. This air is squeezed to a much higher pressure than the air-fuel mixture in a gasoline engine. The pressure raises the air temperature to 1300–1500° F (700–900° C). At the top of the compression stroke, a fine spray of diesel fuel is injected into the cylinder at high pressure. When the fuel spray meets the hot, compressed air, the fuel ignites and burns very rapidly. See **Figure 9-23**. This forces the piston downward. Because of the high pressures involved, diesel engines have to be built stronger than gasoline engines.

Figure 9-22. Gasoline engines power all kinds of vehicles.

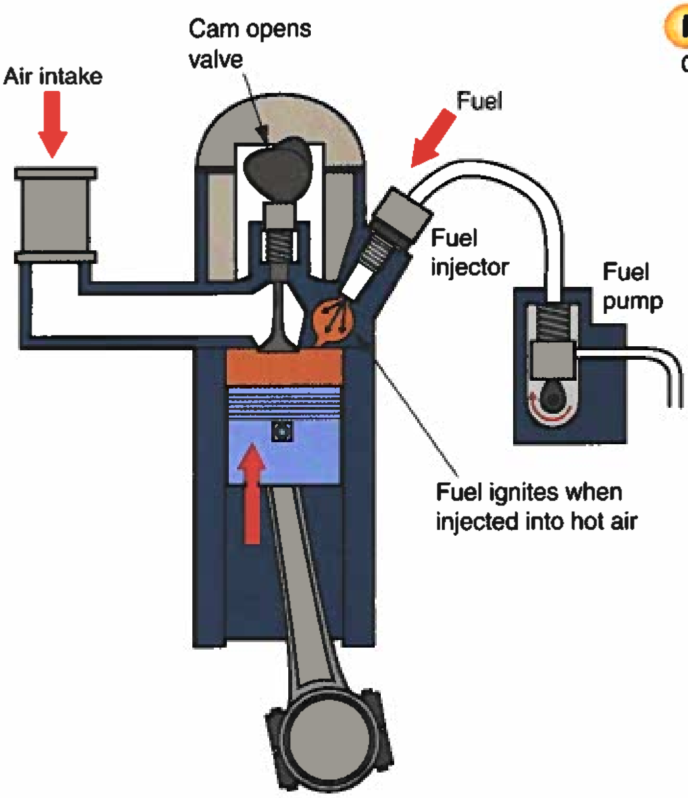


Figure 9-23. Operation of a diesel engine.

The four-stroke diesel engine has the following advantages:

- It uses less fuel than a gasoline engine.
- It lasts longer than a gasoline engine.
- It stands up well to long, hard work.

Early diesel engines were noisy, had poor acceleration, and created more pollution than gasoline engines. Most of these problems have now been reduced. Diesel engines are frequently used in passenger cars in Europe, and cars with diesel engines are becoming more popular in North America. They are commonly used everywhere to power large machines and vehicles, including tractors and buses. See **Figure 9-24**.

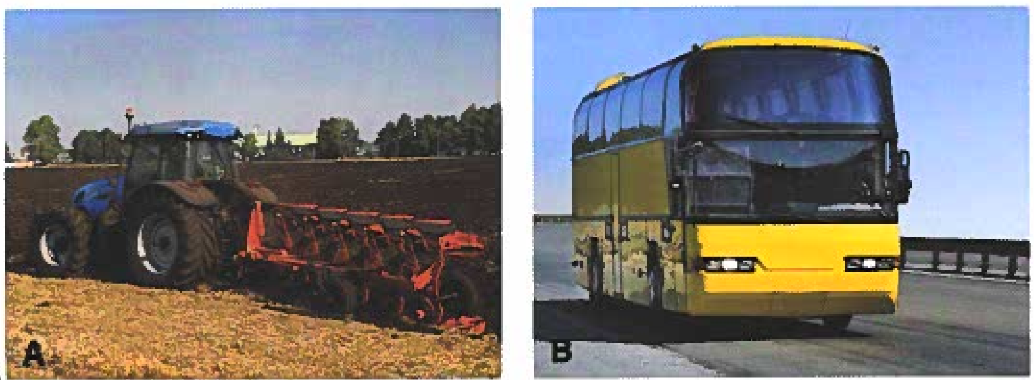


Figure 9-24. Diesel engines power: A—Tractors; B—Buses.

The Steam Turbine

The term *turbine* originally described machines driven by falling water, such as the waterwheels described in the Engineering Application. Later, the term *steam turbine* was also given to heat engines powered by steam. Engineers discovered that a strong jet of steam could turn a large wheel with blades on it. A steam turbine's hundreds of blades are set on a long shaft enclosed in a strong metal case. The blades on the rotor spin to drive the shaft. Blades on the stator are fixed to the outer casing and cannot spin, as shown in Figure 9-25. Each stator fan guides the steam flow so that as it moves along the turbine it has plenty of thrust to move the next rotor fan in its path. The spinning fans turn the drive shaft. The shaft, in turn, drives a propeller.

After its journey through the turbine, the steam cools and turns into water. This water then flows back to the boiler. Heated to steam again, it returns to work the turbine. The water is heated either by burning fuel or by a nuclear reactor outside the turbine.

The steam turbine has several advantages. It runs smoothly, has a long life, and is powerful and suited to slow, large machines that require an engine bigger than a diesel. This is shown in Figure 9-26.

One disadvantage is that it needs a lot of room, because space is needed for a boiler. Another is that it does not adapt as easily to changes in speed as piston engines.

Jet Engines

You have learned how Bernoulli's principle keeps an airplane in the sky. To get an airplane into the air, though, you need pushing power or *thrust*. What is thrust? Think of stepping forward off a skateboard, as shown in Figure 9-27. As you go forward, the skateboard moves backward.

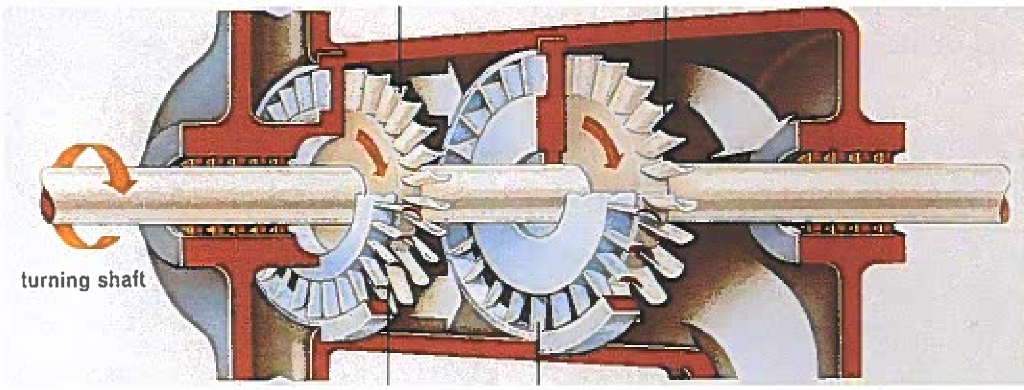
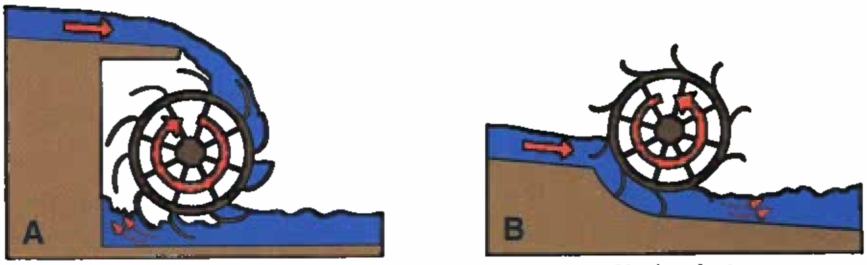


Figure 9-25. This cutaway of a steam turbine shows how it is similar to a waterwheel. The stator blades (colored blue) do not move. They guide the steam so that it passes over and turns the rotor blades.

Engineering Application

Testing Waterwheels

The original, water-driven turbines were also known as waterwheels. There are two types. The overshot wheel is driven with water from above. The wheel rotates clockwise. An undershot wheel is driven with water from below so that the wheel turns counterclockwise.



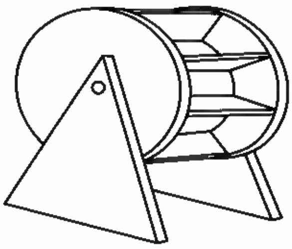
Overshot Undershot

Which type of wheel do you think was more powerful? What are the advantages and disadvantages of each type? To find out, perform the activity described below.

Engineering Activity

Design and make a waterwheel to test the advantages and disadvantages of overshot and undershot waterwheels. Materials you may need include:

- Corrugated cardboard or foam board (to make the wheel)
- Hot glue gun (to glue the blades to the sides of the wheel)
- Metal rod cut from coat hangers or wooden barbecue skewers (to make the axle)
- Pencil, ruler, compass, and protractor (to mark out and draw the parts for the wheels)
- Box cutter (to cut the cardboard or foam board)



One example of a waterwheel model is shown at the right.

When the wheel is assembled, place it in a sink and allow a small flow of water to spin the wheel. Position the wheel as necessary to use your model as an undershot waterwheel and an overshot waterwheel. Use the same flow of water for both tests. Does the wheel spin faster when it is used as an overshot or undershot waterwheel? Which type is affected by backwater pressure?

Write up your design, experiments, and results in a formal technical report. Be sure to evaluate your design and include ideas about how to improve the waterwheel and your testing process. Add the report to your portfolio.

Figure 9-26. Steam turbines power large seagoing vessels.

Figure 9-27. Pushing backward against the ground with one foot creates thrust. This pushes the scooter and the boy forward.

Think about what happens when you turn on a garden hose. Suddenly, a jet of water bursts out, and the hose jumps backward. Firemen are sometimes pushed over by this backward force. Blow up a balloon and let it go without tying the neck. The balloon is driven in much the same way as the hose and skateboard.

These are just three examples of Isaac Newton's third law of motion. This law states that for every force in one direction, there is always an equal force in the opposite direction.

All jets work on this principle—for every action there is an equal and opposite reaction. The reaction to the rush of gases out of a *jet engine* is a thrust that drives the airplane forward. The engine sucks in air at the front, squeezes it, and mixes it with fuel. The mixture ignites and burns quickly. This creates a strong blast of gases. These hot gases expand and rush out of the back of the engine at great speed. Many people believe that the gases "push" against the air to propel the plane forward. This is not true. As the gases shoot out backward, the jet goes forward.

The *turbofan* is one kind of jet engine that powers aircraft. See **Figure 9-28.** A jet engine produces a very noisy gas stream. In a turbofan engine, however, the gas stream drives a large fan located at the front of the engine. This creates a slower blast of air. Thrust is as great as a simple jet, but the engine is quieter.

Air is drawn into the engine by the compressor fans. As pressure increases, the compressed air mixes with fuel. Ignition takes place, and temperature and pressure increase even more. The burned mixture leaves the engine through the turbine, which drives the compressor and the fan at the front of the engine. Pressure thrusts the engine forward, while the exhaust gases rush out of the back in a jet stream. The turbofan is an internal combustion engine.

The turbofan engine has several advantages. It is relatively lightweight, very powerful, and uses less fuel than other jet engines.

Science Application

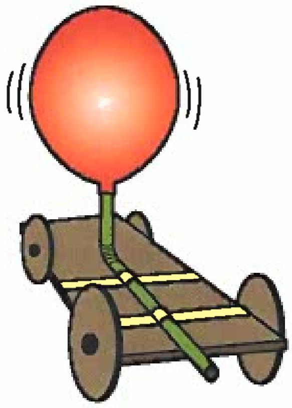
Integrated STEM Curriculum

Newton's Third Law of Motion

We may think that the forces we experience are one-sided. However, when a bird's wings push the air downward, the air reacts by pushing the wings, and the bird, upward. When playing ice hockey, a player pushes backward with one skate, and the ice pushes the player forward. When the player stops on ice, the skate's sharp blade cuts into the ice deep enough to create a barrier. As the player pushes against the barrier, it pushes in the opposite direction and the skater stops. When a rocket is fired, it pushes hard on the ground and the ground pushes upward with an equal force. All of these situations are examples of Newton's third law of motion: For every action, there is an equal and opposite reaction.

Science Activity

Design and make a dragster to demonstrate Newton's third law of motion. The diagram shows one simple shape for the dragster, but you should modify the shape to improve its efficiency. After you have built the model, test it on a 33 ft. (30 m) track to see how far it can travel.



Materials you may need include cardboard, masking tape, bendable straw, box cutter, compass, pencil, ruler, party balloon, and pins to fasten the wheels in place. Follow these steps:

1. Assemble the parts according to your design.
2. Inflate the balloon to stretch it and then let the air out.
3. Place it over the short end of the bendable straw.
4. Inflate the balloon again by blowing into the long end of the straw.
5. Place the dragster on the floor and let go of the straw.
6. Measure the distance the dragster travels.

Write up your design, experiments, and results in a formal technical report. Include a chart to compare your results with those of several classmates. Explain how Newton's third law of motion is demonstrated in this experiment, and include labeled sketches to illustrate the principle. Add the report to your portfolio.

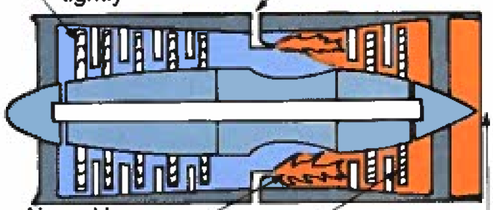


Figure 9-28. A—Operation of a turbofan engine. B—Most passenger jets today use turbofan engines.

The Turboshaft Engine

Like the turbofan engine, the *turboshaft* engine uses a stream of gases to drive turbine blades. The blades turn a shaft, as shown in **Figure 9-29**. However, the turboshaft differs from the turbofan in that this shaft is connected to rotors or propellers. The spinning propeller blades are angled to push air backward similar to the jet engine thrust, and the vehicle moves forward.

The Rocket Engine

As described in the section on jet engines, when you release an inflated balloon, it zooms around the room. The compressed air that was forced into the balloon rushes out of its nozzle. This creates thrust, resulting in forward motion. Inside a rocket, a fuel is burnt to produce hot, high-pressure gas. This escapes from the rocket to provide the thrust.

Figure 9-29. Turboshaft engines are used on all but the smallest helicopters.

What pushes rockets forward? Imagine that the fuel is burning and the rocket's exhaust is closed. As the high-pressure gas burns, it pushes out in all directions against the inside of the rocket. See **Figure 9-30A**. The rocket does not move because the force is equal in all directions. Now imagine that the exhaust is opened. Hot gas will rush through the opening. There is little or no downward force on the bottom of the combustion chamber, but there is upward force on the top. The rocket is pushed up. See **Figure 9-30B**.

The difference between a jet engine and a rocket engine is how each obtains oxygen to burn its fuel. The jet uses the oxygen in the surrounding air. A rocket must carry its own oxygen if it operates outside the earth's atmosphere, where there is no oxygen-containing air.

Rocket engines burn a variety of fuels called *propellants*. Some propellants are solid, and others are liquid. Nearly all space rockets use liquid propellants, such as kerosene or liquid hydrogen, plus liquid oxygen or some substance that can provide the oxygen for combustion. See **Figure 9-31**.

Alternative Motors and Engines

For the last several decades, automobile companies and other inventors have experimented with other types of motors and engines for use in passenger vehicles. Their purpose is to reduce pollutants as well as reduce dependence on petroleum-based products.

Electric and Hybrid Vehicles

Electric vehicles and small delivery vehicles have been in use for 100 years. *Electric motors* change electrical energy into mechanical energy. They provide smooth turning power to drive a shaft. They have many advantages, including little maintenance and no oil changes.

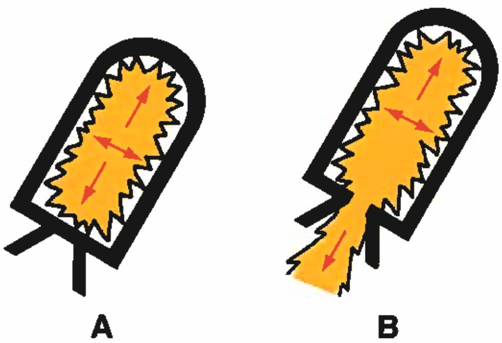


Figure 9-30. A—This rocket will not move because the pressure inside is pushing equally in all directions. B—When the exhaust valve at the rear of the rocket is opened, the rocket moves forward because the pushing force is greatest in the forward direction.

Figure 9-31. Because space has no oxygen, rockets that travel in space must carry both fuel and oxygen for combustion.

In the past, electric vehicles have had several disadvantages. Most use batteries that provide a driving range of only 100 to 200 miles (160 to 320 km). In contrast, gasoline-powered vehicles usually have a driving range of more than 300 miles. Also, recharging the batteries takes several hours. Finally, the batteries are large and heavy, and they take up a large amount of space in the vehicle.

These limitations mean that, until recently, forklift trucks, local delivery vehicles, and golf carts have been the most common electric vehicles. However, this is starting to change as new, smaller batteries that last longer are being developed. Several types of gasoline-electric hybrid vehicles have recently become popular. They combine a gasoline engine with electric motors. See **Figure 9-32**.

The Tesla Roadster, produced in California, is 100% electric. It goes from zero to 60 mph (100 km/h) in four seconds. It can go 250 miles (400 km) on a charge, and then its lithium-ion batteries can be recharged in only three-and-a-half hours. See **Figure 9-33**.

Some vehicles, such as trains and trolleys, are connected directly to a source of electricity by overhead cables. Others, such as subway trains, are attached to electrified rails. See **Figure 9-34**.

Solar Vehicles

Universities and technical colleges have been making experimental solar cars for many years. Usually, the solar cells that convert sunlight to electricity totally cover the upper surfaces of these cars. Each solar cell produces only about 1/2 volt of electricity, so hundreds of them are needed to power the car.

The sun's energy not only powers the car's motor, but it also charges a battery that can supply the energy needed when the sun is hidden behind clouds. This method of powering a car is very interesting because the energy source is inexhaustible and no pollution results from its use. The 2009 North American Solar Challenge Race was the eighth such race. The 24 teams racing from Dallas to Calgary were mostly from American

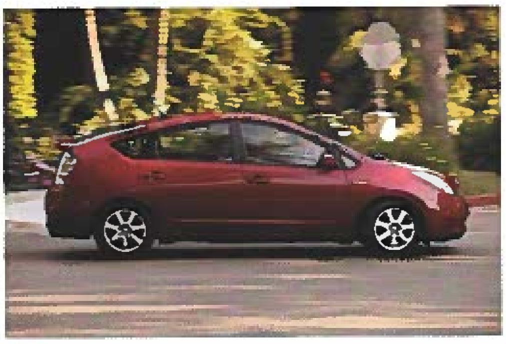


Figure 9-32. Gas-electric hybrid cars such as this Toyota Prius employ a regenerative braking process, which can provide power to the battery or directly to the electric motors.

Figure 9-33. The all-electric Tesla provides high performance and an attractive sports-car design.

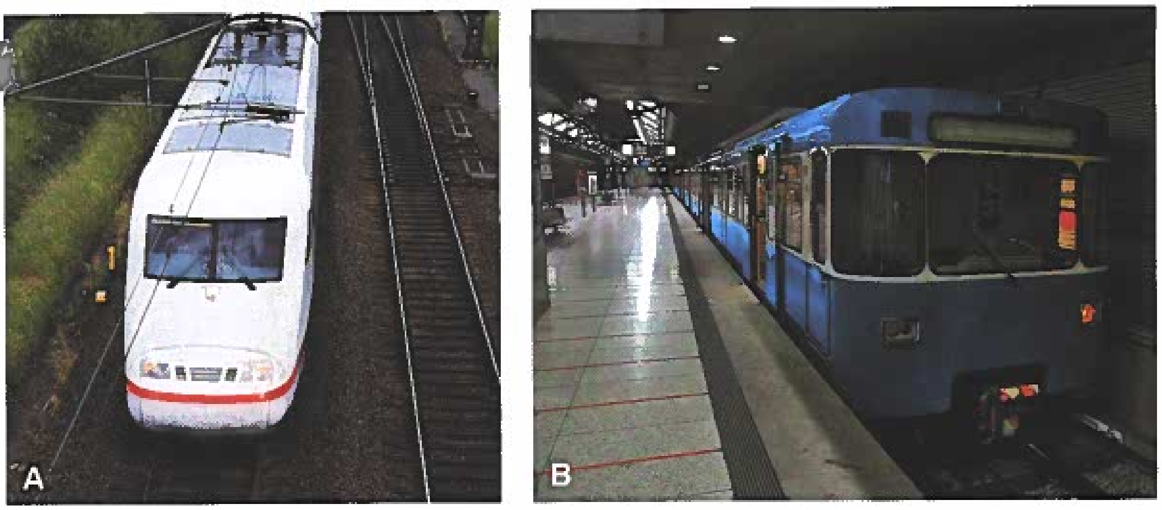


Figure 9-34. Electric motors power several types of transportation vehicles. A—Some trains and most trolleys are connected directly to a source of electricity by overhead cables. B—Other electric trains and subway trains use electrified rails.

universities and colleges, but they also included Canadian entries such as the Éclipse VI from École de technologie supérieure (ETS, Montreal), **Figure 9-35**, and Schulich 1 from the University of Calgary.

Fuel Cell Vehicles

Fuel cell cars may solve the problem of distance, while also having the same low emissions level of electric vehicles. The ***fuel cell vehicle*** creates power by combining oxygen from the air with hydrogen from an on-board tank. See **Figure 9-36**. The power is used to turn electric motors that drive the wheels. The only material leaving the exhaust pipe is water vapor. There are several different designs for fuel cell vehicles. **Figure 9-37** hydrogen-powered vehicles at a hydrogen filling station.

Figure 9-35. Eclipse VI was a competitor in the 2009 North American Solar Challenge. The solar cells, which cover most of the upper body surface, convert the energy in light into electrical energy.

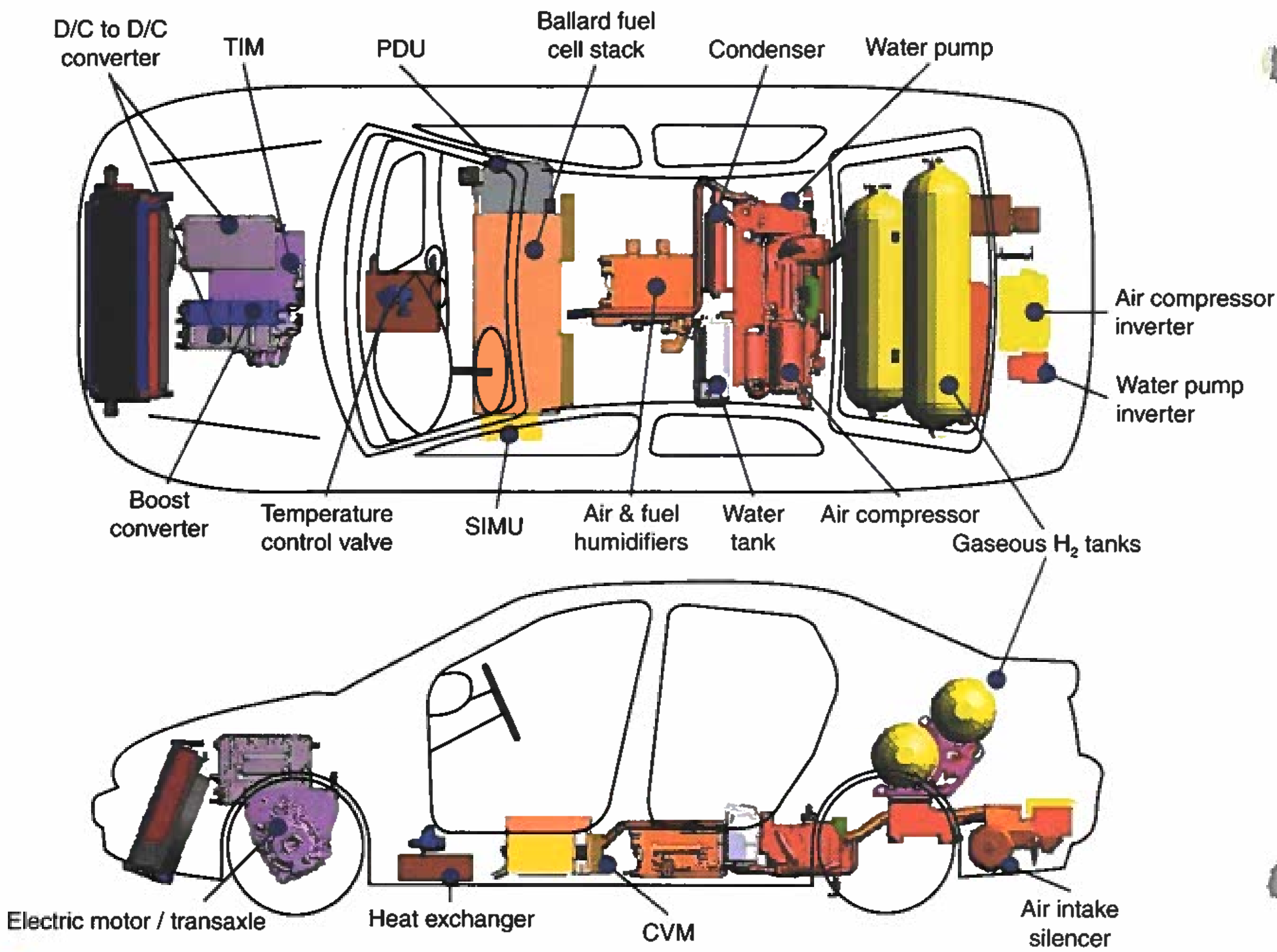


Figure 9-36. Fuel cell vehicles are very complex. This diagram shows typical components.

Figure 9-37. As more hydrogen-powered cars become available, hydrogen filling stations like this one will become more common.

Think Green

Transportation Alternatives

This chapter describes several technologies that may provide good alternatives to today's pollution-rich vehicles. Some of them are in limited use today. Many of these solutions are still in development, however, and it may be years before they become feasible for most people.

Other alternatives that provide at least partial solutions are available today. Ride-sharing, for example, cuts fuel emissions by reducing the number of vehicles on the road. If three people share a ride to work or school instead of taking separate cars, they reduce their contribution to vehicle-related pollution by two-thirds. Using public transportation when possible is another way to "go green." For short distances, you may consider walking or riding a bicycle.

Most of these alternatives save money as well as lower pollution levels. Why don't more people use them? There are several reasons. For example, bus stops may not be conveniently located for some people. Others may just enjoy the "quiet time" alone in their cars while they commute.

In many cases, however, our means of transportation is purely a habit. We hop into a car without thinking about possible alternatives. Think about your transportation needs. Discuss options with your friends. Try to develop an alternate means of transportation for getting to ball games and other activities. What are your alternatives?

Transportation Systems

Modern vehicles, such as cars and buses, are complex machines composed of a number of subsystems. Automobiles have systems that control the emissions, lights, speed, and many other functions.

Systems in Vehicles

The modern car is composed of the following subsystems: electrical, emission control, computer, fuel, axles and drive train, steering, suspension, brake, climate control, navigation, and engine. If one of these systems is not working correctly, the car's performance and efficiency will suffer. For example, power brakes use a vacuum to help you push the pedal. A leak in its vacuum lines is dangerous because it leads to a loss of braking power.

Systems to Coordinate Transportation

Transportation systems that coordinate modes of travel within a geographic area are usually run by the local government. For example, in Chicago, the Chicago Transit Authority (CTA) has schedules for all three of its different modes of transportation—bus, subway, and "L" train. All three of these parts of the CTA must run on time. To achieve this, both the vehicles and the people in the systems must be reliable. People depend on these forms of transportation for timely arrivals to their destinations.

Imagine that you are meeting friends at a movie theater across town. Your journey might start with a bus ride from your local bus stop at 6:30 to the central bus station. From there, you could take another bus at 6:50 in order to catch the 7:10 subway train. Upon arrival at the second stop, you walk two blocks to the theater to meet your friends. But what if the 6:50 bus were running late? You would miss the 7:10 train and your friends might think you weren't coming. If one part of the CTA is late, people pay the price of being late for their daily activities.

Transportation systems are not limited to those at the local level, such as the CTA. They also include national and international systems that utilize planes, helicopters, boats, barges, trucks, and trains to deliver passengers, foods, and other goods. Schedules are made for each of these systems. Within each of these systems, processes may include receiving, holding, storing, loading, moving, unloading, evaluating, marketing, managing, and communicating. These are all necessary for the successful day-to-day operation of our modern transportation systems. Like regional systems, these systems rely on both people and vehicles to transport people and goods. However, the design and operation of national and international transportation systems must be guided by government regulations.

Parts of a Transportation System

Like all other technological systems, transportation systems include inputs, processes, outputs, and feedback. Inputs include the people and materials that are transported; the people who develop, operate, and maintain the system; and the machines and structures within the system. Processes include managing and organizing the system, along with the actual transport of materials or people from one location to another. Outputs include the successful transportation of materials or people, the impacts on society, and the impacts on the environment. Feedback involves periodic checks comparing the location of cargo within the system to the transportation schedule. Another example of feedback is the evaluation of the completed transportation process. Did the cargo arrive at the intended location at the intended time without unintended incidents?

Transportation systems play a vital role in today's economy. Their influence reaches nearly all today's industries:

- Agriculture—Trucks, trains, and planes deliver fruit, vegetables, and other agricultural goods to vendors and grocery stores.

- Manufacturing—Coal, iron ore, steel, and lumber are taken to mills and plants by boats, trains, and tractor-trailers.
- Construction—Trucks take lumber, bricks, mortar, and concrete to job sites.
- Communication—News vans, trucks, and helicopters go on-location with camera operators and news anchors to broadcast stories. Helicopters also fly over the city and report the traffic to TV and radio stations.
- Health—Vans, ambulances, and helicopters take organs from donors to recipients and take injured people to the hospital.
- Safety—Police and government agencies use squad cars, vans, buses, planes, and helicopters to enforce laws and respond to accidents.

Exploring Space

People have always wondered about what lies beyond Earth. In the 1960s, we reached a milestone when the first human set foot on the moon. More recently, scientists have sent probes to the far reaches of our solar system. As transportation technology improves, we can send more sophisticated equipment over longer distances to find out more about our solar system and beyond.

Space Shuttle

The space shuttles were the first reusable space vehicles. They enabled people to fly into Earth's orbit and remain for several days before returning to Earth.

Imagine being one of seven people strapped to rockets the height of a 20-story building. When the solid rocket boosters (SRBs) are ignited there is no going back. The fuel cannot be extinguished. The booster rockets propel the orbiter to a speed of 3,500 miles per hour (5,700 km per hour). Once the vehicle has left earth's atmosphere, large thrusts of energy are not needed. The spacecraft is no longer trying to overcome the earth's gravity. Therefore, after two minutes of flight, the SRBs separate from the orbiter at an altitude of 30 miles (50 km). They fall to the earth with the aid of parachutes and are picked up by retrieval ships.

The orbiter's main propulsion unit then takes over. It consists of three engines burning liquid hydrogen and oxygen. After about eight minutes of flight, the orbiter's main engines shut down and the small orbiting maneuvering system (OMS) engines take over. To return to earth, the orbiter turns around and fires its OMS engines. After descending through the atmosphere, it lands like a glider. On-board computers control all the functions.

The Constellation Program

The space shuttle orbiters were retired in 2011. The new successor, Orion, will be a key component of the Constellation program. It will be able to accommodate larger crews than Apollo plus an emergency escape rocket. Testing of the launch vehicles, including the Ares I rocket shown in Figure 9-38, began in 2009.

International Space Station

There was a time when the destination of flights into space was the moon. Today, flights with humans aboard are destined for the $100 billion International Space Station (ISS), in order to deliver component parts to build or maintain the space station. See Figure 9-39. The ISS is a sprawling assembly of laboratories, living space, service areas, and solar panels the size of two football fields. Sixteen countries are cooperating in its construction.

No large cranes are available in space to lift the pieces of the ISS into place. In their place, astronauts use a "space arm" known as the Space Station Remote Manipulator System (SSRMS). See Figure 9-40. The SSRMS not only assembles the station but also maintains the station and maneuvers equipment and payloads. Its two hollow booms, which are the diameter of telephone poles, are made of 19 layers of carbon fiber. They are joined at an aluminum elbow and end in a "hand" that is similar to sockets from a mechanic's ratchet set.

Space station technology involves programs to develop and transfer technology to other sectors of our economy. Space arm mechanisms are being modified to control prosthetic hands for children. Space arm hardware and software are used in robotic devices.

Figure 9-38. New, improved rocket boosters are being designed for the Constellation program. Testing of the Ares 1 rocket began in 2009.

Figure 9-39. The International Space Station (ISS) is in use as an engineering and science laboratory.

Figure 9-40. The Space Station Remote Manipulation System (SSRMS) contributed to the International Space Station by the Canadian Space Agency.

Living on the ISS is, in one way, like going to the Arctic or to a drilling rig in the Atlantic Ocean. People stay there for one to three months, then return to Earth for a long rest. Since the ISS is expected to have a 15-year life span, there could be a hundred visits from space shuttles over this period in order to deliver personnel, supplies, and experimental cargo.

Future Objectives

Future space exploration has three objectives. First, scientists want to prepare a defense against asteroids. While very large asteroids collide with Earth on average once every 100 million years, there is a much greater risk of smaller asteroids striking at any time. The aim is to evaluate the potential of one landing and make a trial test to deflect an asteroid in space.

Another objective is to look for life in our solar system. Some planets appear to have underground seas and other raw materials for life. *Phoenix*, a recent American mission to Mars, landed near one of Mars' poles where ice and water may be present. The current goal is to analyze rocks and dirt from Mars and to get ready for exploration of two of Jupiter's moons: Europa and Titan.

Finally, scientists want to explore the outer boundaries of our solar system. An interstellar probe could use a solar sail, like a big mirror, to capture sunlight to provide power on its way to Mercury and Jupiter.

The Impact of Transportation

Transportation systems make our lives much more convenient, but they do have negative impacts. See Figure 9-41. Several modes of transportation pollute the environment. The pollutants in exhaust emissions from cars, trucks, buses, and airplanes cause many problems.

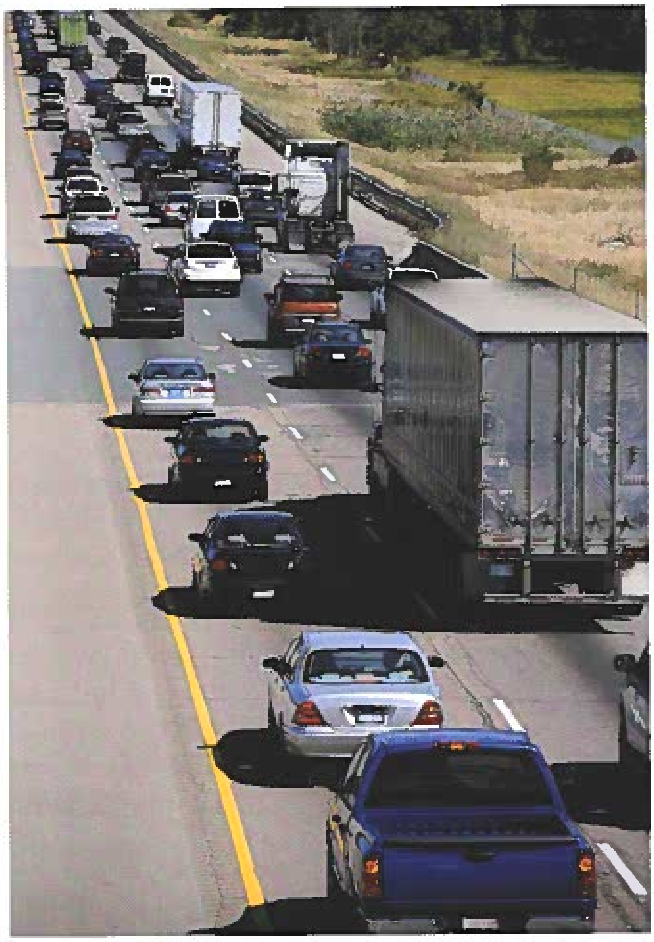


Figure 9-41. Private transportation has both positive and negative impacts. What are the impacts of today's passenger vehicles?

Air pollution causes a bad smell in the air and may contain disease-causing particles. The pollution level may be so high that people have difficulty breathing. Their eyes water, and they experience a burning sensation in their lungs. Air pollution can also corrode the surface of buildings. Noise pollution is another problem.

Technology can provide the answers to some of these problems. In the next few decades, you and your friends may be able to help. You may find new methods of transportation that reduce the negative impacts of current transportation technology. You may also find ways to help fix problems, such as pollution, that occurred as a result of earlier technology.

End Note

Transportation systems move people or freight from a point of origin to a point of destination. These systems rely on both the vehicles and the people that operate, maintain, and repair the vehicles. A system may use one or more modes of transportation including bicycles, cars, trucks, buses, trains, subway cars, ships, airplane, or a space shuttle.

Most modes of transportation need an engine to make them move, and most of today's vehicles have internal combustion engines that use gasoline and diesel as fuels. As environmental and climate concerns become greater, scientists and inventors have begun experimenting with alternatives to gasoline and diesel engines.

Electric and gas-electric hybrid vehicles are current alternatives to gasoline engines. Car manufacturers are also experimenting with fuel cells, compressed natural gas, and biofuels.

The transition from gasoline powered to electrically powered cars will depend largely on the development of suitable batteries such as lithium ion and nickel-metal hydride batteries. Public transit, intercity trains, cars and trucks can all be powered by electricity or hybrid systems. Electric buses could even be run by capacitors, without batteries. A bus could go about five stops, then recharge in less than a minute, at a quick-charging station, as passengers get on and off the bus.

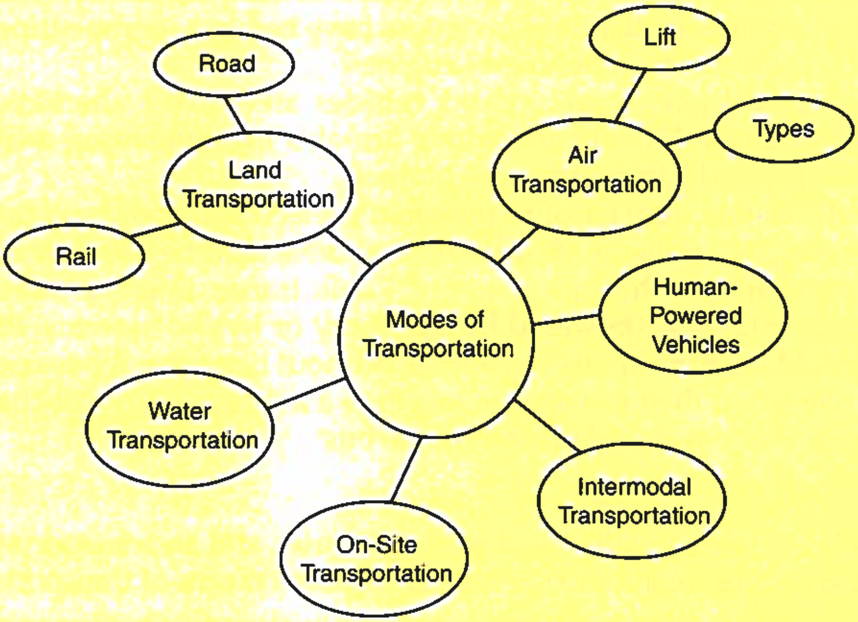
Summary

- Modes of transportation include land, water, and air transportation. These are often combined to form intermodal means of transportation.
- The most common types of internal combustion engines are gasoline and diesel engines, but other engines are being developed to address environmental and economic concerns.
- Like other types of systems, transportation systems include inputs, processes, outputs, and feedback. Transportation systems play a large role in all of today's industries.
- National and international efforts are ongoing to explore Earth's moon, other planets in our solar system, and even far beyond solar system.
- Transportation technology has both positive and negative impacts on our lives.

Reading Target

Finding the Main Idea

Create a bubble graph for each main idea in this chapter. Place the main idea in a central circle or "bubble." Then place the supporting details in smaller bubbles surrounding the main idea. A bubble graph for the first part of the chapter is shown here as an example, but your bubble graph may look different.



Test Your Knowledge

Write your answers to these review questions on a separate sheet of paper.

1. Describe the ways in which the modes of transportation affect the way you live.
2. State the best mode of transportation to move:
   - A. A student traveling five blocks to the sports field
   - B. A huge load of grain from one continent to another
   - C. A prize bull from a farm in Texas to a farm in Alberta
   - D. 10,000 commuters from a suburb to a city center
   - E. A transplant organ from one city to another city 500 miles away
   - F. A large supply of fresh fruit from South America to North America
3. Name, in the correct sequence, the four strokes of an internal combustion engine.
4. What is the major difference between a gasoline engine and a diesel engine?
5. Make a sketch to show how a jet of steam can be used to turn a shaft.
6. What is the basic principle of a jet engine?
7. Explain why a rocket engine must carry its own oxygen.

Test Your Knowledge (Continued)

8. In what ways do industries rely on transportation systems?
9. An electric motor changes electrical energy into what kind of energy?
10. Several current modes of transportation pollute the environment. State one way in which this pollution can be minimized.

Critical Thinking

1. Recreate the chart shown below using a word processing program. Do not write in this textbook. Fill in the Advantages and Disadvantages columns for each mode of transportation. Then use critical thinking skills to fill in the Ways to Minimize Disadvantages column.
2. Identify one problem in your town related to a mode of transportation. Research the problem and determine specific causes. Then suggest specific ways to solve the problem that would work in your town.

Mode of Transportation	Advantages	Disadvantages	Ways to Minimize Disadvantages
Bicycle			
Car			
Truck			
Bus			
Train			
Subway train			
Ship			
Airplane			
Space vehicle			

Apply Your Knowledge

1. Form a group with five classmates. Brainstorm future possibilities for powering spacecraft. Compile a list of at least 10 ideas. Then agree on one idea that seems the most feasible. As you decide, be courteous and show appreciation for the ideas of all team members. Draw a picture of your chosen method, describe its operation, and comment on its advantages and disadvantages.
2. Design a poster to show the relative distances of Earth, Mars, Venus, and Jupiter. Add interesting information about each of the planets to your poster.
3. If we were able to make contact with a civilization that is 250 light-years away and ask a question, it would take 500 light-years to get a reply. What question would you ask, and why?
4. Maintenance is the process of inspecting and servicing a product or system on a regular basis. Maintenance is done to extend the life of an item, help it continue to function properly, or upgrade its capability. Research the maintenance needs of a four-cylinder gasoline engine and those of a rocket engine. Write a report comparing and contrasting the needs of the two types of engine. What are the major concerns for each? Are similar processes used? Why or why not?
5. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **SCIENCE** The human body is adapted specifically for life in the conditions on Earth. When we send people into space, the conditions are much different. Find out what negative effects an astronaut may experience by being in space for prolonged periods. What happens to the person's muscles, ears, sense of touch, heart, spine, bones, lungs, stomach, and eyes? Why?
2. **TECHNOLOGY** Design an extraterrestrial character, either as a drawing or in 3D form, for use in a new movie. Specify where the character came from (a specific planet, another solar system, or other place). Research the conditions in that place and give the character the features it would need to live there. Create a basic 3D model of your character using computer software.
3. **ENGINEERING** Use a formal design process to design a vehicle to transport eggs up and down a flight of stairs without breaking. The vehicle must be able to carry at least 6 eggs in each trip. Build a prototype and test it thoroughly. Be sure to test it first without eggs to make sure the vehicle is stable. Make any design modifications necessary and retest the model. When you are sure the eggs will not break, add the eggs for your final tests. When you are satisfied with the result, document the design, your test procedures, and the results. Place the documentation in your portfolio.

CHAPTER 10

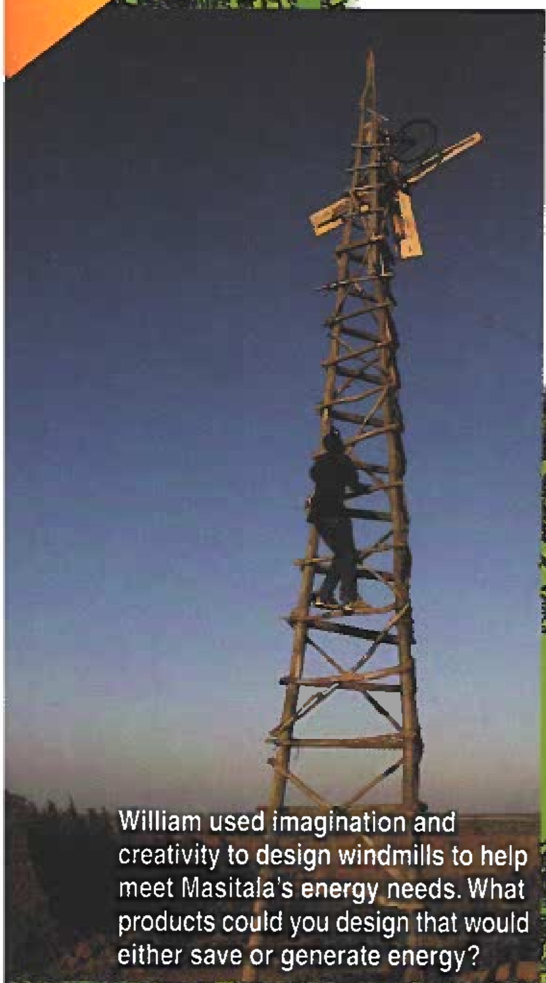
Energy

William's home and the first windmill.

Better by Design

William Kamkwamba designs and makes windmills

When he was 14 years old, Malawian William Kamkwamba designed and built his family an electricity-generating windmill from spare parts and scrap, working from rough plans he found in a borrowed 5th-grade textbook. He first built a 5-meter prototype out of a broken bicycle, tractor fan blade, old shock absorber, and blue gum trees. He then built a 12-meter windmill to better catch the wind above the trees, and added a car battery for storage. He also added homemade light switches and circuit breakers. He has now built three windmills in his yard. The tallest is 39 feet. William is currently working on a design for a windmill powerful enough to pump water from wells and provide lighting for Masitala, a cluster of buildings where about 60 families live.



William used imagination and creativity to design windmills to help meet Masitala's energy needs. What products could you design that would either save or generate energy?

"I was thinking about electricity. I was thinking about what I'd like to have at home, and I was thinking, "What can I do?""