10.3

Engineering Solutions to Environmental Impacts

Engineering solutions help solve problems, such as the need for more renewable energy.

CAN YOU EXPLAIN IT?

Highways are the main transportation solution for goods and people on land. Building new highways and maintaining existing ones can lower traffic congestion and provide more travel choices. Highways also are barriers that fragment, or break apart, habitats, making it difficult for animals to access their entire home range.

FIGURE 1: Wildlife crossings meet a variety of needs.

a Highway overpass

b Highway underpass

c Canal overpass

d Fish ladder

Gather Evidence
As you explore the lesson, identify how wildlife crossings help both society and the environment.

Wildlife crossings can be designed to help wildlife navigate different types of barriers, as shown in Figure 1. For example, wildlife overpasses are raised structures over a barrier, like a road. Fences or natural features in the landscape are used to funnel wildlife to the overpasses. Wildlife underpasses provide the same function as wildlife overpasses, but the underpasses direct wildlife under a barrier instead of over it. A canal overpass allows aquatic animals to move over a barrier. Fish ladders allow fish to navigate past barriers in a waterway, such as dams or waterfalls. Many other types of wildlife crossings are available, and many more could be designed. Each situation has to be evaluated to determine the best wildlife crossing for the problem presented.

Predict How could you use the engineering design process to design the best wildlife crossing for deer along a stretch of highway?

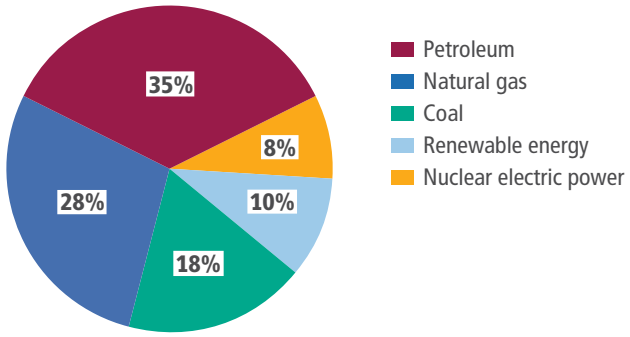
Converting Energy

The primary sources of energy in the United States are shown in Figure 2. Petroleum products are mostly used as fuel for transportation. Natural gas is used to produce electric power and to heat buildings. Most coal is burned to produce electric power. All three fuels emit greenhouse gases when burned. Nuclear power plants use nuclear fission to produce electricity. Its main environmental impact is the production of nuclear waste, which must be stored properly for thousands of years. The process of finding and extracting fossil fuels and nuclear material can result in habitat destruction, fragmentation, and pollution. Renewable energy is used for both electric power and transportation and does not emit greenhouse gases.

Analyze What are the potential environmental impacts for each of the energy sources shown in Figure 2? How could these impacts be lessened through engineering solutions?

U.S. Energy Consumption by Energy Source

FIGURE 2: Primary energy sources for the United States in 2014.



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (March 2015), preliminary data

Converting Waste into Energy

Humans make a lot of waste. How waste is handled and where it is stored can have major impacts on the environment and human health. Landfills are a common solution for storing waste. One of the problems associated with landfills is the release of methane as organic waste decomposes. Methane is a greenhouse gas that is better at trapping heat than carbon dioxide. It is estimated that methane has 25 times more impact on the climate than a similar amount of carbon dioxide. A solution to this problem would manage the waste while reducing methane emissions.

FIGURE 3: Special incinerators convert waste into electricity.

Burning Waste

Household and commercially generated waste is often available and is not considered valuable. In fact, most people and businesses pay to have their waste removed. Engineers designed waste-to-energy incinerators as a solution to reduce the amount of trash entering landfills while capturing some of the energy stored in the waste. These incinerators burn waste at high temperatures, producing steam. The steam causes a turbine to spin, which generates electricity. The raw ingredients needed for waste-to-energy incineration are reliable since people always generate more trash. Incinerators lower the amount of biomass in landfills, which lowers the amount of methane emissions from landfills.

The reduction in landfill emissions of methane is beneficial to the environment, because methane traps a significant amount of heat in the atmosphere. However, incinerators still emit greenhouse gases and other pollutants. Some critics question whether waste incineration plants will make people less willing to reduce and reuse and recycle. This could result in more trash in landfills.

Language Arts Connection Research the costs and benefits of waste-to-energy incinerators. Make an infographic to synthesize information from several sources.

FIGURE 4: Some waste can be converted into biofuel.

Making Biofuel from Waste

Some waste can be converted into biofuel, which keeps trash out of landfills and provides an alternative fuel source. A common example of biofuel is reused vegetable oil that can be used to power motor vehicles. The main source for waste vegetable oil is used cooking oil from restaurants. Waste vegetable oil is also processed into biodiesel, which can be used in any diesel engine. Using waste vegetable oil or biodiesel as fuel emits fewer greenhouse gases than diesel.

Ethanol is another example of biofuel and is commonly made from corn or other commercial crops. However, growing crops for biofuels can have environmental impacts, such as food shortages and increased water consumption. Biofuel also can be made from cellulose waste, such as agricultural by-products and waste paper. Making biofuels from waste reduces the strain on crops and allows farmland to produce more food for human consumption.

Anaerobic Digestion of Biomass

Collaborate With a partner, discuss the role the carbon, nitrogen, or phosphorus cycle plays in the anaerobic digestion of biomass.

During anaerobic digestion, microorganisms break down organic matter, or biomass, in the absence of oxygen. Anaerobic digestion can be used to break down material often thrown away or composted, such as food waste or livestock manure. During this process, the microorganisms produce a mixture of gases mostly composed of carbon dioxide and methane, called *biogas*. Facilities can then harvest the biogas for energy use, rather than releasing it into the atmosphere. This means fewer greenhouse gases are released into the atmosphere than from landfills or compost piles. The residue that remains after the biogas has been collected is called *digestate*. Digestate can be used as a fertilizer, which returns important nutrients to the soil, where they can cycle through the ecosystem.

Engineering

Analyzing Waste-to-Electricity Solutions

Analyze Make a decision matrix for this problem that analyzes potential solutions for developing energy from waste. Evaluate the town's criteria and determine which solution is the best for this town.

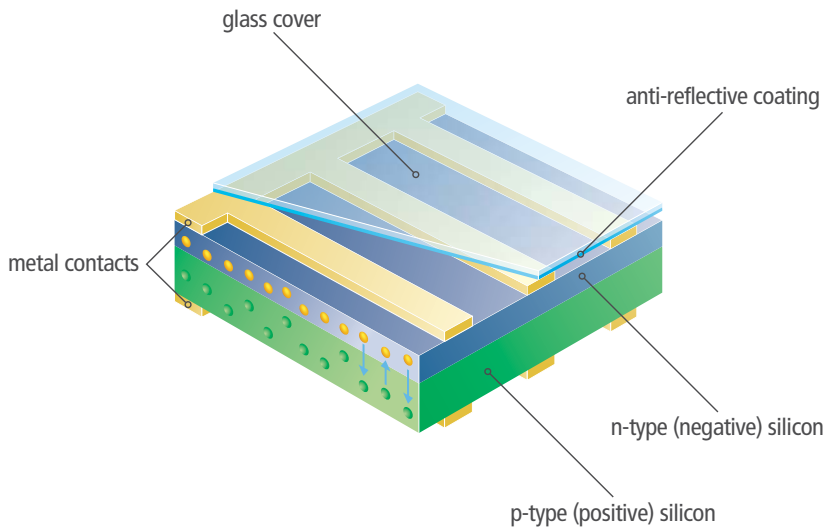
Decision matrices are used to evaluate the desirable features, or criteria, associated with each solution, such as which waste-to-energy method is best for a given situation. Imagine a town that wants to convert waste headed to the landfill into energy to offset rising electricity costs. The primary goal is to implement an energy capture method that provides a reliable source of electricity year round. The town produces the same amount of urban waste all year, and farms from the surrounding rural areas contribute manure to the landfill in the spring and summer. The secondary goal is to reduce net greenhouse gas emissions.

Remember, in a decision matrix, each criteria is given a number, or weight, based on how important that criteria is. The more important the criteria, the greater the weight assigned to it. Then each design is rated based on how well it meets those criteria. The scores for each design are multiplied by the weight and combined so engineers can determine how well the design is meeting the criteria.

Improving Solar Energy Efficiency

Solar energy is a renewable alternative to more traditional forms of energy, such as electricity produced from coal. Currently, solar panels can be expensive to manufacture and install, and they are less efficient at converting energy than other sources. Rising costs to produce electricity from fossil fuels and environmental concerns, however, keep solar energy at the forefront of the renewable energy discussion.

FIGURE 5: The movement of electrons within solar cells generates an electric current.



Solar cells work by absorbing light energy and transferring it to a semiconductor. Figure 5 shows how electrons in the semiconductor absorb the energy and break free to flow in a current. A common semiconductor in solar cells is silicon. In a solar cell, a layer of n-type, or negative, silicon is next to a layer of p-type, or positive, silicon. The n-type silicon has free electrons that interact with the p-type silicon. When energy from the sun knocks an electron "loose," it moves through the silicon layers. Layering allows the electrons to flow in a single direction, generating an electric current.

One of the biggest expenses of solar cells is the cost to produce silicon semiconductors. To solve this problem, engineers have designed organic semiconductors to replace silicon in solar cells. Organic semiconductors are made from hydrocarbons, the same raw materials used to make plastic. Hydrocarbons are cheaper than silicon, which reduces the cost of solar cells. Also, organic semiconductors can be produced in large sheets that require less energy and less money to make than silicon sheets. One drawback to organic semiconductors is that they are generally extremely poor conductors. Molecular engineers are working to develop solutions that will make semiconductors that are cheaper to produce and are better conductors.

Engineers are working on many solutions to increase the efficiency of solar cells. For example, a gel coating was designed that increases the range of wavelengths that solar cells can absorb. Another coating was designed to sort and concentrate usable sunlight as it hits the solar panels.

Explore Online

Hands-On Lab

Building Dye-Sensitized Solar Cells Conduct an investigation to determine if an organic dye can be used to develop a functioning solar cell.

Gather Evidence How do solar cells meet the needs of society and the environment?

Engineering

New solar cell designs are optimized during the design process. What evidence is there that organic solar cells are a result of design optimization during the engineering process?

Explain How is the engineering design process helping to meet human energy needs while also reducing human impacts on the environment?

Engineering and Conservation

FIGURE 6: Human populations are becoming more urban.

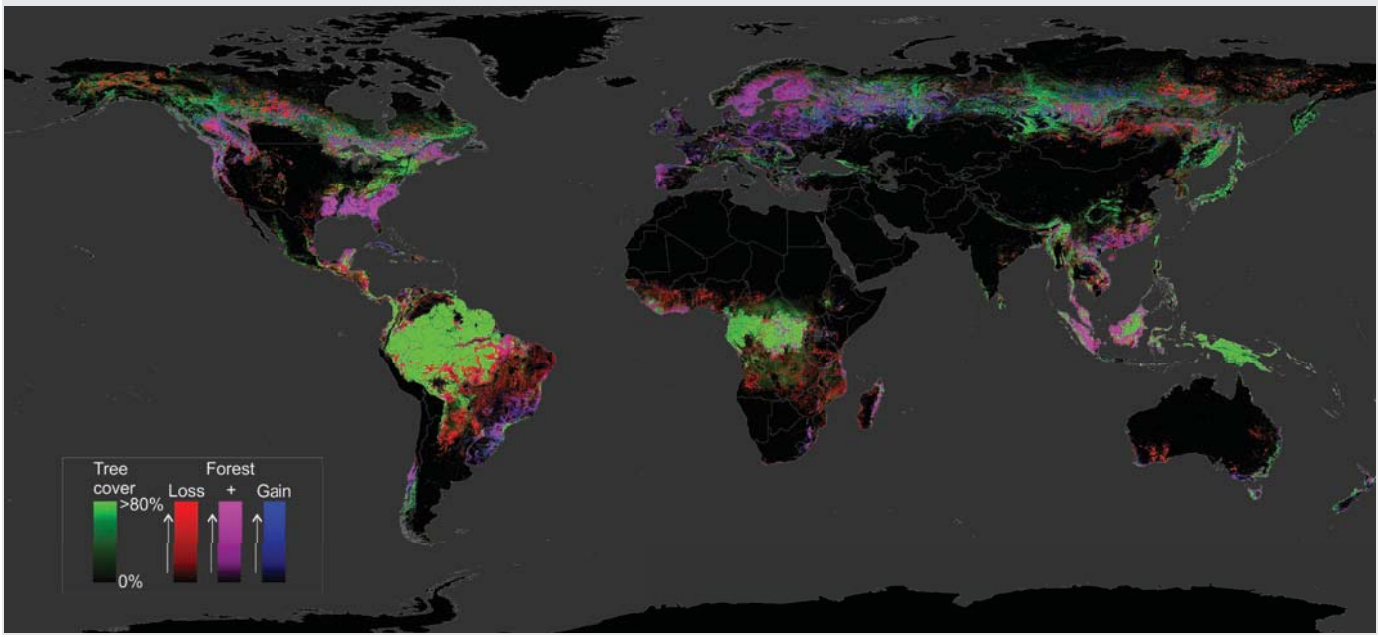
Habitat fragmentation, the spread of invasive species, and overharvesting to the point of extinction are a few examples of how humans can negatively impact the environment and biodiversity. The increasing human population will make human impacts on the environment more common and more severe. Deforestation, habitat destruction, and carbon dioxide emissions are some of the biggest challenges facing the global community. The fields of engineering and conservation are investigating ways to meet the needs of society while protecting natural habitats.

Collaborate With a partner, discuss how your town or city, or the one closest to you, may impact the environment.

Preventing Deforestation

Deforestation is the removal of trees and other vegetation from an area. The map in Figure 7 shows occurrences of deforestation across the world.

FIGURE 7: Forest cover extent, loss, and gain from 2000 to 2012.



Analyze What evidence does the map provide that the rate of deforestation from 2000 to 2012 is unsustainable?

Deforestation impacts the plant, animal, and human communities living in direct contact with the forest. It also impacts the rest of the planet, because forests are large carbon sinks, storing carbon as biomass. When the trees are removed, the stored carbon is eventually released into the environment, contributing to climate change. This also causes a loss of plant and animal habitat and a loss of plants that could be used for medicine. Deforestation reduces biodiversity, interrupts the water cycle, reduces water quality, and reduces oxygen production. All of these changes impact global communities.

The current rate of deforestation is unsustainable—the rate of deforestation is greater than the rate of new tree growth—making forests a nonrenewable resource. The demand for wood is one cause of deforestation. Engineers are developing wood alternatives to take the place of traditional wood materials.

FIGURE 8: Wood alternatives can be used in place of newly harvested wood products.

a Reclaimed wood

b Wood by-products

c Alternative plants

d Recycled paper

Some wood alternatives include reclaimed wood, wood shavings or by-products, alternative plants and trees, and recycled paper products. Examples of these alternatives are shown in Figure 8. Some sources of reclaimed wood are pallets, old buildings, and old barns. Reclaimed wood is often used for detail work and home items. Figure 8a shows a table made from a reclaimed wood door. Wood by-products, like wood shavings, can be turned into paper products or particleboard. For example, Figure 8b shows how wood shavings can be used as packing material. This approach avoids cutting down more trees for products that require only wood fragments.

Fibers from plants other than trees can be used to make the pulp used in paper products and fabrics. Bamboo, hemp, and flax are all examples of alternative plant fibers. Using less commonly harvested tree species to meet wood demands can also minimize the pressure on overharvested species. This approach can lessen the effects of deforestation, because some alternative tree species are more sustainable and grow faster than traditional species.

Recycled paper can be processed to produce new paper products. It keeps a large amount of waste out of landfills and reduces the pressure on forests. For many wood-containing products, wood alternatives are satisfactory replacements for newly harvested wood. Decreasing the need for wood products in construction and manufacturing would lessen some of the economic pressures driving deforestation.

Gather Evidence What products do you use, or could you use, that come from wood alternatives? Check the labels of items in your classroom or home. Are any of them made from wood alternatives?

Engineering

Finding Wood Alternatives

Wood is typically thought of as a building material, but it also is used in hundreds of products, some of which may surprise you. For example, wood products are used to make Ping-Pong balls, chewing gum, and eyeglass frames. The use of wood in such a wide variety of products is one of the reasons deforestation is so problematic. It also is the reason finding wood alternatives is so important.

Explain What criteria would be important to research before using a wood alternative for hardwood flooring?

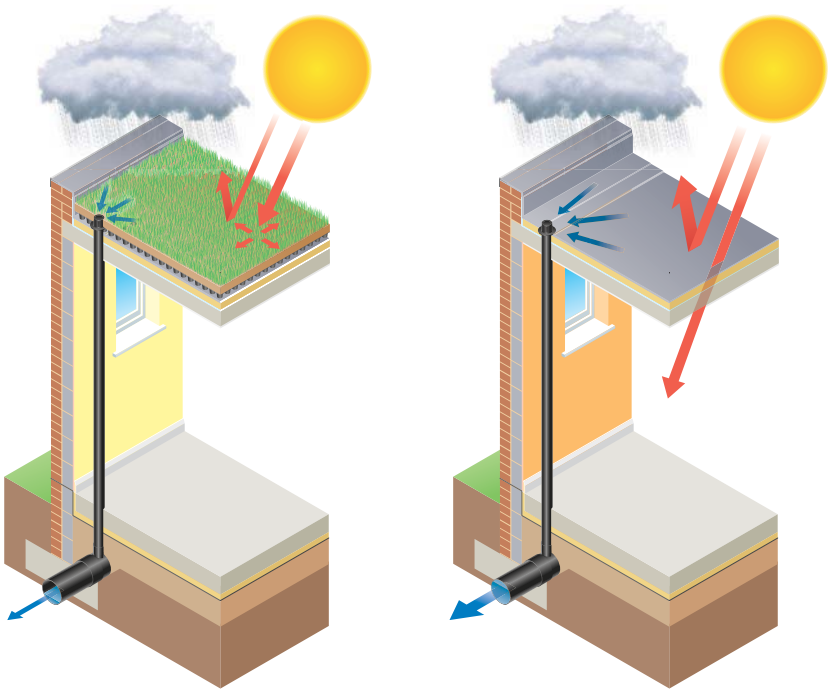
Making New Habitats

FIGURE 9: Green Roof

Human populations have become increasingly urban over the last two centuries. Around three percent of the human population lived in cities in 1800. By 2014, 54 percent of people lived in urban areas. Urban areas fragment habitats for many animals. Replacing soil with impermeable concrete disrupts the water cycle by reducing the amount of water that is absorbed by soil. This can cause increased runoff and flooding. Urban areas are also heat islands, because a high concentration of dark-colored building materials and asphalt absorbs heat and radiates it back into the environment.

Green roofing is an example of a solution that can lessen some problems of urbanization. Green roofs reduce the air temperatures in large cities, because they radiate less heat than traditional roofs. Green roofs can also provide habitat space for birds and insects. Rooftop habitats do not help all species, but they do provide green spaces and resources. Not only does this add habitat, but it also increases connectivity between habitat patches and may provide migration or dispersion corridors through cities for some organisms.

FIGURE 10: Green roofs can provide more insulation, absorb and store more water, and reduce heat emissions compared to traditional roofs.



As shown in Figure 10, green roofs include plants which absorb carbon dioxide and produce oxygen. Green roofs also absorb water and reduce runoff, which reduces flash floods and pollutants in waterways. Finally, green roofs insulate buildings. Figure 10 shows how less heat enters a building with a green roof than one with a traditional roof. This helps keep the buildings cool in the summer and warm in the winter, reducing energy needs for heating and cooling which account for a large portion of home electricity usage.

Explore Online

Hands-On Lab

Design a Green Roof Design and build a green roof prototype to decrease surface temperature and increase water retention.

Systems and System Models

Imagine an engineering team wants to use green roofs to minimize heat and habitat fragmentation in a large city. How might they break these large problems into smaller ones?

Lowering Carbon Dioxide Emission

Regulating greenhouse gas emissions is becoming more common in many countries, but many scientists are worried that atmospheric carbon dioxide concentrations have already reached a tipping point. Some scientists think it may be possible to slow or stop the advance of global warming by reducing the amount of CO_2 in the atmosphere. They are working with engineers to design efficient solutions.

The process of removing CO_2 or other pollutants from the atmosphere is known as *negative emissions*. This is accomplished by installing devices called *scrubbers* in factory flues to catch the gases. Removing CO_2 from factory flues is easier than removing it from the air around us. This is because CO_2 is up to 300 times more concentrated in factory emissions than in ambient air.

Analyze How could removing CO_2 from the atmosphere slow global warming?

FIGURE 11: Reducing carbon dioxide emission may slow global warming.

a "Clean" coal technology injects CO_2 underground.

b CO_2 gas can be stored in basalt rock.

Coal, considered one of the dirtiest fossil fuels, is responsible for up to 44 percent of CO_2 emissions. Engineers have been working on ways to reduce this number and make burning coal a "cleaner" energy option, shown in Figure 11a. After the coal is burned, engineers have designed technology that removes CO_2 from the gas produced, compresses it, and injects it underground.

While known as "clean" coal when treated in this manner, this energy source is not a form of clean energy, such as solar energy. Coal mining and burning still releases large amounts of pollution into the environment. Scientists are also worried that storing CO_2 gas underground may not be a long-term solution. Areas used for storage may have an increased risk of earthquakes due to the increased pressure from the gas. If earthquakes were to occur, the stored gas may leak out and enter the atmosphere.

To avoid this potential complication, engineers are looking at storing CO_2 in volcanic basalt rock, shown in Figure 11b. The CO_2 can react with the calcium in this type of rock, forming a carbonate rock. When the carbon becomes part of the rock itself, there is no risk of leaks. These technologies, though, are expensive. In many countries, including the United States, governments do not tax carbon emissions or require factories to limit their emissions. So, for many companies, it is not financially feasible to use such an expensive solution.

Engineering

A recurring theme in the development of new solutions to environmental problems is the need to make the solutions economically viable. With a partner or small group, research negative emissions solutions and debate which approach you think has the most promising future. Use evidence to support your claims.

Explain How is the engineering design process helping conservation efforts?

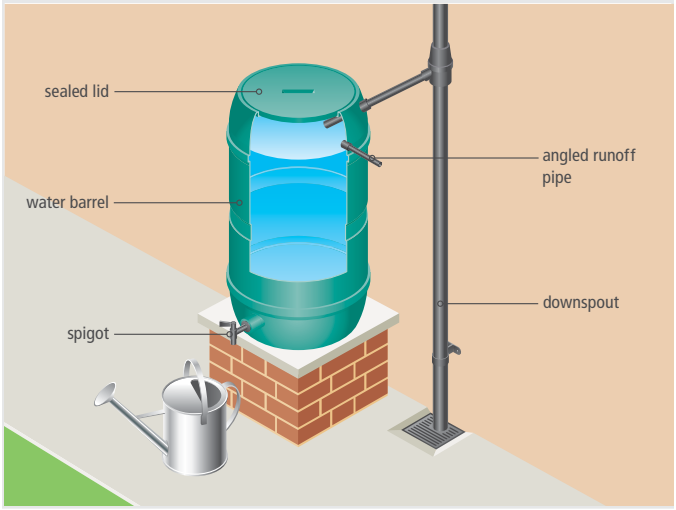
Decreasing Water Pollution

Water pollution and water shortages are endangering access to clean fresh water for humans and other organisms. Chemical runoff from pesticides, herbicides, and fertilizers is one of the many causes of water pollution. Water shortages are driven by increasing population sizes, high usage rates for personal and agricultural needs, and long periods of drought. Engineers are developing ways to solve the problems related to water access, water usage, and water pollution in order to ensure water is available in the future.

Predict Part of the engineering process is to take a larger problem and break it down into smaller problems. How could you break down the problem of obtaining clean water into smaller problems that can be addressed more easily?

Rainwater Harvesting Systems

FIGURE 12: Many rainwater harvesting systems divert water from a roof into a storage container.



Rainwater harvesting systems allow people to collect rainwater for household and commercial use instead of relying on freshwater sources that are in danger of being depleted. A simple rainwater harvesting system, shown in Figure 12, consists of a barrel to store the water, a conveyance system to direct the water to the barrel, a screen or lid to keep out insects and debris, a runoff pipe to allow excess water to escape, and a spigot to access the water. More advanced harvesting systems use large reservoirs instead of a barrel for water storage, pumps to move the water through a building, and even filtration systems to make the water safe to drink. Access to clean water remains a critical problem across much of the world.

Small rainwater harvesting systems are often used to meet the personal water needs of a household or to water a garden. Farmers or small towns may use entire ponds to store rainwater for agricultural or human needs.

Explain How could a rainwater harvesting system lessen the stress on a water supply even if the water collected is not safe to drink?

To maximize efficiency, rainwater harvesting systems should be designed to meet the specific needs of the people using it. Small harvesting systems can be scaled up to store larger amounts of water to meet agricultural needs or the needs of a larger community. Engineers understand that changes in scale can affect a system's structure and performance. For example, an uncovered rainwater harvesting system that did not have problems with evaporation on a small scale may suffer high levels of evaporation when built on a larger scale. A potential solution to this problem could be to store the water in underground tanks, lowering the amount of evaporation.

Hands-On Lab

Design a Rainwater Harvesting System

What makes a good rainwater harvesting system? The answer depends partly on how the collected water will be used. Some users may want to maximize water capture. Others may trade off quantity for improved quality. In this activity, you will design and test a rainwater harvesting system.

DESIGN

Brainstorm characteristics of a good rainwater harvesting system, and make a design of a system that you can make. Have your teacher approve your design before you begin writing your procedure.

PROCEDURE

Write your own procedure for building and evaluating a prototype of your design. Think about what question or questions you would like to answer about your prototype. For example, do you want to know how much water it collects? Or perhaps you want to know how long it will store water before it evaporates? Your evaluation should include collecting quantitative data that can be graphed to analyze the success of your design. Measurements will relate to the questions you decide to investigate. For example, a question about how much water is collected or how much water evaporates would require measuring the amount of water in your device at different times. Have your teacher approve your procedure before you begin building your prototype.

ANALYZE

1. Graph the data you collected. What trends or patterns do you notice?
2. How did you measure success, and how successful was your design?
3. How could your design be optimized to make it more successful on this scale or a larger scale?

FIGURE 13: Rainwater harvesting systems can be built from simple materials.

POSSIBLE MATERIALS

- container, plastic
- gutter or other conveyance system
- lid, solid or screen
- pipe or other overflow device
- spigot or other mechanism to access water

Water Treatment

Water treatment plants are designed to remove pollutants from water to increase water quality. Some facilities can make wastewater—such as water from flushing your toilet—clean enough to drink. This multistep recycling process first removes solid waste and organic matter. Then the water is treated using procedures such as microfiltration, reverse osmosis, and exposure to UV light and hydrogen peroxide. Microfiltration forces water through tubes that have holes large enough to let water pass through but small enough to trap bacteria and protozoa. Reverse osmosis further filters pharmacological substances and viruses from the water. Finally, exposing the water to UV light and hydrogen peroxide destroys any remaining organic material. The treated water meets or exceeds water quality guidelines for drinking water.

FIGURE 14: Water treatment plants make wastewater potable.

Water treatment plants, such as the one shown in Figure 14, are one solution to water pollution. Water treatment plants remove pollutants that are dangerous to humans and the environment and produce potable water—water that is safe to drink. They also reduce the stress on freshwater resources. Recycling wastewater reduces the amount of water that must be taken from water resources to meet human demands. New engineering advances have made recycling wastewater into potable water more accessible for many communities.

Collaborate The idea of drinking wastewater is not very appealing, even after it has been treated. As an engineer, how would you overcome this cultural barrier? Write down your solutions and share them with a partner.

Providing Clean Drinking Water

Clean drinking water is essential for human health. Waterborne illnesses in polluted water can cause life-threatening diseases. Similar to local rainwater harvesting, some engineers have begun focusing on the local and personal levels of water treatment. Engineers have developed personal water filtration devices that are relatively cheap and easy to carry. They can be used in and out of the home to filter harmful bacteria and contaminants from drinking water. This is accomplished through a variety of methods, including microfiltration, chlorination, ceramic filters, or solar filters.

Engineering

FIGURE 15: Personal Water Filtration Device

Scaling Down Water Filtration Systems

Personal water filtration devices are essentially miniature water treatment plants—an example of engineers scaling down a large-scale solution. Scaling up and scaling down solutions enables the same technology to be applied to multiple problems. The technology must be redesigned and optimized for the new scale, but further development will benefit from previous testing stages.

Model Make a model that shows how personal water filtration methods and water treatment plants are similar processes on different scales.

Personal filtration systems have many advantages over boiling, a common method of sanitizing drinking water. The filtration systems are quicker and have a lower carbon footprint than boiling, which requires fuel and releases greenhouse gases. Fuel also can be cost- and time-prohibitive to obtain, making boiling a more difficult option.

Explain How is the engineering design process helping to make clean water and reduce the stress on freshwater sources?

Careers in Science

Environmental Engineer

Environmental engineering focuses on the relationship between humans and the environment to improve sanitation and control pollution. Environmental engineers use concepts from biology, chemistry, physics, mathematics, and soil science. They solve problems dealing with solid waste and wastewater management, water supply and quality, air quality, and other types of pollution.

Desalination removes salt from seawater or brackish groundwater. The water produced can be treated to meet water quality standards for human consumption. Desalination plants require a source of water to treat and a place to dispose of the salts and other contaminants removed during this process. Desalination plants help increase the water supply of an area.

The first task in designing a desalination plant is to define the problem and identify the social, technical, and environmental criteria and constraints that could limit potential solutions. The engineer would research background information on the project site, past and current water supply issues, the government permits required for this type of project, potential community involvement, and much more. During this and subsequent processes, the engineer may work in either an office or field setting.

Once the problem is defined, an environmental engineer may be asked to design potential solutions. Environmental engineering solutions often build off of existing technology. An environmental engineer might study existing desalination plants and make adjustments based on the unique parameters for the project, evaluating and refining solutions throughout the design process to optimize the final solution for the given problem.

FIGURE 16: An environmental engineer working at a desalination plant.

Next, modeling may be used to determine if the system will work as expected and what, if any, environmental or societal impacts can be expected from the solution. An engineer could make a mathematical model of the desalination process to determine the efficiency of the design.

Finally, an environmental engineer would communicate the solution through presentations and reports. For a desalination project, this could include an explanation of why the proposed solution will be effective and suitable for solving the water supply problem.

Environmental engineers may focus on only one aspect of the design process or they may complete the design process from beginning to end.

Language Arts Connection

You are consulting on an environmental engineering project. The client needs a reliable source of water in a remote desert location without surface water. Groundwater salinity is triple that of seawater. Electricity is not available in this location. The client would like to know whether desalination is a possible option or if another method for accessing water is recommended. Present your solution as an e-mail to the client. Include the steps you will take to solve the problem, identify criteria or key variables that will impact the solution, and how the solution could be tested.

DESIGNING CLIMATE CHANGE SOLUTIONS | DESIGN A GREEN ROOF | BUILDING DYE-SENSITIZED SOLAR CELLS

Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 17: Wildlife crossings meet a variety of needs for animals and humans.

a Highway overpass

b Highway underpass

c Canal overpass

d Fish ladder

Wildlife crossings help wildlife navigate barriers, but crossings do not just benefit wildlife—they benefit society as well. For example, vehicle collisions with animals on highways can be deadly for humans as well as animals. Wildlife crossings provide a way for animals to cross a barrier, such as a highway, while minimizing the possibility of vehicle collisions. The crossings also act as corridors for animals. They can connect habitats that have been fragmented by roads or infrastructure. Vegetation on overpasses provides a more natural corridor between habitat patches.

Aquatic species encounter different barriers. They rarely need to cross a road but may need to get past a dam or waterfall. Fish ladders are typically established to provide a pathway for migrating fish that need to move either up or down the waterway at different stages in their lives.

Explain Refer to the notes in your Evidence Notebook to explain how you could use the engineering design process to design the best wildlife crossing for deer along a specific stretch of highway.

Developing wildlife crossings requires an understanding of both engineering and conservation. Engineers must consider the needs of people, the logistics of building the crossing, the habitat and behavior of the animals targeted for the crossing, and many other factors. Each crossing is unique. The problem that each crossing is trying to solve, whether it is minimizing vehicular collisions on a roadway or providing a migration route on a waterway, should be looked at from different perspectives and broken down into smaller problems if possible.

Decision matrices can be used to evaluate solutions against the criteria and constraints involved. Testing and prototyping provides an opportunity to optimize a wildlife crossing or improve a previous design. Engineering designs increasingly use environmentally friendly materials and construction methods to decrease the impacts of development on the environment. Finally, engineers solving a problem, such as the installation of a new wildlife crossing, can use existing structures and technology as inspiration for a new project.

CHECKPOINTS

Check Your Understanding

1. Which type of rainwater catchment would be best for a town that receives a relatively small amount of precipitation each year?
   - **a.** small, uncovered pond
   - **b.** large buried, storage tank
   - **c.** large, uncovered reservoir
   - **d.** rain barrels

2. What are some advantages of collecting rainwater for human and other uses? Select all correct answers.
   - **a.** lowers stress on freshwater resources
   - **b.** improves access to water
   - **c.** frees time usually spent collecting water
   - **d.** reduces the occurrence of acid rain
   - **e.** reduces runoff and flooding

3. Critics argue that adoption of a waste-to-energy incineration program may encourage communities to do which of the following? Select all correct answers.
   - **a.** produce less waste
   - **b.** recycle less
   - **c.** use less electricity
   - **d.** consume more and throw out more waste

4. How might building a prototype of a negative emissions machine help engineers get funding for moving the design up to a larger scale?
   - **a.** The prototype demonstrates the proof of concept and proves that the technology is functional.
   - **b.** The prototype functions exactly like the end product.
   - **c.** Building a prototype allows engineers and investors to evaluate the design against set criteria and constraints.
   - **d.** The prototype shows potential investors that the design has been optimized.

5. Which project would be best suited for each wood alternative: recycled paper, alternative plant fiber, alternative wood species, reclaimed wood? Match each wood alternative to the project for which it is best suited.
   - **a.** commercial paper products
   - **b.** fabric
   - **c.** new building
   - **d.** wood crafts

6. How are negative emissions related to stability and change in the climate?

7. What are some general criteria for green roofs? Select all correct answers.
   - **a.** waterproof
   - **b.** weight supported by building structure
   - **c.** native plant community
   - **d.** established plant community

8. Imagine your company is designing a flexible silicon solar cell that can be rolled up. Which of these solar cell components would most likely need to be optimized?
   - **a.** anti-reflective coating
   - **b.** n-type silicon
   - **c.** p-type silicon
   - **d.** glass cover

9. What are the advantages of an organic semiconductor over a silicon semiconductor?

10. Which characteristic of organic semiconductors must be optimized in order for them to be a better solution for solar cells than silicon semiconductors?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

Engineering solutions are used to lessen human impacts on the environment. For example, energy alternatives, wood alternatives, and water treatment solutions can reduce pollution and environmental impacts.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how engineering solutions can influence the way humans interact with the environment.