

ENERGY-WATER NEXUS STEM INVESTIGATIONS

Sustainability Challenge

OBJECTIVES

Students will be able to:

- **Compare** the inputs and outputs for photobioreactors, anaerobic digesters, and composting.
- **Create** recycling loops by matching resource inputs and waste outputs to convert waste into resources.
- **Construct** flowcharts mapping the energy, water, and nutrient flows within and between biorecycling systems.

OVERVIEW

In this activity, students will create recycling loops by turning their waste into resources. In small design teams, they will identify solutions to hypothetical challenge scenarios that require them to sustainably manage both resources and waste. They will discover the relationship between energy, water, and food by selecting biorecycling techniques (algae photobioreactors, anaerobic digesters, and composting) to map the flow within and between their biorecycling systems.

CONNECTION TO THE ENERGY-WATER NEXUS

- It is important to understand that the world is consuming more resources and producing more waste than the planet can regenerate or absorb in the atmosphere.
- Improving awareness of the need to make wise and resourceful use of water and energy will help us find solutions to prevent waste, increase efficiency and pursue options for using renewable energy.

NATIONAL STANDARDS

Next Generation Science Standards

- **MS-ESS2-1 Earth's Systems**
Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.
- **MS-ESS3-3 Earth and Human Impact**
Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

ITEA/ITEEA Standards for Technology Literacy

- **Standard 15**
Students will develop an understanding of and be able to select and use agricultural and related biotechnologies.
H: Biotechnology applies the principles of biology to create commercial products or processes.

BACKGROUND

Did you know that, according to the EPA, the average person generates 4.5 pounds of solid waste per day? This solid waste includes boxes, food, yard waste, plastic, and anything else that you would place in a trash or recycle bin. Unfortunately, food continues to be the largest component of landfills in the United States. Each American also uses an average of 88 gallons of water each day! This water usage primarily comes from flushing toilets, showers, baths, kitchen sinks, and laundry. Wastewater can also come from manufacturing and industrial operations such as food processing plants.

Our ecological footprint is a measurement how we consume our resources and generate waste compared to how fast nature can absorb our waste and generate new resources. As the human population continues to grow, so does our waste production and resource consumption. Sustainability is the ability to meet the needs of the current generation without compromising the ability of future generations to meet their needs. Mismanagement of waste still poses a threat to human health, local environments, and our climate. Composting, anaerobic digesters, and photobioreactors are three innovative waste management strategies that can turn our waste into valuable resources in a sustainable way.

KEY VOCABULARY

- Photobioreactor
- Decomposer
- Biorecycling
- Aerobic
- Microalgae
- Photosynthesis
- Anaerobic
- Biogas
- Anaerobic digester
- Biofuel

GROUP MATERIALS

- White boards or poster paper
- Markers
- Glue or tape

TEACHER PREPARATION

- Copies of *Sustainability Challenge Capture Sheet* for each student
- Copies of *Composting, Photobioreactors, and Anaerobic Digestion* for each group
- Print and cut the *Sustainability Challenge Scenarios* to assign one per group
- Print and cut the *Sustainability Challenge Cards* to make a set for each group

ATTENTION PARENTS AND CAREGIVERS



Like many girls her age, your daughter is no doubt interested in learning more about the environment around her and how she can respect and protect our planet. That's why she'll be interested in joining [Girl Scouts of the USA](#) and participating in their "It's Your Planet—Love It!" program. It gives girls the opportunity to learn about environmental topics such as clean water and air, noise pollution, climate change, agriculture, and so much more! Plus, it's packed with fun activities and the most up-to-date environmental information and offers girls ways to improve life for everyone on the planet! Troop Leaders can also make this program part of troop meetings. Check out the [It's Your Planet Love It Journey](#) now.

PROCEDURE

1. Open the lesson by asking students if nature creates waste. Ask them to define the term waste. What happens to leaves when they fall from trees? Decomposers break them down into nutrients and those nutrients become resources for other plants to grow. The plants use the nutrients to make new leaves and the cycle continues. In nature, there is no waste, everything is reused. Environmental engineers develop biorecycling technologies that mimic nature. By using biorecycling techniques, we can greatly reduce, or possibly eliminate, our waste by turning it into resources. This is a sustainable practice because the resources are always available, and the waste does not build up.
2. Place students into small groups of three and distribute copies of *Composting*, *Photobioreactors*, and *Anaerobic Digestion* to each group. Have groups identify inputs, outputs, and applications for each biorecycling technology. Invite groups to share what they have discovered and record the answers on the board.
3. Ask the class to generate a list of what a person needs to survive. Draw a person on the board with arrows entering to represent needed resources and arrows leaving to represent waste produced.
4. Distribute the *Sustainability Challenge Cards* to each group. Ask them to find the person and compare the inputs and outputs with the card to the answers they provided on the board. Address any questions or misconceptions before moving on.
5. Explain to the students that there will be a challenge scenario where they will be applying the biorecycling technologies to meet their needs and manage waste. Assign a *Sustainability Challenge Scenario* to each group. Inform groups that they must meet the needs of the person/community and minimize waste for their specific scenario.
6. Have each group pull out the four reservoir cards: atmosphere, soil, freshwater, and energy. Explain to each group that these are potential resources that they have access to, but not all resources are available for each scenario. Provide time for each group to identify reservoirs that are not accessible to them based on their scenario limitations. For example, the underground fallout shelter does not have access to natural sunlight.
7. Distribute the *Sustainability Challenge Capture Sheet* and have each group discuss and answer the questions to the identifying constraints section. Invite groups to share their scenarios, limitations, and reservoirs that are not available to their community with the class.
8. Direct students to spread their *Sustainability Challenge Cards* on the poster paper. Cards that are not accessible to their scenario should be removed. Explain that each card has resource inputs and waste outputs. Challenge them to design solutions that are sustainable, matching all waste outputs to resource inputs. Challenge them to eliminate all waste.
9. Have students use pencils to draw and label connections between the cards and identify biorecycling loops. They may have to rearrange their cards multiple times before they find all the connections and biorecycling loops. When they are satisfied with their solutions, instruct them to tape their cards to the poster paper and use markers to label the connections.

10. Have groups discuss and answer the questions to the developing solutions section on the *Sustainability Challenge Capture Sheet*. Invite groups to share and communicate their solutions with the class.
11. To close the activity, have students individually identify two sustainable pathways that their group developed and draw a flowchart showing the circular connection between the inputs and outputs for each pathway. This should be completed on the diagram of a sustainable pathway section of the *Sustainability Challenge Capture Sheet*.

EXTENSION

As an extension of this activity, have students select a sustainable practice (i.e. composting bins, having trashless lunches, maintaining a green rooftop, installing water bottle fountains, using solar chargers for electronics in the classroom, etc.) and write a persuasive letter convincing the principal to consider implementing their practice at their school.

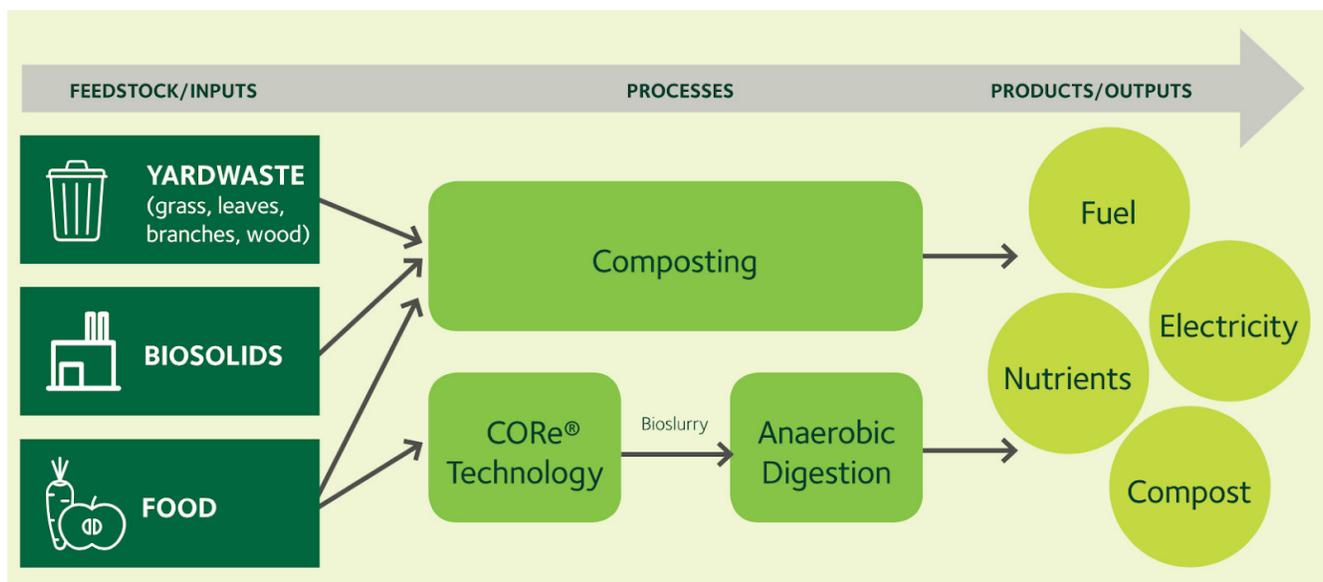
SOURCES

<https://www.epa.gov/sustainability>

<https://www.youtube.com/watch?v=HCZOKmojrkw&feature=youtu.be>

How Does Composting Work?

Composting is the controlled decomposition of grass clippings, food scraps, manure, dry leaves, wood chips, and even human feces! This same process takes place in nature when decomposers, such as fungi and bacteria, break down dead leaves and branches on the forest floor. Composting uses microscopic decomposers to break down complex organic matter like sugars, fats, and protein into its simpler elements such as carbon, hydrogen, oxygen, nitrogen, and phosphorus. The microorganisms living in a compost pile need enough moisture to survive. Water is essential as it helps transport substances within the pile and makes nutrients accessible to the microbes. The microbes also require oxygen to break down the organic waste, which is why this process is known as aerobic decomposition. During the decomposition process, the microbes release carbon dioxide and heat. The carbon dioxide that is released can be recycled back into plants that require it for photosynthesis.



Applications for Composting

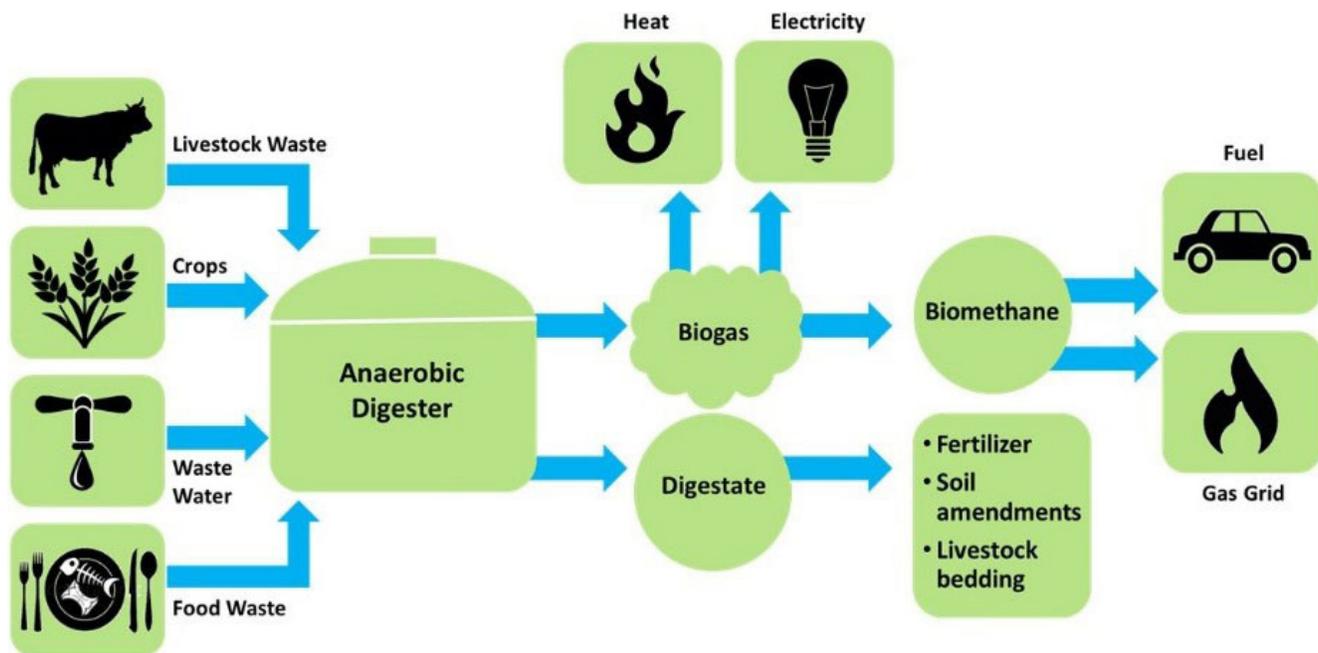
- Large scale composting facilities take in waste from farms and cities, decreasing the amount of landfill waste.
- Composting produces heat that could be used for energy to heat greenhouses or water heaters.
- Compost could be used as fertilizer to increase the quality of nutrients in the soil.
- Using waste heat can decrease our dependence on fossil fuels.
- Photosynthetic organisms can consume carbon dioxide in photobioreactors.

Challenges for Composting

- A limited amount of available space.
- Waste has to be separated (e.g. yard trimmings, food waste).
- Microorganisms require a certain temperature range for optimal activity, so weather and climate may delay decomposition.
- Depending upon the size of the container, composting may take 3 months to 2 years.

How Does Anaerobic Digestion Work?

Anaerobic digestion breaks down biodegradable materials to release nutrients and creates biogas, which is a combination of carbon dioxide and methane gas. Anaerobic digestion is like composting, but it occurs in environments without oxygen. In nature, anaerobic environments occur in soil, mud, swamps, and deep lakes, among other places. As leaves, fish, and other dead organic materials sink to the bottom of lakes and swamps, they are broken down by anaerobic microbes, organisms that do not require oxygen to live. As the nutrients from these materials are released, plants in the lakes use them to grow. Anaerobic digestion also occurs in cow stomachs. Microbes in the stomach break apart grasses and plant fibers, releasing nutrients that are absorbed by the cow intestines.



Applications for Anaerobic Digestion

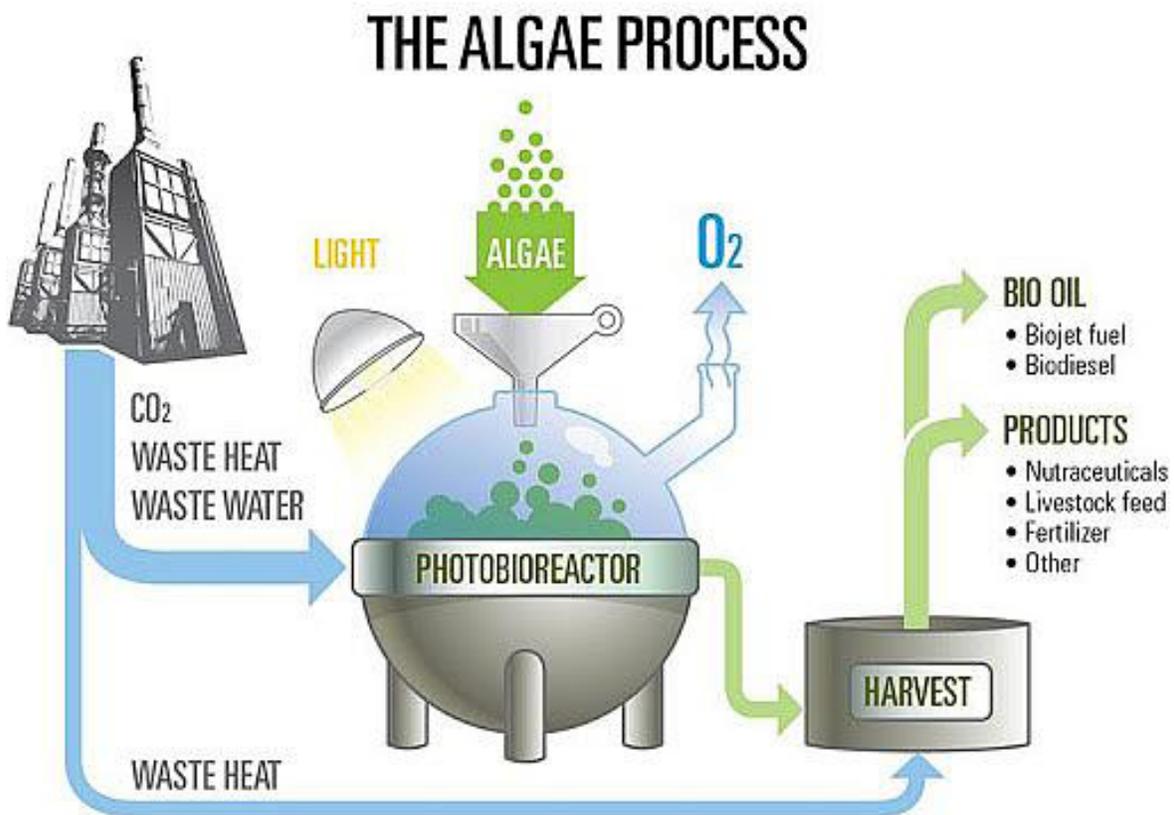
- Biogas can be burned to generate electricity or heat.
- Human, food, and yard waste can be fed to anaerobic microbes.
- Broken down organic materials can be used as fertilizers.
- Carbon dioxide can be consumed by photosynthetic organisms used in photobioreactors.

Challenges for Anaerobic Digestion

- It requires a lot of space.
- It is time consuming.
- Some organic waste is more difficult to break down. Food waste, fats, oils, and greases are the easiest organic waste to break down, while manure is the most difficult.
- There must be a constant source of raw materials (animal or human waste) to be successful.
- The waste products from the process will require a large chunk of land for storage.

How Do Photobioreactors Work?

Engineers build photobioreactors, or controlled artificial environments, to grow specific types of algae, cyanobacteria, seaweed, or plant cells. These photosynthetic organisms require light as the required energy source to build organic matter like sugars from carbon dioxide. Photosynthetic organisms produce a very important waste product needed by almost all organisms on earth, oxygen! Photobioreactors are usually clear so that sunlight can penetrate, and the water temperature, nutrient content and carbon dioxide levels are kept at just the right conditions. Many kinds of algae can also naturally produce oil, which can be used to make liquid fuels. Crops, such as corn, are grown specifically to make biofuel, a renewable plant-based fuel made from biomass. Corn can be changed into ethanol, which can be used in place of petroleum-based fuels. The reason engineers are investigating microscopic algae is because it grows much faster under controlled conditions and can achieve a higher biomass than in nature.



Applications for Photobioreactors

- Algae can take in nitrogen and phosphorus from wastewater treatment plants.
- Carbon dioxide converted into biomass can be used as food, animal feed, biofuel, and fertilizer.
- Algae can use waste gases, like carbon dioxide, from combustion or power plants.

Challenges for Photobioreactors

- Availability of light
- Amount of carbon dioxide present
- Nutrients to grow microalgal biomass
- Space requirements

Identifying Constraints:

1. What is your challenge scenario?
2. What limitations does your community have to overcome to survive?
3. What reservoirs are not available for your community?

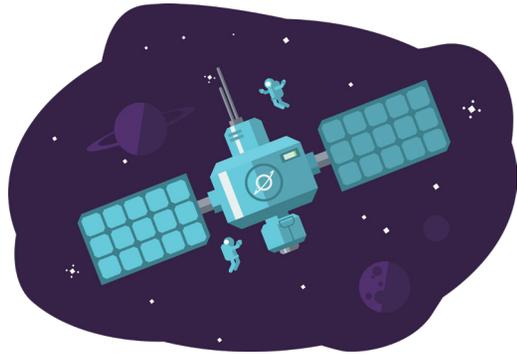
Developing Solutions:

1. How were you able to provide food for your community from biorecycling?
2. How were you able to provide energy for your community from biorecycling?
3. How were you able to provide freshwater for your community from biorecycling?
4. Were you able to use all your waste as resources?
5. What biorecycling techniques did you use?
6. Discuss and explain why you think your community would survive or would not survive the next 100 years.

Diagram of Sustainable Pathway

Identify two sustainable pathways that your design team developed in your scenario and draw a flowchart showing the circular connection between the inputs and outputs for each pathway.

International Space Station



Your community must survive in space until you reach an inhabitable planet.

Underground Fallout Shelter



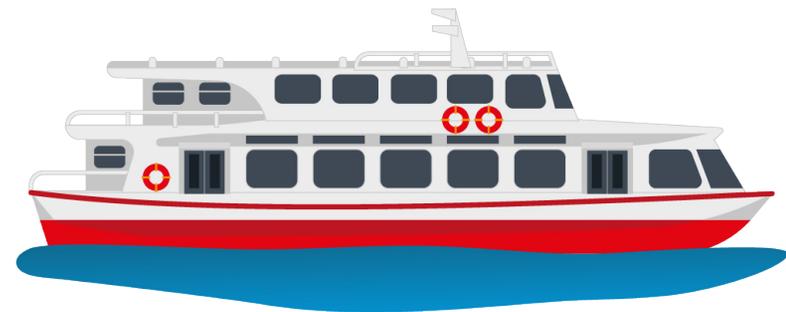
Your community must live underground to avoid harmful nuclear radiation.

Biodome



Your community must live in a dome to avoid harmful solar radiation.

A Pirate's Life



Your community must live on a ship because of waring countries and lack of natural resources.



Atmosphere Reservoir



Nitrogen (N), Oxygen (O₂),
Carbon Dioxide (CO₂), Water Vapor (H₂O)

Energy Reservoir



Natural Heat and Light

Freshwater Reservoir



Lakes, Rivers, Aquifers,
Groundwater, Rainwater

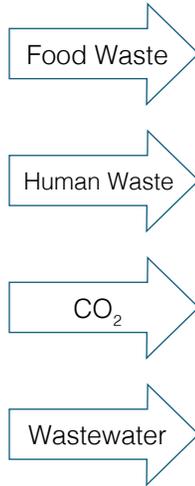
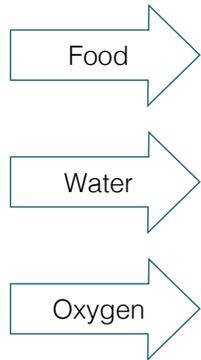
Soil Reservoir



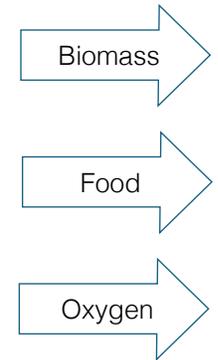
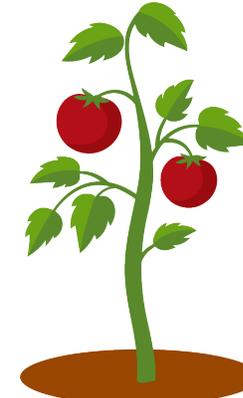
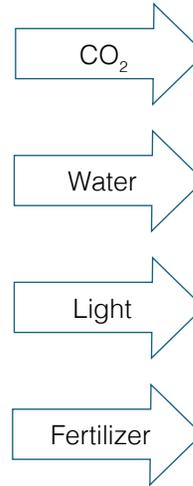
Minerals and Biomass



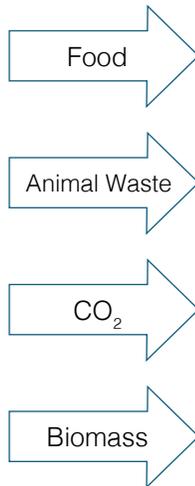
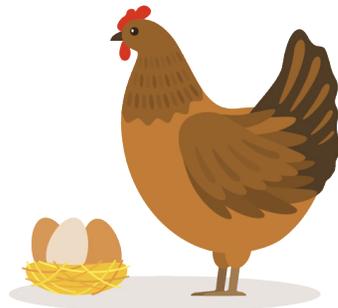
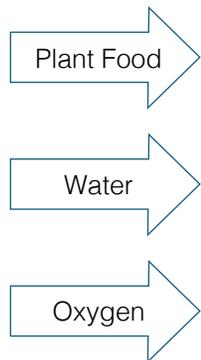
Person



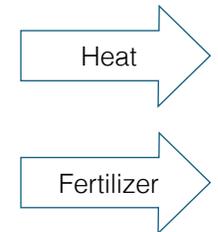
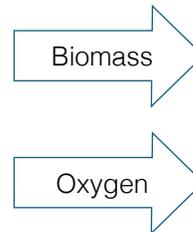
Plants



Animals



Compost

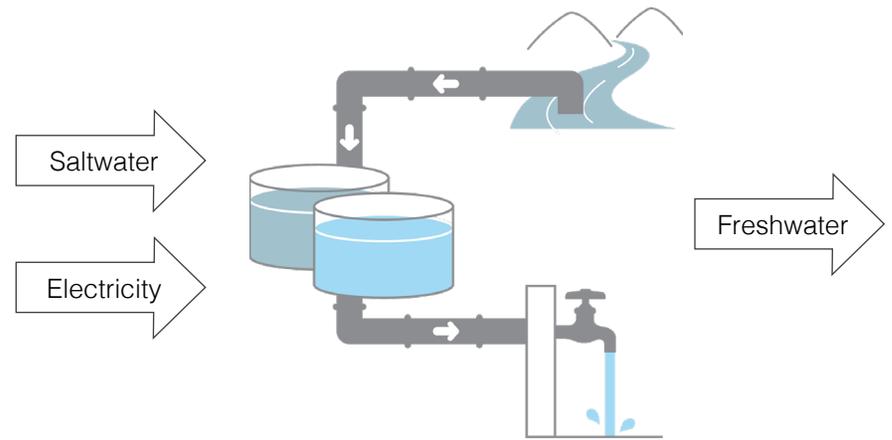




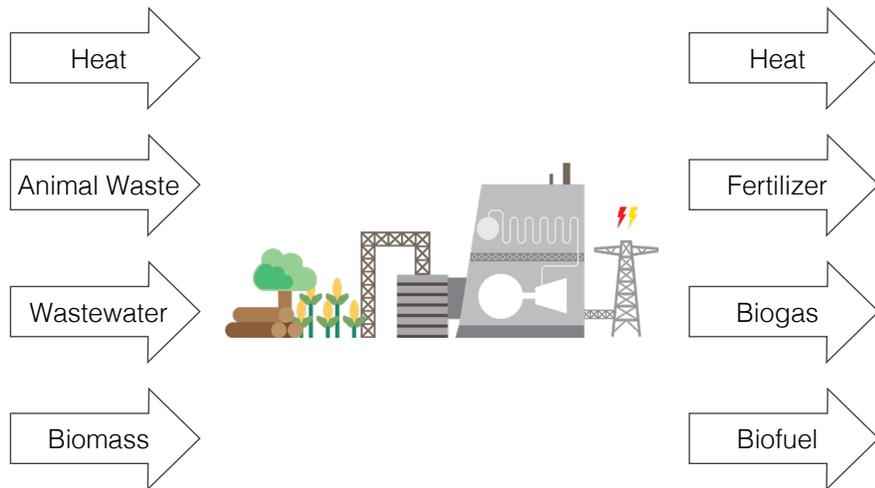
Photobioreactor



Water Treatment



Anaerobic Digester



Power

