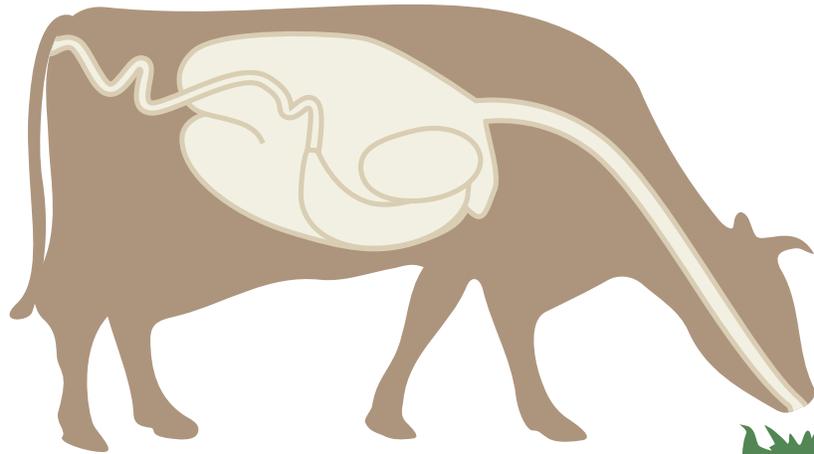


ScienceNews

IN HIGH SCHOOLS | EDUCATOR GUIDE



GREENER COWS



SOCIETY FOR
SCIENCE & THE PUBLIC

About the article

The *Science News* article “Greener Cows” examines methane production by cows and various approaches to reduce this production. Recent research shows that cows release enough methane to meaningfully contribute to global climate change. By understanding cow digestion and studying the resulting burps, scientists can guide industry to make feeding and breeding choices that are better for the environment.

“Greener Cows” can be used across a wide range of curricula, with a focus on **biology, chemistry and engineering design**, and with connections to **algebraic thinking**. The activities, questions and discussions in this educator guide can be used to support the following education standards:

Next Generation Science	Common Core
Matter and its Interactions: HS-PS1-1	ELA Standards: Reading Informational Text (RI): 4
Energy: HS-PS3-3	ELA Standards: Writing (W): 2, 7, 9
Ecosystems: Interactions, Energy and Dynamics: HS-LS2-3	ELA Standards: Speaking and Listening (SL): 1, 4
Biological Evolution: Unity and Diversity: HS-LS4-4	ELA Standards: Reading for Literacy in History/Social Studies (RH): 8, 9
Earth and Human Activity: HS-ESS3-2 , HS-ESS3-4	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 7, 9
Engineering Design: HS-ETS1-2 , HS-ETS1-3	

Prior to reading

Guide student reading by pointing out connections between this article and what students are learning in class. Here, find some ideas for standard-aligned paths to follow while reading:

- Ask students what they know about digestion. Can they name the parts of the human digestive system? What about a cow’s digestive system? Use [Blackline Master #1](#) to foster a discussion on the similarities and differences between the two systems. How do the physical and biological differences affect what humans and cows can and can’t eat? (*Some similarities include the mouth, tongue, esophagus, intestine, anus and stomach – of sorts. Both rely on bacteria to aid digestion. Some differences are the length of the esophagus and intestine; the number of stomachs; the ability of the microbes to digest cellulose in cows but not in humans.*)
- Ask students what they know about selective breeding. How long have humans been employing this tool? How has it transformed agriculture and human lives? (*Students might mention the selective breeding of wheat, rice and maize, dating back millennia. They might mention sheep breeds, cow breeds and pet breeding.*) Also ask them what they know about genetic engineering? How is it similar to and different from selective breeding? You can revisit these questions once students have read the article, to see what the students have learned.

After reading: Comprehend

You can adapt and print these questions ([Blackline Master #2](#)) to check for comprehension and analysis before or after discussion:

1. **What is the main topic of the article?** (*How scientists are working to reduce methane production by cows.*)
2. **How do cows produce methane?** (*The methane is a waste product created by microbes called methanogens that live inside the digestive system of the cow to help it break down cellulose from the food it eats.*)
3. **Why is methane production of particular concern to scientists and farmers?** (*Methane is a significant contributor to climate change. 26% of U.S. methane emissions are from enteric fermentation. Of the methane from enteric fermentation, cattle produce 96.5%. The U.S. has pledged to reduce methane output from dairy cattle by 25% by 2020.*)
4. **What are some ways scientists are exploring to reduce methane emissions from cows?** (*Some ideas from the article include: Giving cows different types of food, including adding nitrates, concentrates, synthetic additives and plant extracts; giving cows vaccines; selective breeding for cows that burp less methane.*)
5. **Why would the U.S. government like to see more farms using digesters?** (*Manure produces a substantial 10% of U.S. methane emissions. Digesters are efficient at converting manure and other organic material into methane, which can be captured and used as fuel or burned to generate electricity.*)

After reading: Analyze

1. **How have farming technology and practices changed since the Industrial Revolution? How has science changed how farmers raise crops and livestock?** (Students might draw on examples from the text, but they may also want to go beyond the text. Farmers, for example, have developed ways to keep animals healthy in large populations. Others have turned to urban agriculture and microfarms.)
2. **Countries export their beef worldwide. Some, like Japanese Kobe beef and Canadian natural beef, are prized for their unique taste and appearance. Based on the information in the article, what factors do you think could account for differences in the flavor and texture of beef?** (Answers will vary but might include: the animals' diet and environment, artificial selection for specific traits like marbled muscle.)

Calculate

You can use information provided in the article to create mathematical exercises:

- The article says, "emissions from a grown dairy cow can amount to about 260 to 650 grams of methane per day." If there are 98 million cows in the United States, and assuming the methane output of beef cows is similar to that of dairy cows, how much methane is produced by cattle daily? (25.48 billion to 63.7 billion grams of methane per day.) What is that in kilograms? If one mid-sized animal puts out almost 150 kg of methane every year, and cattle live an average lifespan of 15 to 25 years, depending on their living conditions, how much methane does a cow produce in its lifetime? (3,750 kg methane over 25 years.) To take this further, students can research the methane produced by sheep and goats to compare natural production by different animals.

Discuss and Assess

After students read the article independently, return as a group to the concepts outlined prior to reading. Invite students to share their answers and observations from the article and lead a class discussion that further underscores your current curriculum. The discussion can serve as an informal assessment. Ideas for further reading discussion or writing prompts include:

- Ask students what they learned from the article about selective breeding. (Maybe they didn't realize that foods have been modified for thousands of years, since the days of ancient Egypt, using artificial selection. Students' pets are selectively bred for traits that make the animals more desirable for domestication.) In light of this history, why have some people viewed genetically modified organisms (GMOs) so negatively? Students may want to research examples of GMOs, current labeling practices and scientific evidence that speaks to the GMO debate.
- Ask students to consider the multiple approaches that scientists are trying out to introduce cows that produce less methane. Each approach has its trade-offs. Ask students to take a broader view: Targeting the methane production of cows is just one of many approaches to lower greenhouse gas emissions. Can they think of others? (Carbon capture, for example; reducing emissions from cars and other vehicles; switching to renewable energy sources instead of fossil fuels; reducing consumption.) Why is tackling a problem from multiple angles important in science? What about in society? (Not all scientific strategies will work out, so pursuing a problem from multiple angles will yield a greater chance of success. The same is true for society. Also, one strategy might not be enough. Sometimes there is no silver bullet and cumulative effects are required to make a difference.)

Extend Offer students other ways to explore the content of the article as it relates to your curriculum, such as:

MAKE THAT MOLECULE

- Students studying chemistry can build ball-and-stick models of cow emissions and other greenhouse gases, such as ammonia, methane, carbon dioxide, nitrous oxide, water vapor, ozone and chlorofluorocarbons. Provide [Blackline Master #3](#) to the students for this activity.

BUILD A BIODIGESTER

- **Purpose:** Students will construct biodigesters and test their designs for effectiveness, reliability and aesthetics.
- **Prior knowledge:** Some students may have experience building mechanical devices. This expertise should be distributed to as many teams as possible.
- **Potential misconceptions:** Students may not realize how much gas can be produced by bacteria found in manure, or how long it actually takes for a quantity of gas to be produced. Students may think that biodigesters are rare or that they are only used in developing nations. There are opportunities to connect this activity to the use of biodigesters around the world (at different scales).
- **Notes to teacher:** There are a variety of variables you can have students test with this project, depending on how much time you want to devote to it. Therefore the project is divided into two sections: building the digester and using the digester. This project is well-suited for a club, science fair or other ongoing experience.

Decide whether you want students to drill holes as part of their work or prepare materials ahead of time.

- **Background:** A biodigester essentially does what the cow's stomach is doing, using bacteria stored in optimal conditions to turn organic material into methane and carbon dioxide. Methane is 25 times as efficient at trapping heat in the atmosphere as carbon dioxide, making it one of the most potent greenhouse gases. However, when burned, methane releases fewer greenhouse gases into the atmosphere than coal or oil, making it a very important source of fuel. Methane from a biodigester can be compressed to run vehicles, burned directly or used to generate electricity. This experience can be a tool for helping students understand anaerobic cycling of matter and the transformation of energy from one form into another.

There are "wet" and "dry" digesters. "Wet" digesters, which are more common, have a main compartment where liquefied manure is stored. Bacteria naturally occurring in the manure can break down organic material more quickly when it is liquefied. This liquefied manure is called slurry. The digester has an access point where pulverized food material is added to the manure mixture. Under anaerobic conditions and optimal temperature, the bacteria decompose the pulverized food, producing carbon dioxide and methane gas as a waste product. This gas rises and is trapped at the top of the closed system digester where it can be siphoned off for use. Decomposed manure and food left behind in the biodigester can be used as fertilizer.

- **Materials for building one biodigester:**

- The digester's frame:

- Two straight-sided buckets that nest with one upside down inside the other

- Food scrap input throat:

- 1 threaded fitting ($\frac{3}{4}$ inch recommended), be sure it has an o-ring for a water-tight seal
- 1 PVC elbow that fits onto the threaded fitting
- 3 feet PVC pipe that fits on the end of the PVC elbow
- Funnel to help pour pulverized food into the PVC pipe

- Fertilizer output:

- 1 threaded fitting ($\frac{1}{2}$ inch recommended), be sure it has an o-ring for a water-tight seal
- 1 foot flexible tubing (hose) that fits onto the threaded fitting
- 1 on/off in-line valve that fits the end of the hose

- Gas output:

- 1 slip fitting ($\frac{1}{2}$ inch recommended), be sure it has an o-ring for a gas-tight seal
- 1 PVC elbow ($\frac{1}{2}$ inch recommended)
- 1 to 2 feet flexible tubing (hose) that fits onto the slip fitting
- 1 on/off in-line valve to place at one end of the hose (near the elbow is recommended)
- Brass fitting that fits one end of the flexible tubing*

**The brass fitting can fit a single burner stove or a camp stove to test the amount of fuel produced. It can also be attached to a storage bladder to collect the gas.*

- Tools for construction:

- Drill with various drill bits for making holes in buckets
- Scissors
- Sealant tape or liquid

- **Materials for testing the biodigester:**

- Manure, along with a stick for stirring the manure and water mixture
- Food waste, along with a blender to pulverize the waste
- Covered buckets for the collection and transport of food waste and manure
- A ruler and permanent marker to mark how high the upside-down bucket rises as it fills with gas
- A measuring cup to quantify the input of manure, water, food scraps and output fertilizer
- A single burner stove and a timer, to test how much gas is produced

- **Procedures:**

- **Section 1: Building the biodigester**

- **Option 1**

1. Form teams and have students build their biodigesters following the directions provided ([Blackline Master #4](#)).

- **Option 2**

1. Explain what biodigesters do. Use [Blackline Master #5](#) to describe to students the essential parts of biodigesters and what each part is designed for.
2. Form teams and present the opportunity for students to design and build their own biodigesters.
3. Remind students that engineers draw out their designs and explain the reasoning for their designs.
4. You can limit student designs based on materials you make available, or allow students to bring in their own supplemental materials based on their vision.

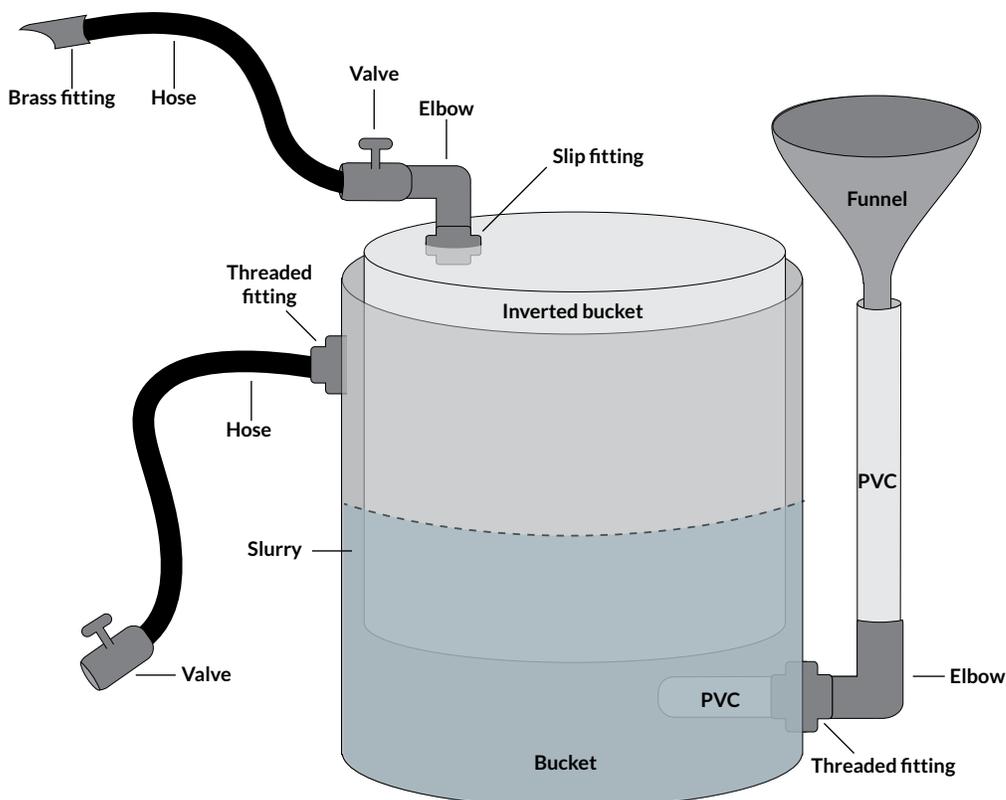
5. Give students time to draw their designs and present them to the class. Students should critique designs, offering suggestions to improve upon them.
6. When teams are ready, give them time to build their digesters.

Section 2: Using the biodigester

1. Now that students have a biodigester design, they will test it. You might want to set up a control biodigester for students to compare their results. To do this, decide on the type and quantity of manure and food inputs you will use. Decide if your biodigester will run before students do their experiments or concurrently. Measure the weight or volume of manure and pulverized food added to your biodigester for comparison.
2. Determine the variables students will test. Remember that a student can only test one variable at a time, so all other factors must be held constant: style of biodigester, type of manure, quantity of manure, type of food waste, quantity of food waste.
3. Have students decide what kind of manure to use based on what is available.
4. Decide how much water will be needed. Are students creating a wet or dry biodigester? Dry digesters take significantly longer for processing. If a wet digester, a helpful guideline is 15 liters of water for every kilogram of manure and more water for other materials.
5. Decide what type of food waste and quantity will be added to the liquefied manure (the slurry) to feed the bacteria. This will need to be pulverized to become water soluble.
6. Discuss safety issues that must be considered, including: handling of inputs (wear gloves! wash hands often!), storage of the biodigester (no spills, please!), measurement of gas production (fire safety), and so on.
7. Decide where to place the digesters for testing. They need to be kept in a warm environment to create conditions optimal for the bacteria.
8. Run tests, controlling for time. Then, measure how much fertilizer and gas is produced. Fertilizer can be measured using a measuring cup, beaker or graduated cylinder. Gas can be measured by timing how long the gas can keep a burner lit. Can students determine the amount of fertilizer and gases made (production capacity) by their biodigester design?
9. Compare and discuss results. Students should decide which biodigester design was the most successful. Conclusions may be based on cost versus fuel production, safety, reliability of production, aesthetics of the digester, environmental impact, and so on.

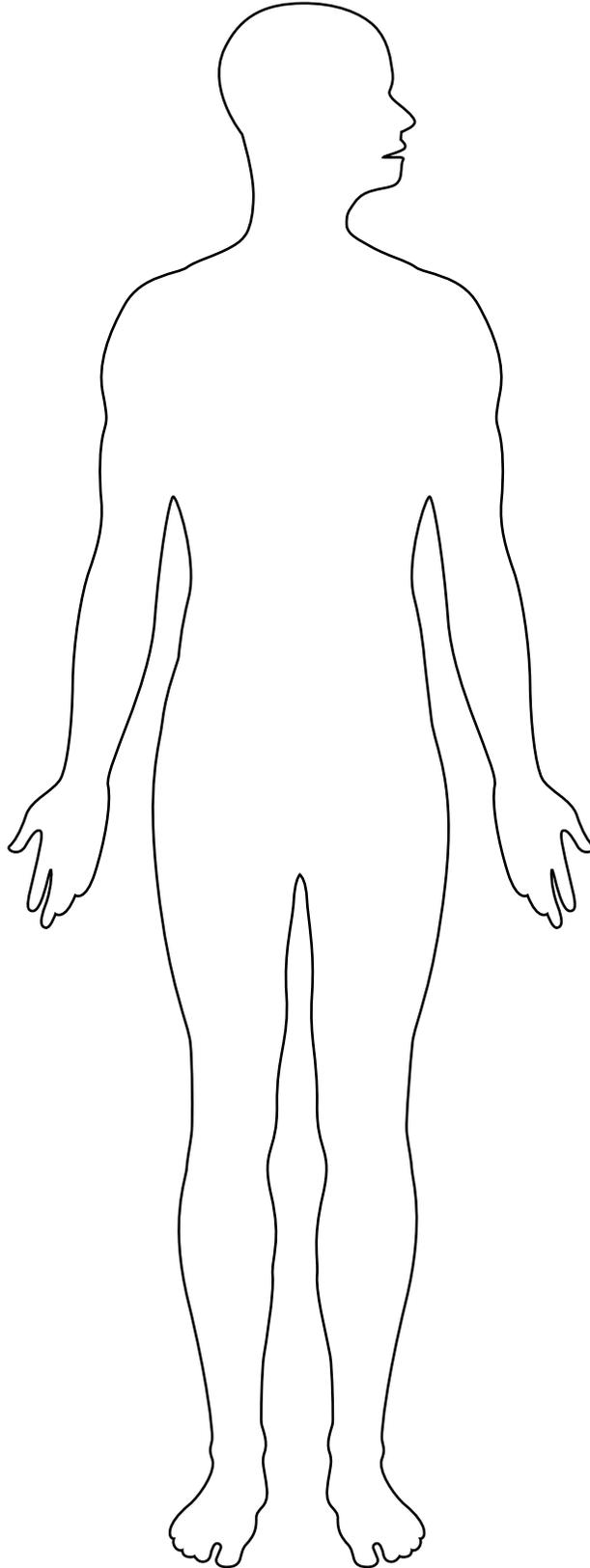
Extension: Students can research the benefits of using a biodigester (*produces biogas, a renewable resource that can replace fossil fuels; can offset farm-based costs including heat and, if powering a generator, electricity production; can reduce the cost of waste disposal*).

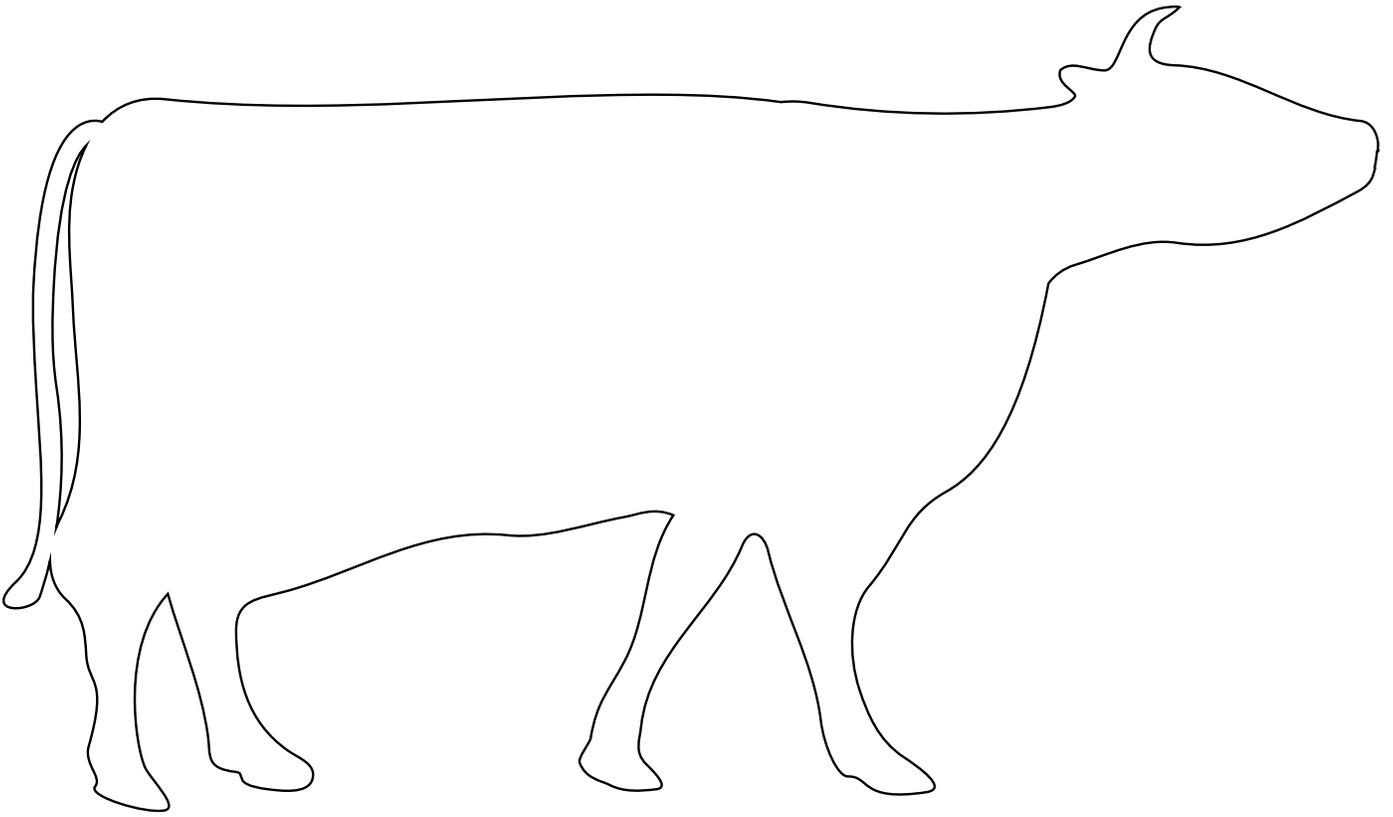
This exercise was inspired by an [online YouTube guide for making a mini-biodigester](#) and a guide from the [Saskatchewan Research Council](#).



Digestive Systems

Directions: Do you know the parts of your digestive system? What about a cow's digestive system? Draw what you know and label the parts:





1. How are humans' and cows' digestive systems similar?

2. How are they different?

Comprehend

After reading the article "Greener Cows," answer these questions:

1. What is the main topic of the article?
2. How do cows produce methane?
3. Why is methane production of particular concern to scientists and farmers?
4. What are some ways scientists are exploring to reduce methane emissions from cows?
5. Why would the U.S. government like to see more farms using digesters?

Make that Molecule

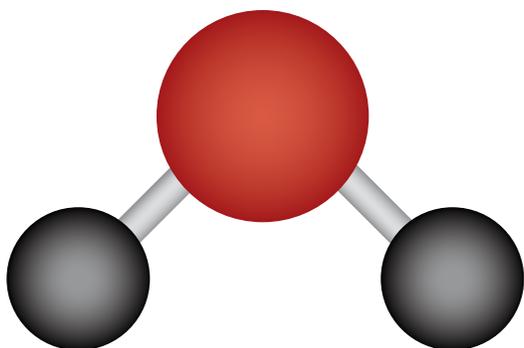
Materials:

Molecular model set including colored balls, springs and sticks

Directions:

Often scientists build models so that they can see the structure of a molecule and compare it with other molecules.

The most significant greenhouse gas is water vapor, accounting for about 95% of Earth's greenhouse effect. Water, H_2O , can be built by connecting an oxygen atom with two hydrogen atoms. Your finished model should look like this:



Use the formulas provided to create models of the following greenhouse gases:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)

Cows create ammonia as well as methane. How would you make ammonia (NH_3)?

Extension: There are a variety of chlorofluorocarbons that also act as greenhouse gases. Look up a few and see if you can build them.

Build a Biodigester

PROCEDURES:

■ Create the food scrap input throat.

1. Drill a hole about an inch above the base of the larger bucket the correct size for your fitting ($\frac{3}{4}$ inch recommended).
2. Place your fitting into the hole with the o-ring on the inside for a water-tight seal.
3. Attach a length of PVC so that the PVC reaches into the center of the bucket.
4. To the outer side of the fitting, attach an elbow and a longer piece of PVC that reaches to or above the top of the bucket (about 2 feet, depending on the size of the bucket). When you want to add pulverized food waste to your biodigester, place the funnel on top of this PVC and pour it in.

■ Create the fertilizer output.

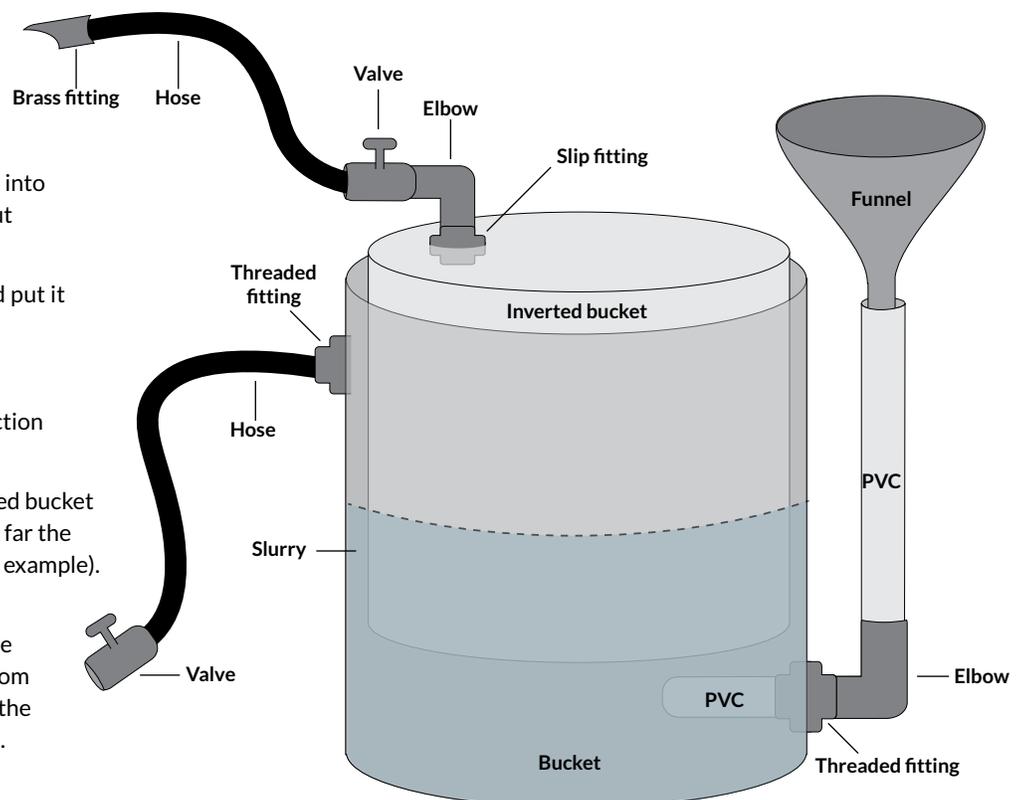
1. Drill a hole about an inch from the top of the larger bucket (used above) the correct size for your fitting ($\frac{1}{2}$ inch recommended).
2. Place your fitting into the hole with the o-ring on the inside for a water-tight seal.
3. Attach a length of hose to the fitting. You might want to use a sealant for a water-tight connection.
4. At the end of the hose, attach a valve that can be turned off and on. This is where your fertilizer will leave the system.

■ Create the gas collection bucket and output.

1. Drill a hole in the bottom of the bucket the correct size for your fitting ($\frac{1}{2}$ inch recommended).
2. Place your fitting into the hole with the o-ring on the inside for a gas-tight seal.
3. Attach an elbow, a valve and hose to the fitting in line. Decide if you want to attach a brass barb connector (direct connection to a single-burner stove) or some other type of fitting for gas storage (you can store the gas in a rubber bladder, like a tire).

OPERATE YOUR BIODIGESTER:

1. Place your manure with water in the bottom of the larger bucket, under the horizontal PVC.
2. Pulverize your food waste and insert it into the bucket through the food scrap input throat.
3. Flip over the gas collection bucket and put it in place.
4. Make sure all valves are closed.
5. Because gas is produced, the gas collection bucket will rise.
6. You can mark the outside of the inverted bucket with a permanent marker to track how far the bucket rises (an inch every 6 hours, for example).
7. When you are ready to collect or use the gas, open the valve on the top of the overturned bucket to siphon the gas from the biodigester. As the gas is released, the overturned bucket will sink back down.



Build a Biodigester

1. Find out what a biodigester does. Your teacher may provide notes or you can do your own research.
2. The biodigester needs a container that can form an air-tight seal. It will hold liquefied manure and food scraps, which will take up some space in your container. Decide on the type of container you will use and how full you will load your biodigester. Draw a picture of your container and mark how full you will load it.
3. When in operation, you do not want to open your biodigester in order to add pulverized food. How will you get the food into the digester? Add your idea to your drawing. Label the parts you plan to use to build this portion of the biodigester.
4. As the bacteria in the manure break down the pulverized food, the waste product of this process is methane and carbon dioxide. Gas rises. How will you collect the gas from your biodigester, siphon it off and store it for use? Add your idea to your drawing. Label the parts you plan to use to build this part of the digester.
5. Decayed organic matter will build up in your biodigester. This can be siphoned off as fertilizer to help your bacteria stay healthy and have room to keep producing gases. How will you siphon off the fertilizer from the manure and pulverized food? Add your ideas to your drawing. Label the parts you plan to use to build this part of the digester.
6. Make a complete list of the parts you will need to build your digester.
7. Scientists and engineers present their ideas to look for weaknesses and missed opportunities. Share your design with other teams and your teacher for critical feedback. Revise your plan based on the feedback you receive. Think about how you will know if your design is effective and efficient. Look for potential weak spots in your design and improve them. Now redraw your final biodigester design.
8. Once you have your teacher's approval, start building!

Initial Biodigester Design

Parts List #1

Revised Biodigester Design

Parts List #2