ChemMatters

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Teacher's Guide for

From Waste to Energy … Thanks to Methane

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About the Guide

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Student Questions

1. What additional ingredient is needed to convert a mixture of waste food and animal dung into methane gas?
2. What does anaerobic mean?
3. What is the difference between methane and biogas?
4. What are the three main chemical groups found in biological waste (food, sewage, dung)?
5. What smaller molecules are produced by hydrolysis of the larger molecules of carbohydrates, proteins and fats?
6. Why is burning biogas better than burning fossil fuels?
7. What are two advantages of using methane gas for cooking (indoors) in Nigeria?
8. In India, what benefits have come from using public toilets connected to biogas generators?
9. How has the modern Swedish city of Kristianstad reversed its dependence on purchasing natural gas and oil from the Middle East and Norway in the last 20 years?
10. For what purposes is methane used in Kristianstad that are different compared with Lagos, Nigeria?

Answers to Student Questions

1. **What additional ingredient is needed to convert the mixture of waste food and animal dung into methane gas?**
   You need to add bacteria such as those found in the soil.
2. **What does anaerobic mean?**
   Anaerobic means "without oxygen".
3. **What is the difference between methane and biogas?**
   Biogas is a mixture of gases that includes methane, along with carbon dioxide, hydrogen sulfide and nitrogen.
4. **What are the three main chemical groups found in biological waste (i.e., food, sewage, dung)?**
   The main chemical groups found in biological waste are proteins, carbohydrates, and fats.
5. **What smaller molecules are produced by hydrolysis of the larger molecules of carbohydrates, proteins and fats?**
   The smaller molecules that are produced include amino acids, simple sugars, and fatty acids.
6. **What are two advantage of using methane gas for cooking (indoors) in Nigeria?**
   The advantages of using methane for indoor cooking are that
   a. methane replaces wood which is often in short supply, and
   b. methane reduces indoor air pollution, a major problem when burning wood.
7. **Why is burning biogas better than burning fossil fuels?**
   It is better to burn biogas than fossil fuels because the burning of biogas is carbon-neutral, meaning that burning it does not add to the amount of carbon dioxide already in the atmosphere, hence <u>not</u> adding to the amount of greenhouse gases and thus <u>not</u> having a negative effect on global warming.
8. **In India, what benefits have come from using public toilets connected to biogas generators?**
   When available, a public toilet prevents people from relieving themselves in public which spreads disease-causing germs. Perhaps more importantly, it also allows for generating electricity.
9. **How has the modern Swedish city of Kristianstad reversed its dependence on purchasing natural gas and oil from the Middle East and Norway in the last 20 years?**
   The city generates biogas to power its municipal cars, buses and trucks. It is also used to generate electricity. The city also uses the fuel to heat its municipal buildings.
10. **For what purposes is methane used in Kristianstad that are different compared with Lagos, Nigeria?**
    Lagos developed a sanitation plan to prevent primarily human waste from getting into the local drinking water. The waste was directed into household methane generators reducing a health hazard while generating usable methane gas. The city of Kristianstad generates methane gas from a variety of sources for the purpose of fueling vehicles and heating buildings to minimize their dependence on outside sources of fossil fuels, rather than protecting drinking water.
    Besides chemical processes, mechanical processes are also involved in cleaning. Clothes must be agitated to expose the stains to surfactants and water. Heat is also almost essential to cleaning. Besides its effect of speeding up chemical reactions in the washing machine, it also increases the solubility of both detergent in the water and stains from clothing.

Anticipation Guide

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

Directions: *Before reading*, in the first column, write "A" or "D," indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Today, methane produced from food waste, human sewage, and animal dung is being used for energy in homes and buildings.
		2. Biogas contains mostly methane, carbon dioxide, and hydrogen.
		3. Burning methane produces carbon dioxide and water.
		4. Producing methane from food scraps is carbon-neutral.
		5. Most disease-causing bacteria are anaerobic, meaning they do not require oxygen.
		6. Methane has less density than carbon dioxide.
		7. Wood smoke pollutes the air less than products produced from burning methane.
		8. In India, families have their own toilet-biogas units which produce methane.
		9. A city in Sweden uses biogas for municipal cars, buses, trucks, and to heat its buildings.
		10. Currently, no landfills in the United States collect methane for energy.

Reading Strategies

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Teaching Strategies:

1. Links to **Common Core Standards for writing**:
    a. Ask students to defend their position on sustainable choices, using information from the articles.
    b. Ask students to revise one of the articles in this issue to explain the information to a person who has not taken chemistry. Students should provide evidence from the article or other references to support their position.

2. **Vocabulary** that is reinforced in this issue:

- Emulsion and emulsifiers
- Coalescence
- Green chemistry
- Joule
- Allotrope
- Hydrolysis
- Fermentation

3. To help students engage with the text, ask students what **questions** they still have about the articles. The articles about green chemistry ("Going the Distance: Searching for Sustainable Shoes" and "It's Not Easy Being Green—Or Is It?") may challenge students' beliefs about sustainability.

***Directions*:** As you read, use your own words to describe how biogas is being produced and used in different places around the world.

	Source of waste	**Special equipment needed**	**Uses for biogas**
Nigeria			
India			
Sweden			
Future			

Background Information (teacher information)

More on methane generation in landfills

Methane generation around the world has different sources as well as uses. A short history about methane generation includes the following:

> Scientific interest in the manufacturing of gas produced by the natural decomposition of organic matter was first reported in the 17th century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes. In 1808, Sir Humphry Davy determined that methane was present in the gases produced by cattle manure. The first anaerobic digester was built by a leper colony in Bombay, India, in 1859. In 1895, the technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting. Also in England, in 1904, the first dual-purpose tank for both sedimentation and sludge treatment was installed in Hampton. In 1907, in Germany, a patent was issued for the Imhoff tank, an early form of digester."
> (Source: http://en.wikipedia.org/wiki/Anaerobic_digestion)

In the United States, methane generation is done not only at landfills but also in various agricultural settings, including small livestock holdings, as well as large, commercial cattle feedlots. There are some 150 active biodigesters producing methane gas at various livestock operations both large and small. The EPA estimates that there are some 8000 additional sites that could be outfitted to produce methane gas.

There are some 600 active landfill sites that generate an estimated 500 billion cubic feet of methane per year. There is actually a computer-based software tool available from the Environmental Protection Agency (EPA) for estimating the amount of various gases that might be emitted from a landfill. It is called the Landfill Gas Emissions Model (see http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf). This number of active landfills is in contrast to what the *ChemMatter*'s author said, that "In the United States collecting methane and converting it into energy is relatively rare…".This energy production offsets almost 2 million tons of coal per year. There are other sources for collecting methane gas generated from the anaerobic decomposition of animal waste at farms and cattle feedlots. There is a very useful map of the USA showing how many methane generators are in operation as well as the number of potential sites for development. Refer to page16 of the pdf at http://epa.gov/lmop/documents/pdfs/overview.pdf.

Although there are some 600 landfills currently generating methane gas, there is the potential to develop another 400. The important reason for setting up a land fill to collect methane gas is to prevent the methane gas, normally generated in a landfill, from escaping into the atmosphere. Methane is a greenhouse gas that is 20 times more effective than carbon dioxide in absorbing infrared radiation that is responsible for the heating effect in the atmosphere (global warming). Another benefit to the environment is that fact that using methane gas offsets the use of non-renewable energy sources such as coal and oil which in turn reduces the amount of gaseous emissions of sulfur dioxide, nitrogen oxide compounds, particulate matter, and carbon dioxide (particularly when using coal). Besides performing this preventive exercise, there are obvious financial benefits in the commercial use of the captured gas for generating electricity (for 1.2 million homes), providing a heating source (for 750 thousand homes), powering vehicles, and as a stock material for synthesizing a variety of chemicals including ethanol (rather than using fermentation of corn).

Several issues about landfill natural gas generation include startup costs, the lifespan of a landfill, and several environmental issues including leaking liners for the landfill and whether or not heavy metals and other toxins can escape into the atmosphere. But some well known companies are making use of landfill-generated methane to power their operations. In the case of Microsoft, they have deliberately built a new facility near to a landfill for methane acquisition. In this particular case, they are also being very innovative because they are using the methane to power fuel cells for electricity generation rather than channeling the gas through an electric turbine for power generation. Another company, SC Johnson in Racine Wisconsin, is also using methane from a landfill to generate electricity to power up their plant operation. The United States Environmental Protection Agency (EPA) is actively promoting the use of landfill-generated methane (LFGM) for industrial use. Their Web site (http://www.epa.gov/lmop/projects-candidates/index.html) provides information to interested commercial operations who want to use LFNM. At this site you can find a map of the USA that shows the number of LFGM sites currently in operation and how many more potential sites exist.

More on biochemical activity in landfills

The biological and chemical activity in a landfill is well documented in terms of the expected outcomes for the final degradation products. Interaction between different types of bacteria and their physical/chemical environments is explained below.

The Four Phases of Bacterial Decomposition of Landfill Waste
Bacteria decompose landfill waste in four phases. The composition of the gas produced changes with each of the four phases of decomposition. Landfills often accept waste over a 20- to 30-year period, so waste in a landfill may be undergoing several phases of decomposition at once. This means that older waste in one area might be in a different phase of decomposition than more recently buried waste in another area. **Phase I** During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried. **Phase II** Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the land-fill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow

introduced into the landfill, microbial processes will return to Phase I.

Phase III
Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane-and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

Phase IV
Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill (Crawford and Smith 1985). Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

(http://www.atsdr.cdc.gov/HAC/landfill/html/ch2.html)

The various conditions that affect bacterial and chemical activity in a landfill include the following:

- Waste composition. The more organic waste present in a landfill, the more landfill gas (e.g., carbon dioxide, methane, nitrogen, and hydrogen sulfide) is produced by the bacteria during decomposition. The more chemicals disposed of in the landfill, the more likely NMOCs and other gases will be produced either through volatilization or chemical reactions.
- Age of refuse. Generally, more recently buried waste (i.e., waste buried less than 10 years) produces more landfill gas through bacterial decomposition, volatilization, and chemical reactions than does older waste (buried more than 10 years). Peak gas production usually occurs from 5 to 7 years after the waste is buried.
- Presence of oxygen in the landfill. Methane will be produced only when oxygen is no longer present in the landfill.
- Moisture content. The presence of moisture (unsaturated conditions) in a landfill increases gas production because it encourages bacterial decomposition. Moisture may also promote chemical reactions that produce gases.
- Temperature. As the landfill's temperature rises, bacterial activity increases, resulting in increased gas production. Increased temperature may also increase rates of volatilization and chemical reactions. The box on the following page provides more detailed information about how these variables affect the rate and volume of landfill gas production.
(http://www.atsdr.cdc.gov/HAC/landfill/html/ch2.html

The chemical equation for the production of methane by bacteria is:

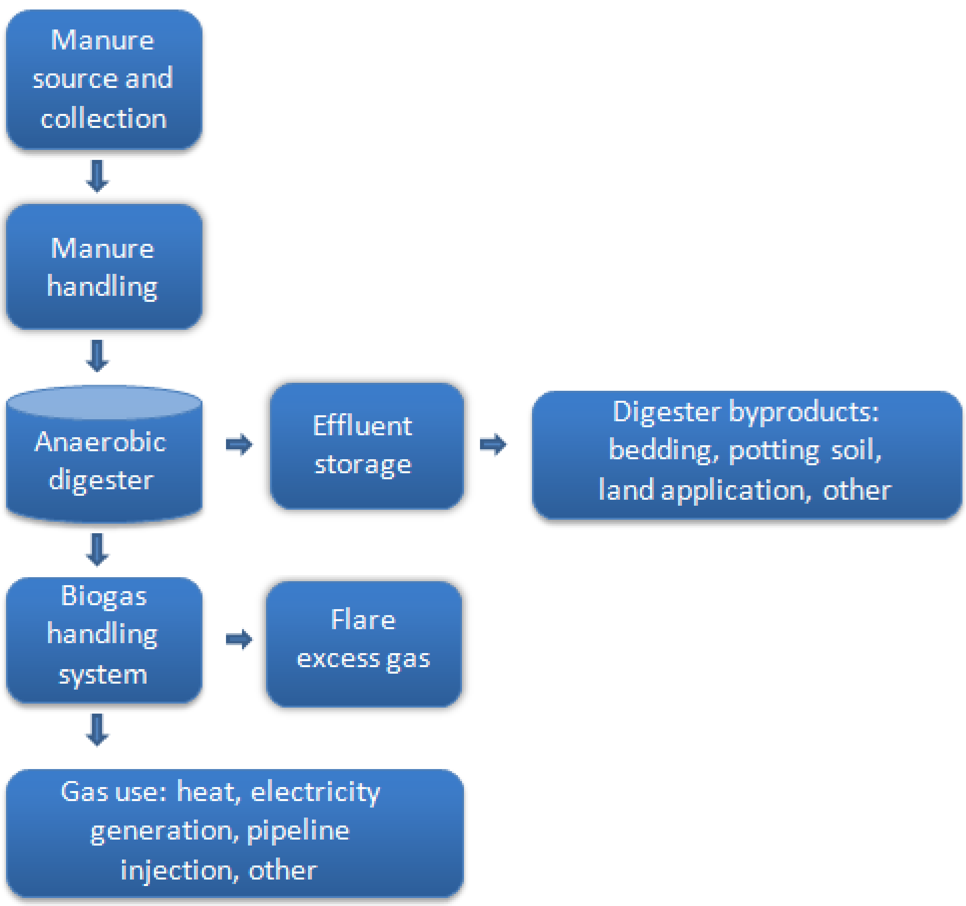
$$CO_2\,(g) + 4H_2\,(g) \rightarrow CH_4\,(g) + 2\,H_2O$$

The bacteria are using this biochemical reaction to generate energy through electron transfer that occurs in the production of the chemical, adenosine triphosphate (ATP). The carbon dioxide is the oxidizing agent and the hydrogen is the reducing agent. The hydrogen is the “waste” end product from the metabolism of other heterotrophic microorganisms. Heterotrophic bacteria chemically change carbon-containing compounds into water and carbon dioxide, an energy-generating process for the bacteria. Both the carbon dioxide and hydrogen are then available in the environment for the bacteria that generate methane.

(Note: The methane-generating bacteria are not considered bacteria, technically speaking. They belong to the domain, archaea, which are considered to be ancient life forms that evolved separately from bacteria and blue-green algae. Sometimes they are referred to as Archaea methanogens.)

More on anaerobic digesters (methane) for livestock excrement

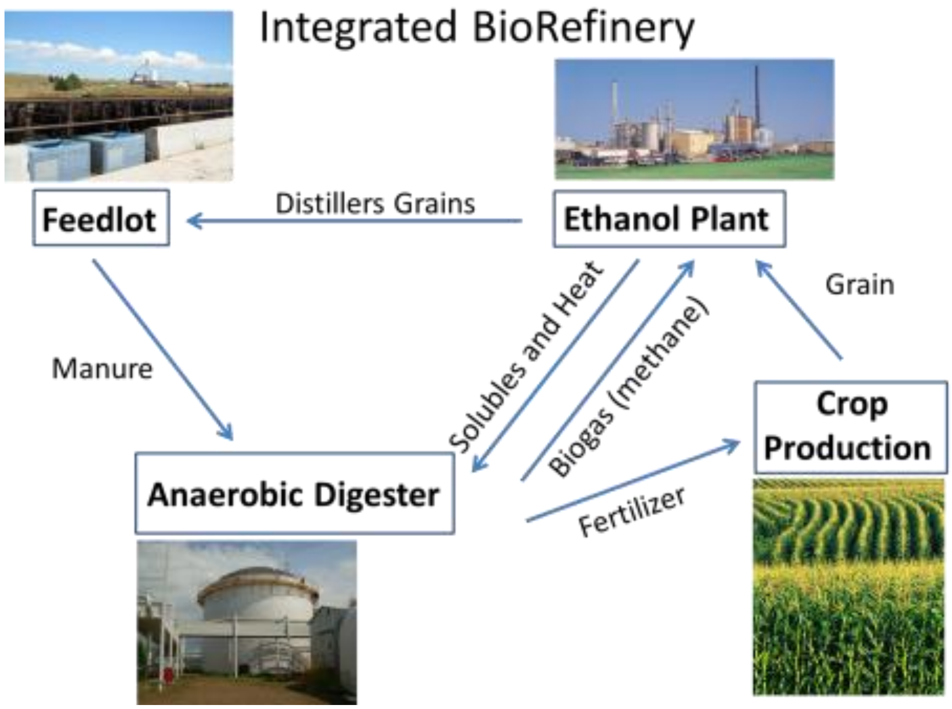
In the United States, there are productive methane generators using the excrement of various types of livestock including beef and dairy cattle, swine, and poultry. The methane produced is used on site for electricity and heat production needed in various aspects of a farm operation. Large livestock feedlots generate enough methane for electricity production to be self-sufficient in electrical usage.



(http://www.epa.gov/agstar/anaerobic/ad101/index.html)

From analysis, it is felt that the residue left over in a biodigester contains organic material that is actually of higher nutritive content for fertilizer use than the original animal dung.

A good example of an integrated approach (called a closed loop system) for a manure-based biodigester generates methane for heat and electricity to power an ethanol production plant. In this the setup, the ethanol plant uses locally grown corn crops to produce the alcohol through fermentation. The fermentation tanks are kept at an optimum temperature through heating, using some of the methane gas produced by the bio digester. The biodigester utilizes the manure gathered from cattle feedlots in the area. And the cattle feed includes the spent distillers' grains left over from the ethanol fermentation tanks.



(http://www.extension.org/pages/67633/anaerobic-digestion-of-finishing-cattle-manure#.Up4rNCeZcx4)

More on biodigesters for local (home) use

Both India and China have actively promoted the use of biodigesters for home use for well over thirty years. Consequently they have had much experience in modifying the design of these permanently installed devices. One of the important concepts behind the efficient operation of the biodigester is to have the proper ratio of a nitrogen-to-carbon mix. When the fermentation rate decreases (other than due to too low an operating temperature), operators are advised to alter the N:C ratio of 1:30. Usually the system has too high a nitrogen content (primarily from excrement) which can be modified by adding a carbon source such as plant material—in particular, plant stalks and leaves. The addition of something like grass is a good choice.

In China, government programs to promote the use of biodigesters in rural areas have been successful because the poor people recognized the economic value of producing usable energy as well as fertilizer from the compost. Figures for 2006 show some 22,600 biogas tanks supplying 30,000 households in more than 3,100 villages in the province of Guangxi. For the town of Fada in that province farmers have been freed from having to spend a lot of their time collecting firewood which allows them to be more productive on their farms. It is estimated that some 56,600 tons of firewood can be saved each year. And agriculture production has increased—tea production has gone from 400 kilograms to 2,500 kilograms per day. Average income has quadrupled from 26 US cents to US $1.00. The poverty line in this area is 26 US cents per day. More information on China's biogas projects can be found at http://www.ruralpovertyportal.org/country/voice/tags/china/biogas. Several videos that show villages in China involved in biogas projects can be found at http://www.youtube.com/watch?v=sfHZJ6w77Io and http://www.youtube.com/watch?v=bCRps9Jnwbk.

In the U.S., the most likely place to find local methane generators utilizing animal dung is on farms. The states of New York and Vermont are actively promoting such projects to supplement the source of methane gas (as opposed to fracking operations) for utility usage (generating electricity). These farms, most often dairy farms, use the methane for both heat and electricity to run all aspects of the farm operation. Some of the heat is used to keep the biodigester at an optimum operating temperature, particularly in the winter time. Excess electricity is sent out into the electric grid in general, but also to local residents who pay the farmer for the utility. According to the New York project Summit attendees set a 2020 goal that 40 percent of all manure from New York dairy farms goes through the anaerobic digestion process, which captures methane from manure and generates clean, renewable energy. The energy produced from this effort could power 32,000 homes while strengthening the economic vitality of New York's dairy farms. It also would reduce New York's greenhouse gas emissions by 500,000 metric tons of carbon, equivalent to taking 100,000 cars off the road. This project is modeled after the Vermont Cow Power project. Information about this project, including a PBS video shot at one of the participating dairy farms, can be found at http://www.greenmountainpower.com/innovative/cow/how-it-works/.

Another agricultural application of a biodigester is increasingly found on pig farms, particularly those large "factory" farms that produce very large volumes of manure that is routinely flushed into outdoor open lagoons. These lagoons often represent an improperly managed resource. If you have ever been near a pig farm, you know the very unpleasant odors associated with the operation. Further, these open lagoons obviously emit plenty of methane gas, a wasted resource. They are also subject to overflow during heavy rainfalls. The overflow does pollute local streams and rivers, which can damage their ecosystems. There have been major lawsuits in recent years brought on by local residents as well as government entities because of the air and water pollution problems. Utilizing large scale biodigesters not only eliminates the aforementioned problems but generates the methane gas which can, once again, reduce operating costs for energy, both in terms of heat and electricity. Further, the remaining product from the digester is an excellent fertilizer. It can also be used for animal bedding because it is essentially odorless. For pig producers not to use a biodigester is to ignore an important financial asset for the farm operation. A Web site (http://www.biogas-energy.com/site/pig.html) for a commercial developer of biogas generators for pig operations explains all about the value and application of digester equipment.

For the other probable location for agricultural biodigesters, look to large scale feed lots. One interesting example of an integrated operation is in Hereford, Texas. Hereford is known as the cattle capital of the world with more than one million head of cattle and 100,000 dairy cows located within a 100 mile radius of the town. The area is supplying a new ethanol plant with fuel in the form of manure from the cattle feed yards, eliminating the need to burn natural gas. The projected energy savings are equivalent to 1,000 barrels of oil PER DAY, with transportation costs also reduced. The facility is also making use of gray water from the city wastewater facility.

In Texas, large feedlots for livestock have created economic opportunity in the agribusiness. Hogs, beef and dairy cattle, along with poultry, are often fed in close proximity to maximize efficient production and keep costs low. By processing the manure into fuel and a residual product that can be used as fertilizer, among other things, many environmental issues are addressed, including the release of a variety of odors and greenhouse gases such as methane and carbon dioxide along with nitrous oxides, and ammonia. With manure not spread over the landscape, additional environmental problems are eliminated including the uncontrolled runoff of phosphorus and nitrates, known chemicals that can damage a water ecosystem.

More on environmental hazards of landfill-generated natural gas

> Landfill gas is the single largest source of man-made methane emissions in the United States, contributing to almost 40% of methane emissions each year (EPA 1996). Consequently, a growing trend at landfills across the country is to use recovered methane gas from landfills as an energy source. Collecting landfill gas for energy use greatly reduces the risk of explosions, provides financial benefits for the community, conserves other energy resources, and potentially reduces the risk of global climate change.
>
> (http://www.atsdr.cdc.gov/hac/landfill/html/ch5.html)

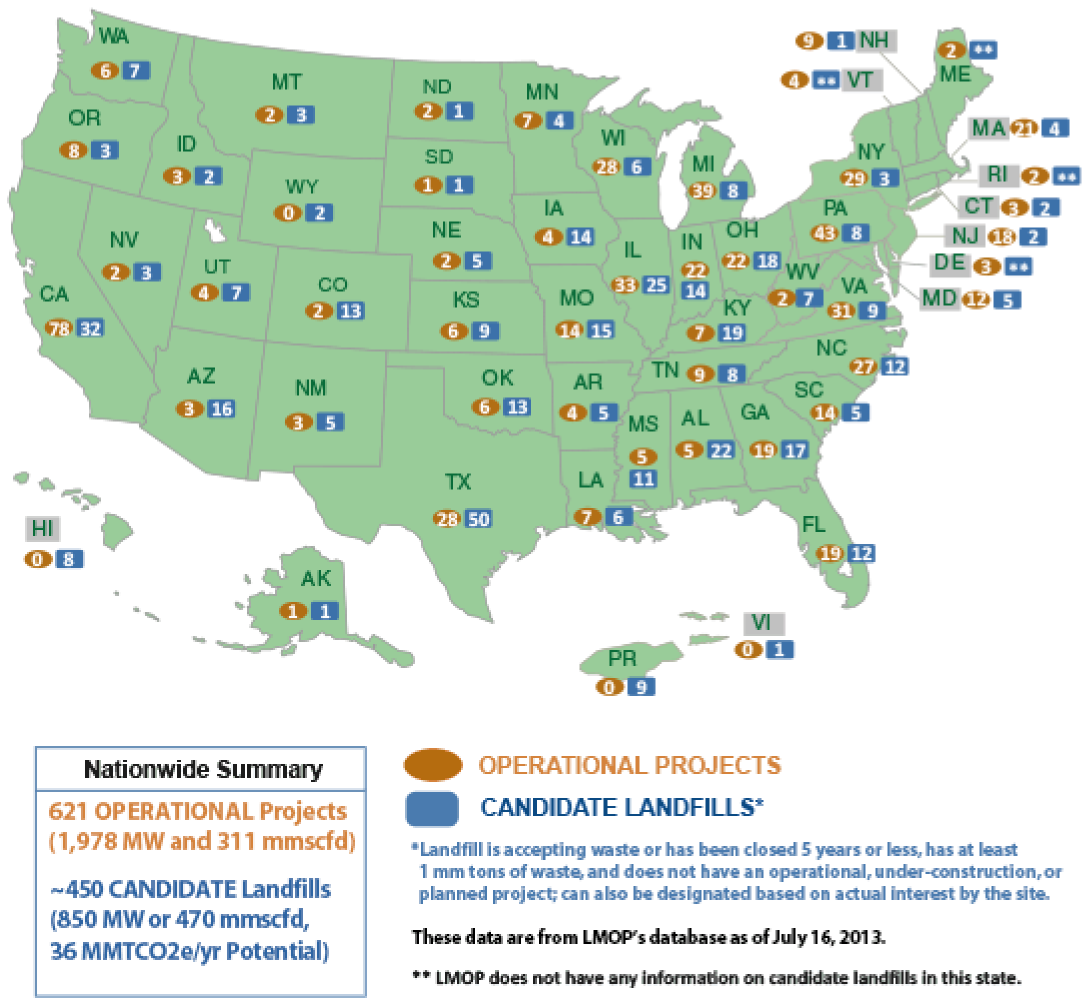
According to an organization called the Energy Justice Network, there are some potential hazards associated with the use of methane gas generated by landfills. Besides the obvious gases of methane, carbon dioxide, varying amounts of nitrogen, oxygen, water vapor, and sulfur compounds, there are also a variety of other contaminants such as mercury and radioactive compounds such as tritium found in the gas mixture. There is also concern for halogenated hydrocarbons being produced in landfills. This type of hydrocarbon is potentially carcinogenic. The organization raises a number of questions about the safety (environmental and health-related) of burning landfill gas (LG). These questions contain a variety of answers that have a “scientific-looking” context. They are worth considering—see http://www.energyjustice.net/lfg and the included reference, “*Primer on Landfill Gas as Green Energy”.* For example, although non-methane organic compounds make up only about 1% of the landfill gases, they include such toxic chemicals as benzene, toluene, chloroform, vinyl chloride, carbon tetrachloride, and 1,1,1 trichloroethane. At least 41 of these are halogenated compounds.

Many others are non-halogenated toxic chemicals. If these halogenated compounds are later burned in the presence of hydrocarbons, they can recombine into highly toxic compounds such as dioxins and furans, some of the most toxic chemicals ever studied. Burning at high temperatures doesn't solve the problem, as dioxins are formed at low temperatures and can be formed as the gases are cooling down after the combustion process. The Energy Justice Network paper provides technology options if one is going to use landfill gases as fuel, given some of the potential hazards when burning this toxic gas mixture. This study is also presented in a very detailed, data-laden PowerPoint (www.energyjustice.net/files/lfg/landfilgas.ppt) that could be used in the classroom.

A government-produced document (http://www.atsdr.cdc.gov/hac/landfill/html/ch5.html) from the Centers for Disease Control and Prevention (CDC) (in the 1990s, no longer maintained) corroborates some of the concerns expressed by the Energy Justice Network above. There are specific admonitions when extracting landfill gas as a fuel. Some of the chapters in the document include:

- Landfill Gas Basics
- Landfill Gas Safety and Health Issues
- Monitoring of Landfill Gases
- Landfill Gas Control Measures

Both the realized and the potential landfill-generated methane gas sites are shown in the map below. As one can see, there still remain more opportunities for reducing the amount of methane that escapes into the atmosphere to become a greenhouse gas, as well as the obvious economic benefit of tapping this gas source as a fuel for vehicle propulsion (municipal vehicles) and usable heat in a variety of applications including public heating and electricity generation.



(*http://www.epa.gov/lmop/index.html*)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Energy production/use**—The whole story of biogas and methane revolves around man's need for energy and his ability to find alternate sources.
2. **Anaerobic biological activity and energy conversion**—This biochemical condition that operates in the absence of oxygen restricts what particular microorganisms, primarily bacteria and fungi, can still be involved in energy transfer and what products are produced. Anaerobic biological activity (fermentation, methanogenesis) is less efficient as an energy conversion process than the aerobic process found in respiration.
3. **Combustion—**It is the burning of biogas and methane that produces the energy people need in all these locations within the article.
4. **Organic chemistry—**The world of carbon is particularly important in the biological realm. The biochemical activities in such processes as respiration, anaerobic decay, and photosynthesis recycle carbon while generating chemical potential energy. Methane production is an oxidation reduction process that captures the energy from electron transfer in the formation of an important organic compound, adenosine triphosphate (ATP) in the anaerobic bacteria responsible for generating methane gas.
5. **Hydrolysis**—This is one of four steps in the process of anaerobic decay. In this step, complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical bonds between the substances. The other processes that follow include fermentation (or acidogenesis) in which carbohydrates are decomposed by enzymes, bacteria, and yeasts in the absence of oxygen. These fermentation products are converted into acetate, hydrogen and carbon dioxide by acetogenic bacteria. Finally, a methane-producing process (methanogenesis) by specific bacteria utilizes the acetate, hydrogen, and carbon dioxide to form the methane.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"Methane gas from landfills has a distinct and unpleasant odor."** *Pure methane gas is actually odorless. The odors from a landfill are from other gases such as hydrogen sulfide. Because methane gas is odorless, gas-providing companies add an odorant to the gas (especially, in this country, "natural" gas is primarily methane) so that a leak in a house or public area can be noticed and dealt with before an explosion might occur. In chemical terms, the odorant is a mercaptan or methanethiol, a chemical family that includes several chemical compounds found in a skunk's spray.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **"Isn't the production of methane gas a dangerous household activity?"** *Since the gas is usually generated in a biogas generator that maintains a positive pressure due to the presence of the gas (and sometimes, a floating cover), it would exit the gas tank (going from*

higher pressure to lower pressure outside) to be ignited. The ignited gas would not back up into the biogas generator tank because of the gas pressure difference. You can show the same thing with a gas jet in the chemistry lab—igniting the escaping gas does not produce an explosion. The other reason it can't explode inside the tank is because there is no oxygen in the tank. Combustion (even rapid combustion, as in an explosion), requires oxygen. So burning can only occur outside the tank, as the gas exits the tank.

2. **"Carbon dioxide doesn't burn or support combustion, so does it need to be separated out from the mixture with methane gas produced in home biogas generators before the methane is used as a fuel? If so, how is that done?"** *Carbon dioxide gas is more soluble in the water solution of the biogas generator than the methane gas, although the amount that dissolves may not be significant. Even so, the carbon dioxide that remains does not have to be separated from the methane gas since it does not lower the BTU value of the methane enough to make it unusable. Pure methane has a value of about 1000 BTUs per 1 cubic foot of gas; a methane/carbon dioxide mix has a value of 600 BTUs per cubic foot of gas. In addition to all this, the article mentions that the lower density of methane compared to carbon dioxide (16:44) results in the two gases separating, and the (mostly) methane is removed for burning through the pipe at the top of the septic tank.*
3. **"Is exposure to the bacteria involved in biogas production dangerous or unhealthy?"** *Actually, any pathogenic bacteria in the biogas unit (or biodigester) can be killed by the fact that many of these bacteria require oxygen to survive, and oxygen is not present in the anaerobic conditions for methane production. This lack of oxygen is the main killer of the pathogenic bacteria. And depending on the physical setup (insulation) and the composition of the fermenting biomass, temperatures can sometimes rise above 40 ^oC, which can also kill some of the pathogenic bacteria. Some biogas generators are actually provided with heat to maximize the preferred operating temperature of the methane-generating (methanogenic) bacteria. In the mix of methanogenic bacteria, some of them are more resistant to the negative effects of higher temperatures (above 37 ^oC) than pathogenic bacteria.*

In-Class Activities (lesson ideas, including labs & demonstrations)

1. Under teacher supervision, students can construct a biogas generator. A reference for instructions on the construction and operation of a biogas generator can be found at http://www.nrel.gov/education/pdfs/educational_resources/middle_school/biogas_generator.pdf.
2. A second set of lesson plans and instructions for building a biogas generator are found at http://www.re-energy.ca/biogas-generator/.
3. Selected slides from the 45-slide pdf document "An Overview of Landfill Gas Energy in the United States" from the EPA could be used in class to discuss how landfills are both reducing the amount of the greenhouse gas methane going into the atmosphere, and using methane from the landfills to serve as an energy source: http://epa.gov/lmop/documents/pdfs/overview.pdf.
4. A fun demonstration that always catches the students' interest (and requests for repeat performances later in the year!) is to bubble methane gas through a soapy water solution, producing soap bubbles filled with methane gas that float into the air. They can be safely ignited before they reach the ceiling. A simple but effective "lighter" is made from a meter stick with a lit candle on one end. You can control the size of the bubbles by the speed with which the methane gas is bubbled through the water container. An approach that shows the

setup for generating methane bubbles is found in a video produced by Flinn Scientific in which the demonstrator, Bob Becker (well known for innovative demos and lab activities), shows how to produce a tall column of small methane bubbles that looks like an undulating snake, hence the term “methane mamba”. Refer to the video at http://elearning.flinnsci.com/StandalonePlayer.aspx?vid=EL1618.flv . A printed lab protocol for generating methane bubbles, including a diagram of the setup that is worth referencing is found at http://www.nce-mstl.ie/_fileupload/Science%20resources/Chemistry%20resources/Class%20Activity-%20Methane%20Mamba.pdf .

5. You can use a virtual experiment (a simulation) online at the *Virtual Chemistry* Web site, http://www.chm.davidson.edu/vce/Calorimetry/HeatOFCombustionOfMethane.html, to have students calculate the heat of combustion of methane. This version requires students to include the calorimeter constant and heat produced by the ignition wire, so it is slightly more complex than the typical heat of combustion of candle wax experiment.
6. If you’re really careful (Safety first, remember?), you can do a demonstration to show the explosiveness of methane in a paint can. The directions can be found here: http://www.csun.edu/scied/4-discrpeant-event/schuster/. And if you don’t want to risk actually doing the demonstration, you can simply show students the 5-second video clip of the explosion the experimenter recorded to show on the site.

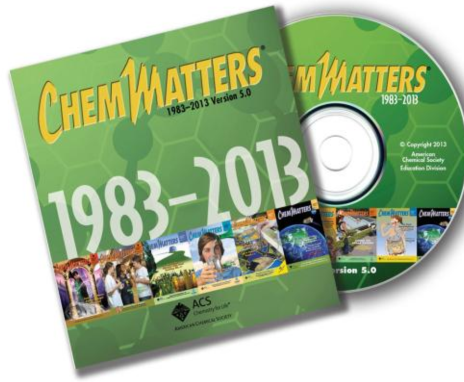
Out-of-class Activities and Projects (student research, class projects)

1. Students could make use of one particular reference, http://www.energyjustice.net/lfg/, for a class presentation (PowerPoint) to educate students about the environmental issues associated with landfill-generated methane as well as delving into the reasons that landfill-generated methane is not as widespread as it potentially could be. Among other reasons is the financial investment needed, relative to the life of the landfill. What is the average life expectancy of a methane-producing landfill? Can these landfills be actively maintained to extend the natural lifespan?
2. The pressing environmental and health issues from cooking with wood should be investigated and presented to the class by students who are most likely not aware of the consequences of depending on wood fuel. There is ample evidence about the environmental destruction caused by wood gathering. Denuding hillsides in China, for instance, is directly related to many instances of soil erosion and massive flooding in recent years. There are other countries on the African continent which have similar problems. For starters, the health issue from cooking-smoke inhalation can be researched from the National Geographic Web site (referenced earlier) at http://news.nationalgeographic.com/news/energy/2013/05/130529-surprising-facts-about-energy-poverty/.
3. Students could research landfills in their area to see if (and how) they are generating methane. The map cited above might be a good place to start.

References (non-Web-based information sources)

The references below can be found on the *ChemMatters* 30-year CD (which includes all articles published during the years 1983 through April 2013 and all available Teacher's Guides). The CD is in production and will be available from the American Chemical Society at this site: http://ww.acs.org/chemmatters.

Selected articles and the complete set of Teacher's Guides for all issues from the past three years are also available free online on the same site. (The complete set of *ChemMatters* articles <u>and</u> Teacher's Guides are available on the 30-year CD for <u>all</u> past issues, (up to April 2013.)



<u>30</u> Years of *ChemMatters* !

Some of the more recent articles (2002 forward) may also be available online at the link above. Simply click on the "Past Issues" button directly below the "M" in the *ChemMatters* logo at the top of the Web page. If the article is available online, you will find it there.

Barnwell, G., Your Personal Greenhouse. *ChemMatters* **1990**, *8* (4), pp 8–10. Thinking in broader terms, this article shows how taking personal responsibility for conserving electricity actually becomes a contribution to reducing greenhouse gases and global warming. Since generating electricity usually requires burning some kind of fossil fuel which, in turn, produces carbon dioxide (a greenhouse gas), reducing electricity consumption reduces the amount of electricity generated and fossil fuel burned. These days methane gas is the fuel of choice rather than coal. Charts from the article help with a number of calculations to show the impact of various fuels on the generation of greenhouse gases.

Garber, C.L. Wastewater. *ChemMatters* **1992,** *10* (2), pp 12–15. A different perspective on biodigesters is found when one looks at processing of sewage in the U.S. Although the goal is to produce water from the sewage that can be safely introduced back into the environment, along the way, some methane gas is produced in one stage of the biological digesting that is needed as a heat source for keeping the methane-producing bacteria (methanogens) alive and working at an optimum temperature. This article also contains a lot of practical chemistry that is important to the multiple steps in the wastewater treatment process.

Black, H. The Exploding Cabin ("Mystery Matters"). *ChemMatters* **1994,** *12* (3), pp. 4–6. Students may find this an interesting article since it provides an investigation into the cause of an explosion in an abandoned government fire tower. The two possible sources of the gas that exploded are methane (from bats) and propane (from a tank used for heating). As it turns out, the explosion is from methane but not produced by bats in the anaerobic decay of their dung but by methane produced in a septic tank that once received human waste which also underwent anaerobic decay (a biodigester). The article presents all the various hypotheses and the evidence needed to support them in this scientific investigation.

Banks, P. Ice That Burns, *ChemMatters* **1995**, *13* (3), pp.8–11. This article deals with one of the more promising but difficult to reach sources of methane called methane hydrates (gas trapped in ice crystals). Students are probably not aware of the current interest in this developing methane source. Who knows how the future world market will impact availability and price of such gas for those who currently depend on producing their own methane from biodigesters?

Sitzman, B., Goode, R. Less Meat = Less Heat. *ChemMatters* **2011**, *29* (1), p 2. Because methane is considered to be a very effective greenhouse gas, students may need some basics on the issue of global warming and greenhouse gases. The one gas more talked about is carbon dioxide even though methane, molecule for molecule, is twenty times more effective in absorbing infrared. This article has a nice illustration/diagram of the various greenhouse gases and their role in global warming.

Although not directly related to methane biodigesters, the October 2013 issue of *ChemMatters* contains an article on the fracking process for obtaining methane gas. (Karabin, S. The Fracking Revolution. *ChemMatters* **2013**, *31* (3), pp 15–17)
This issue also has a useful Teacher's Guide about methane in general and fracking in particular. Because the guide is not yet available on the *ChemMatters* CD, the Teacher's Guide can be accessed at the ACS Web site, using the following URL: http://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues.html. Scroll down to the article, "The Fracking Revolution", and note the Teacher's Guide link for that article.

Web Sites for Additional Information (Web-based information sources)

More sites on biodigesters on farms and homes

There are several videos which show the construction of large biodigesters. For activities in China, refer to http://www.youtube.com/watch?v=sfHZJ6w77Io.

Another construction project of a biodigester in Uganda is found at http://www.youtube.com/watch?v=s4EWOoPY5OY.

And from India, this video shows biogas projects, at http://www.youtube.com/watch?v=txT-1uTfZh8.

From Pakistan, a video on an integrated farm operation utilizing biogas power is found at http://www.youtube.com/watch?v=5lQWiVhjSvo.

An interesting article about a successful recycling program in Cairo that includes the use of biodigesters is found at http://blogs.scientificamerican.com/guest-blog/2013/05/13/second-helpings-recycling-cairos-food-waste/.

A very detailed and scientifically-based biogas project in India can be found at https://c919f6a6-a-5ed2e098-s-sites.googlegroups.com/a/engindia.net/main/completedsolutions/JoannaRead-ANovelDesignforaBiogasGeneratorinDevelopingCountr%E2%80%A6.pdf?attachauth=ANoY7coXJdyjkLLaZS6ut4E5QJuGaJ9KIedduDQoB7LSotVO2pjE7BAFo3cqz5HJihwNOet0xw6avGJ41yJlOomYOKjQEOpnMnOIO-5mx0FWPGu4yruFQmaZ6b9smcoHgw8pfc5iUL2-D079UHwBIDTxohYgqnZGOSTAWkcBVy8Pl9Kqd9A1xqjWlUvYdyzHjQ4eCo5PF7JYk2hE5tH0KPDjgCdN6bpfav3TzXaQTJEokhghb96c5Nj7ZE2tkqk2SReL1UGlPkBWVv-P8s1kfTXbBTLWAwznu-flqrMva6sYcoxIoD3MheFDhZvi3F9KkGF-_HGiq2LV&attredirects=0. Included in the extensive report are diagrams of the various types of biodigesters used, including the "floating dome" type which is actually a good design compared with structures that have fixed domes. The floating dome both seals the operation as well as maintains a constant pressure equal to atmospheric pressure, thereby insuring positive gas pressure for delivery to a house.

A good example of an integrated approach (actually called a closed loop system), using a manure-based biodigester that generates methane for heat and electricity to power an ethanol production plant, is found at http://www.extension.org/pages/67633/anaerobic-digestion-of-finishing-cattle-manure#.Up4rNCeZcx4. There is also a video presentation at this Web site.

A Web site for a commercial company involved in designing and building methane generators for swine operations is found at http://www.biogas-energy.com/site/pig.html. Among other things the site provides many reasons for having biodigesters on farms, particularly when pigs are involved. (Keep in mind that this Web site represents a company that sells these devices, so they have a vested interest in encouraging the use of such methane generators.)

An extensive collection of reference materials from the US government's EPA AgStar Web site concerning all aspects of agricultural biodigesters is found at http://www.epa.gov/agstar/lib/index.html.

All the "poop" about animal waste being used in various types of biodigesters with useful flowcharts to show the integration of the various steps from animal waste collection to gas production and utilization (along with the various evaluative concerns about biodigesters) is found at http://www.epa.gov/agstar/documents/recovering_value_from_waste.pdf.

More sites on landfill methane generation

Here is an EPA Web site that provides an automated tool (LandGEM) for estimating emission rates for total landfill gas, individual gas production of methane, carbon dioxide, non-methane organic compounds (NMOC's), and individual air pollutants from a landfill. Refer to http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf.

Two related government sites that provide statistics on energy production related to renewable sources in general, and biomass sources (methane generation) are found at http://www.eia.gov/renewable/ and http://www.eia.gov/energy_in_brief/article/renewable_electricity.cfm. You will also find explanations for why usage of renewables like methane is not as wide spread, compared with that of the more common energy sources like fossil fuels.

The general Web site for the US Energy Information offices, which includes the above mentioned Web site for renewables is found at http://www.eia.gov/. There are lots of good statistics (various visual presentations) related to energy production of all categories.

More sites on respiratory problems from wood and biomass cook stoves

Most people in the developed world are unaware of the respiratory problems caused by indoor air pollution in the poorer countries, where wood and other biomass fuels are burned without proper ventilation or are used in combustion/cooking devices that are not designed to reduce or eliminate smoke production. There are cook stove designs that are more efficient with significantly reduced smoke emissions through better combustion (more air intake) and/or the use of chimneys. It is estimated that about 3.5 million people, mainly women and children die each year from these smoke-related respiratory illnesses. A good reference about this problem, and the need to use more smokeless burning fuels (and better designed stoves), is found at National Geographic: http://news.nationalgeographic.com/news/energy/2013/05/130529-surprising-facts-about-energy-poverty/.