AP® ENVIRONMENTAL SCIENCE
2009 SCORING GUIDELINES

Question 2

(a) Describe the steps by which methane produced in the digester can be used to generate electricity.

Two points can be earned: 1 point for stating that methane can be burned and 1 point for describing how this generates electricity:

- By producing steam to turn a turbine (to rotate coils in a magnetic field), OR
- Through use in internal combustion engine to turn a turbine (to rotate coils in a magnetic field).

(b) Discuss TWO environmental benefits that may result from the installation of an anaerobic methane digester.

One point is earned for each of two environmental benefits discussed. (Only the first two answers are scored.)

Benefit	Discussion
Reduction in the amount of methane released to the atmosphere	• Methane contributes to climate change (greenhouse gas)
Reduction in runoff or spills of manure in local waterways	• Manure contains nutrients that lead to eutrophication/nutrient loading • Fecal coliform contamination may spread disease
Reduction in amount of manure/waste that needs to be disposed of	• Takes up less space in landfills/waste lagoons
Reduction in use of fossil fuels for electricity generation	• Fewer contaminants such as mercury/sulfur/ particulates in atmosphere • Extends the supply of fossil fuels • Less land disturbance from the extraction (mining) of fossil fuels • Unlike fossil fuels, manure is a renewable resource that can be regenerated, avoiding depletion of natural resources • No net increase in CO_2 emissions (CO_2 released by burning methane comes from plants removing CO_2 through photosynthesis now, rather than from fossil fuels formed millions of years ago)

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Question 2 (continued)

(c) Assuming that the cost of electricity remains constant and the farmer starts using the manure from the cows in an anaerobic digester to produce electricity on the farm, calculate:

(i) The number of kWh of electricity that can be produced in one year

One point is earned for the correct setup and 1 point for the correct answer. (Units are not required, but the student must show calculations in order to receive the answer point.)

$$\frac{500 \text{ cows}}{} \times \frac{3.0 \text{ kWh}}{\text{cow–day}} \times \frac{365 \text{ days}}{\text{year}} = 547{,}500 \text{ kWh/year}$$

or

$$\frac{1500 \text{ kWh}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = 547{,}500 \text{ kWh/year}$$

(ii) The amount of money the farmer can save in one year, NOT counting the installation cost of the digester. (You may round your answer to the nearest $1,000.)

One point is earned for the correct setup and 1 point for the correct answer. (Units are not required, but the student must show calculations in order to receive the answer point.) Incorrect answers transferred from (c)(i) can still earn full credit if used correctly.

547,500 kWh × $0.10 = $54,750 ($55,000)

or

800,000 kWh – 547,500 kWh = 252,500 kWh needed from a utility

800,000 × $0.10 = $80,000
252,500 × $0.10 = $25,250 $80,000 – $25,250 = $54,750 or $55,000 saved

(iii) The amount of time, in years, that it will take to recover the cost of installing an anaerobic digester on the farm. (You may round your answer to the nearest whole number of years.)

One point is earned for the correct setup AND correct answer. (Units are not required, but the student must show calculations in order to receive the point). Incorrect answers transferred from (c)(ii) can still earn full credit if used correctly.

$400,000/$55,000 = 7.2 years (or 7 years)

Question 2 (continued)

(d) Calculate the minimum number of cows the farm would need to produce 800,000 kWh of electricity per year.

One point is earned for the correct setup and 1 point for the correct answer. (Units are not required, but the student must show calculations in order to receive the answer point.) Incorrect answers transferred from (c)(i) can still earn full credit if used correctly.

$$\frac{3.0 \text{ kWh}}{\text{cow–day}} \times \frac{365 \text{ days}}{\text{year}} = \frac{1095 \text{ kWh}}{\text{cow–year}}$$

or

$$\frac{800{,}000 \text{ kWh}}{\text{year}} \times \frac{1 \text{ year}}{365 \text{ days}} \times \frac{\text{cow–day}}{3 \text{ kWh}} = 730.5 \text{ cows} = 731 \text{ cows}$$

or

$$\frac{800{,}000 \text{ kWh/year}}{1095 \text{ kWh/cow–year}} = 730.5 = 731 \text{ cows}$$

or

$$\frac{500 \text{ cows}}{547{,}500} = \frac{x \text{ cows}}{800{,}000} = 730.5 = 731 \text{ cows}$$

2. Anaerobic methane digesters have been used for many years to reduce energy costs on farms throughout Europe and on some large farms in the United States. The digesters operate by using anaerobic bacteria to break down animal waste. During the process, which typically uses a tank heated to about 100°F (38°C) to speed the reactions, raw manure is broken down and methane is produced. The methane can then be used to generate electricity or produce heat.

For a certain dairy farm with 500 cows, the cost of installing a digester is approximately $400,000. Assume that the farm uses 800,000 kilowatt-hours (kWh) of electricity each year at a cost of $0.10 per kWh. The waste from a single cow can produce 3.0 kWh of electricity each day.

(a) Describe the steps by which methane produced in the digester can be used to generate electricity.

(b) Discuss TWO environmental benefits that may result from the installation of an anaerobic methane digester.

(c) Assuming that the cost of electricity remains constant and the farmer starts using the manure from the cows in an anaerobic digester to produce electricity on the farm, calculate:

(i) The number of kWh of electricity that can be produced in one year

(ii) The amount of money the farmer can save in one year, NOT counting the installation cost of the digester. (You may round your answer to the nearest $1,000.)

(iii) The amount of time, in years, that it will take to recover the cost of installing an anaerobic digester on the farm. (You may round your answer to the nearest whole number of years.)

(d) Calculate the minimum number of cows the farm would need to produce 800,000 kWh of electricity per year.

Methane can be burned in order to heat up water. The water would turn into steam and then the steam would turn a turbine. With the turbine turning electricity would be generated. The anaerobic methane digester would help reduce air pollution and eutrophication. If the farm would run only on methane, the amounts of particulates and other pollutants would be reduced. Methane, a natural gas, burns a lot cleaner than other fossil fouls such as coal or oil. By using their own energy, they wont need to get any from other powerplants. ~~These 2 plants~~ Majority of these power plants are powered by coal which release many pollutants in the atmosphere such as sulfer. Using methane as a power source significantly reduces air pollution. ~~Anaerobic~~ Anaerobic methane digesters can also help the envirement by ~~help~~

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

preventing eutrophication. Raw cow manure contains many nutrients. If these nutrients were able to access any body of water, eutrophication would occur. Eutrophication is an enviromental disaster that usually leaves organisms in the body of water dead. If the manure would be used for electricity, it would be handled and managed for better. This would significantly reduce the possibility of manure entering a body of water. thus preventing eutrophication.

C) i. $500 \text{ cows} \times \frac{3 \text{ kWh}}{1 \text{ cow day}} \times \frac{365 \text{ days}}{1 \text{ year}} = \boxed{\frac{547500 \text{ kWh}}{1 \text{ year}}}$

ii. $\frac{547500 \text{ kWh}}{1 \text{ year}} \times \frac{\$.10}{1 \text{ kWh}} = \boxed{\$54750}$

iii. $\$400,000 = \$54750 \times \#$ of years

$\frac{\$400,000}{\$54750} = \#$ of years

# of years $\approx$ 7 years

D) $\frac{1095 \text{ kWh}}{1 \text{ cow} \cdot \text{year}} \times$

$1095 \times = 800,000$

$\times = \frac{800,000}{1095}$

$\times \approx \boxed{730 \text{ cows}}$

2. Anaerobic methane digesters have been used for many years to reduce energy costs on farms throughout Europe and on some large farms in the United States. The digesters operate by using anaerobic bacteria to break down animal waste. During the process, which typically uses a tank heated to about 100°F (38°C) to speed the reactions, raw manure is broken down and methane is produced. The methane can then be used to generate electricity or produce heat.

For a certain dairy farm with 500 cows, the cost of installing a digester is approximately $400,000. Assume that the farm uses 800,000 kilowatt-hours (kWh) of electricity each year at a cost of $0.10 per kWh. The waste from a single cow can produce 3.0 kWh of electricity each day.

(a) Describe the steps by which methane produced in the digester can be used to generate electricity.

(b) Discuss TWO environmental benefits that may result from the installation of an anaerobic methane digester.

(c) Assuming that the cost of electricity remains constant and the farmer starts using the manure from the cows in an anaerobic digester to produce electricity on the farm, calculate:

(i) The number of kWh of electricity that can be produced in one year

(ii) The amount of money the farmer can save in one year, NOT counting the installation cost of the digester. (You may round your answer to the nearest $1,000.)

(iii) The amount of time, in years, that it will take to recover the cost of installing an anaerobic digester on the farm. (You may round your answer to the nearest whole number of years.)

(d) Calculate the minimum number of cows the farm would need to produce 800,000 kWh of electricity per year.

a) First, methane gas can be used to heat water. Once the water is hot enough, it evaporates into steam. The steam pushes turbines in a generator which then produces electricity.

b) One environmental benefit of using methane digesters is the elimination of methane as a greenhouse gas from the atmosphere. Taking out quantities of methane would help slow global warming. Another environmental benefit would be the electricity produced, since there is no non-renewable resources being used. This would help preserve our resources, especially those that aren't clean energy.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

c) i) $500 \times 3 = 1500$ kWh

$1500 \times 365 = 547,500$ kWh per year.

ii) $547,500 \times .10 = \$54,750$

iii) $55,000 \overline{)400,000} \approx$ about 7 years

d) $500,000 \overline{)800,000} \approx 1.6$ $1.6 \times 500 = 800 \approx 800$ cars

2C
1 of 2

2. Anaerobic methane digesters have been used for many years to reduce energy costs on farms throughout Europe and on some large farms in the United States. The digesters operate by using anaerobic bacteria to break down animal waste. During the process, which typically uses a tank heated to about 100°F (38°C) to speed the reactions, raw manure is broken down and methane is produced. The methane can then be used to generate electricity or produce heat.

For a certain dairy farm with 500 cows, the cost of installing a digester is approximately $400,000. Assume that the farm uses 800,000 kilowatt-hours (kWh) of electricity each year at a cost of $0.10 per kWh. The waste from a single cow can produce 3.0 kWh of electricity each day.

(a) Describe the steps by which methane produced in the digester can be used to generate electricity.

(b) Discuss TWO environmental benefits that may result from the installation of an anaerobic methane digester.

(c) Assuming that the cost of electricity remains constant and the farmer starts using the manure from the cows in an anaerobic digester to produce electricity on the farm, calculate:

(i) The number of kWh of electricity that can be produced in one year

(ii) The amount of money the farmer can save in one year, NOT counting the installation cost of the digester. (You may round your answer to the nearest $1,000.)

(iii) The amount of time, in years, that it will take to recover the cost of installing an anaerobic digester on the farm. (You may round your answer to the nearest whole number of years.)

(d) Calculate the minimum number of cows the farm would need to produce 800,000 kWh of electricity per year.

The steps in which methane produced can be used to generate electricity is that by burning the methane to then create super-heated steam. With this steam one can now use it to turn the turnbine that will power the generator so then the generator can create electricity.

Two environmental benefits of this is that the farms won't require energy from coal-burning power plants so inenvertantly causing less coal to be burned so that less CO_2 is omitted into the atmosphere. Another benefit of this would be that instead of worrying about what to do with the manure, it now has a purpose and can be put to good use. Thus, creating less solid-waste to be desposed of.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

$3 \times 500 = 1500$ $\quad 1500 \times 365 \quad 365 \times 15 = 1825 + 3650 = 547{,}500$ kWh/year

The number of kWh that will be produced by 500 cows, if each produces 3 kWh a day, in a year will amount to 547,500 kWh/year. The amount of money that the farmer will save a year amounts to $55,000, not including installation cost. The amount of time that will be required for the recovery of the installation on the farm will be 8 years.

$365 \times 3 = 1095$ $\quad \frac{800{,}000}{1095} = 731$

The minimal amount of cows needed to produce 800,000 kWh would be 731.

AP® ENVIRONMENTAL SCIENCE
2009 SCORING COMMENTARY

Question 2

Overview

The intent of this question was for students to demonstrate an understanding of how fuel sources, such as methane, may be used to generate electricity and how harvesting methane from cow manure provides specific environmental benefits. Students were required to demonstrate their ability to use basic mathematical functions (multiplication and division) and set up equations to calculate the impact on electricity use of a methane digester on a farm where cattle are raised.

Sample: 2A
Score: 10

The response earned 10 out of 11 possible points. In part (a) the student states that "[m]ethane can be burned in order to heat up water," which earned 1 point, and "[t]he water would turn into steam and then the steam would turn a turbine," which earned a second point.

In part (b) the student clearly states two environmental benefits, reduction of air pollution and eutrophication. However, the response earned points only after the student explains why these are benefits. The student discusses the benefits by stating that "the amounts of particulates and other pollutants would be reduced" and links this to the use of coal by power plants, earning 1 point. The response also earned 1 point for stating that "[r]aw cow manure contains many nutrients. If these nutrients were able to access any body of water, eutrophication would occur," after stating that the amount of manure would be reduced by the use of the methane digester.

In parts (c) and (d) all the calculations are clearly shown, with most answers identified in boxes. The student correctly uses dimensional analysis in part (c)(i), earning 1 point, and gives the correct answer, earning another point. In part (c)(ii) the student earned 1 point for the correct setup and 1 point for the correct answer. In part (c)(iii) the response earned 1 point for the correct setup using an algebraic equation and correct calculation of the answer.

The response earned 1 point in part (d) for the correct setup, but no point for answer of 730 cows.

Sample: 2B
Score: 8

In part (a) the response earned 1 point for stating that "[t]he steam pushes turbines in a generater [*sic*] which then produces electricity," but no credit was earned for "methane gas can be used to heat water" because the response does not explain that the gas must be burned.

The response earned 1 point in part (b) for stating, "One enviornmental [*sic*] benefit of using methane digesters is the elimination of methane as a greehouse [*sic*] gas." The second benefit given is the reduction in "non-renewable resources being used," as "[t]his would help preserve our resources," which earned 1 point.

The response earned 1 point for the correct setup in part (c)(i) and 1 point for the correct answer. The response earned 1 point in part (c)(ii) for the correct setup and 1 point for the correct answer. The response earned 1 point in part (c)(iii) for the correct setup and the correct answer that was correctly rounded down.

Question 2 (continued)

The response earned no points in part (d) because the attempt at calculating the answer is an overly gross estimation that gives a significantly incorrect answer.

Sample: 2C
Score: 6

The response earned 1 point in part (a) for the mention of "burning the methane to then create super-heated steam" and 1 point for the statement that "[w]ith this steam one can now use it to turn the turnbine [*sic*]."

The response earned no points in part (b) because although "causing less coal to be burned" is a benefit, "less CO_2 is omitted [*sic*] into the atmosphere" is not a valid discussion point since burning methane also emits CO_2. The response states that using the manure means "creating less solid-waste to be desposed [*sic*] of," without discussing why this is a benefit by explaining that the waste would otherwise be placed in a landfill.

The response earned 1 point in part (c)(i) for the correct setup and 1 point for the correct answer. The response earned no points in part (c)(ii) because, although the answer is correct, no setup is shown. The response earned no points in part (c)(iii) because no setup is shown.

The response earned 1 point in part (d) for the correct setup and 1 point for the correct answer.