Chief Reader Report on Student Responses:

2023 AP® Environmental Science Set 2

Free-Response Questions

- Number of Students Scored 209,757
- Number of Readers 686
- Score Distribution

Exam Score	N	%At
5	17,357	8.27
4	59,527	28.38
3	35,689	17.01
2	55,358	26.39
1	41,826	19.94

- Global Mean 2.79

The following comments on the 2023 free-response questions for AP® Environmental Science were written by the Chief Reader, Dr. Laura J. Hainsworth, Professor of Chemistry and Environmental Science, Emory & Henry College. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

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Question 1

Task: Design an Investigation
Topic: Succession, Soil Properties, and Impacts of Mining
Max Score: 10
Mean Score: 4.07

What were the responses to this question expected to demonstrate?

The intent of this question was for students to demonstrate their ability to interpret a diagram representing the number of plant species in various overburden piles and to identify components of a scientific experiment. Students were asked to explain concepts of ecological biodiversity and succession and their relationship to various biomes. Students were also asked to explain how soil composition may affect runoff from soil and to describe ecological impacts on mine waste on local waterways.

In part (a) students were asked to demonstrate their ability to read data provided in a graph [Science Practice 5 Data Analysis]. In part (b) students were asked to describe the relationship between the age of overburden piles and number of plant species [Science Practice 5 Data Analysis].

In part (c) students were asked to interpret experimental data and results and to make a claim in relation to a given a hypothesis addressing the relationship between the number of plant species and animal species found in overburden piles [Science Practice 5 Data Analysis].

In part (d) students were asked to describe a characteristic of plant species that may be present in recently constructed waste piles [Science Practice 1 Concept Explanation and Topic 2.7 Ecological Succession and 2.4 Ecological Tolerance]. In addition, in part (e) students were asked to relate changes in succession to terrestrial biomes in which they take place [Science Practice 1 Concept Explanation and Topic 1.2 Terrestrial Biomes].

In part (f) students were asked to identify a scientific question from the description of an experiment on how soil covering can affect water runoff [Science Practice 4 Scientific Experiments and Topic 4.2 Soil Formation and Erosion]. Part (g) asked students to identify the dependent variable in the scientific experiment [Science Practice 4 Scientific Experiments]. In part (h) students were asked to explain how changing the composition of the soil in the experiment may have changed the results in the experiment [Science Practice 4 Scientific Experiments and Topic 4.3 Soil Composition and Properties].

In part (i) students were asked to describe an ecological impact of drainage from mine waste into nearby waterways [Science Practice 1 Concept Explanation and Topic 8.2 Human Impacts on Ecosystems]. Part (j) asked students to describe a strategy to reduce mine waste drainage into waterways [Science Practice 7 Environmental Solutions and Topic 8.2 Human Impacts on Ecosystems].

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How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

Students were expected to demonstrate the ability to interpret diagrams and identify and describe experimental design components. Students were also expected to demonstrate concept knowledge about biodiversity, ecological succession, biomes, soil composition, and the effects and solutions related to mine waste drainage.

- Part (a) was related to Science Practice 5 Data Analysis. Most students correctly identified the average number of species as "8" or "9." In part (b) correct responses applied Science Practice 5 Data Analysis to describe that "as the age of the piles get older there are more plant species present." In part (c) students applied Science Practice 5 Data Analysis to correctly make a claim that supports the hypothesis proposed by describing the relationship where more plant species provide more resources for a larger number of animal species.

- In part (d) students applied an understanding of Topic 2.7 Ecological Succession to correctly describe various characteristics of the pioneer species that may have been present in the piles, including "the plant would be able to grow on the bare rocks" and "plants that grow well in full sunlight would be mostly likely the first plants to show." Part (e) asked students to describe how the return of plant life on the piles would have been altered if the piles were in tundra. Many correct answers explained how the colder weather in the tundra would have made the return of plant life slower, e.g., "return of plant life would [be] slower because the tundra is colder," demonstrating their understanding of Topic 1.2 Terrestrial Biomes.

- Part (f) applied Science Practice 4 Scientific Experiments. Students were required to identify a scientific question from a description and data of a study. Correct responses were written as a question, e.g., "What material was best able to limit the surface runoff of the water?" In part (g) students were asked to identify the dependent variable in an experiment showing understanding of Science Practice 4 Scientific Experiments. Most students correctly answered "water appearance" or "the amount of water." Part (h), related to Topic 4.3 Soil Composition and Properties, asked students to explain how the results of the experiment would have been different if the soil had contained more sand. Correct responses stated that "less water would have been collected because of the high permeability of sand, more water would infiltrate into the soil."

- Part (i) focused on Topic 8.2 Human Impacts on Ecosystems. Correct responses described how mine drainage impacted waterways that resulted in a negative impact to species. A correct response would be, "drainage from mines are typically acidic ... it would decrease the pH of the water, which can kill organisms. " In part (j) correct responses described how mine waste can be diverted from waterways or treated to reduce negative impacts. A response earning a point would be, "mine waste can be put into basins where it can be treated."

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What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Students equated the number of plant species to number of plants or biomass.	• "The spontaneous restoration piles had a far higher number of plant species, which in turn would likely result in ... a larger variety of animal species."
• Students did not demonstrate an understanding of how to read text describing an experiment, nor how to write a scientific question based on that experiment.	• "How does the presence of plant life affect the volume of runoff water collected?"
• Students confused the variable and the control of an experiment.	• "A dependent variable in the experiment is water appearance."
• A common misconception was students incorrectly stating that increased soil porosity leads to more runoff.	• "More water would infiltrate into soil rather than runoff."
• A common knowledge gap was the understanding of the environmental impact of mine waste drainage.	• "Drainage from mines are typically acidic so when released into nearby waterways it would decrease the pH of the water, which can kill organisms."
• A common misconception was that a nonspecific law is the same thing as a strategy for decreasing ecological impact.	• "Plant a row of bushes, trees, and grass in front of the water ways ... because the plants will absorb some of the drainage and sediment entering the waterways and killing the fish."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Remind students of the differences required by the task verbs found in the question. "Identify" requires a very short response and does not require an explanation for a point. On the other hand, students should have practice explaining concepts and answers in preparation for the more detailed answer required from an "explain" task verb. Students need to know they should provide more than a vocabulary term when asked for a description of a concept.
- The skills in Science Practice 5 Data Analysis ask students to analyze data in tables and graphs. These skills may be practiced in class so that students can get immediate feedback. Warmup exercises with data analysis can be used for quick practice on this skill.

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- The skills in Science Practice 4 Scientific Experiments should be practiced often in class. Students should practice developing their own independent and dependent variables, constants, and controls with student-driven experiments in class. They also should practice identifying these concepts from a written description of an experiment to prepare them for this portion of the question.

- Students should understand the difference between asking a scientific question and stating/evaluating a hypothesis. Prior to this course, many students have only been taught about hypotheses and might not be familiar with the concept of scientific questions.

- Students should focus on vocabulary found in the CED. For example, they should understand how neurotoxins and endocrine disruptors impact organisms. Students should understand the difference between bioaccumulation and biomagnification and understand which term applies to organisms and which term applies to ecosystems.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

- Teachers will find sample student responses for this question on the exam information page on AP Central, along with commentary explaining why each point was or was not earned. Teachers can use these samples to better understand how each question was scored and to work with students to help practice writing correct responses.

- Teachers will find scoring guidelines for this question explaining how the question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.

- Teachers can have students practice with the examples of FRQ 1 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.

- Teachers can have students practice, score, and review the examples of FRQ 1 found on the three AP Environmental Science Practice Exams that can be accessed in AP Classroom.

- Teachers can use the labs that are available in AP Classroom with their students. Each lab is designed to target specific Science Practice Skill development.

- In AP Classroom, teachers can access a rich collection of resources that includes formative and summative assessment items for every unit of the course.

- AP Daily videos in AP Classroom provide enriching content for every topic in AP Environmental Science. Teachers can integrate these videos into their instruction in a variety of ways to provide students with additional exposure to content throughout the course.

- AP Daily Live videos found on YouTube provide a comprehensive review of the course content for students. Teachers can assign these videos to students in the weeks leading up to the exam to reinforce content learned throughout the course.

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- On the AP Environmental Science Online Teacher Community there are many resources, discussions, tips, and activities that many teachers have found helpful. It is easy to sign up and teachers can search through topics of discussions from previous years.
- Teachers might consider signing up for an AP Summer Institute (APSI). An APSI is a great way to gain in-depth knowledge about the AP Environmental Science curriculum and exam. It is also a great way to network with colleagues from around the world.
- Teachers might consider applying to be an AP Reader. The AP Reading is considered outstanding professional development by most AP teachers. Besides learning how to accurately apply AP scoring guidelines to score student responses, it is a great way to share resources and network with colleagues.

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Question 2

Task: Analyze an Environmental Problem and Propose a Solution
Topic: Invasive Asian Carp and The Great Lakes Ecosystem Services
Max Score: 10
Mean Score: 4.66

What were the responses to this question expected to demonstrate?

The intent of this question was for students to analyze the environmental problem of the introduction of Asian carp to the United States and propose a solution for containment of the invasive species. Students were also asked to analyze the components of a food chain and, lastly, were asked to apply their understanding of the tragedy of the commons to an alternative to commercial fishing, aquaculture.

In part (a) students were asked to identify a labeled body of water invaded by Asian carp [Science Practice 2 Visual Representations], and in part (b) students were asked to describe how this distribution had changed since their introduction in the 1970s [Science Practice 2 Visual Representations].

In part (c) students were asked to describe how the environmental concept represented in the diagram related to broader environmental issues, in this case, an impact on an ecosystem service provided by the Great Lakes region [Science Practice 2 Visual Representations and Topic 2.2 Ecosystem Services]. Part (d) asked the students to propose a realistic solution to help reduce the spread of the Asian carp from their current distribution [Science Practice 7 Environmental Solutions and Topic 9.8 Invasive Species], and part (e) asked the students to justify an additional advantage linked to their solution in part (d) [Science Practice 7 Environmental Solutions].

Part (f) presented students with a simplified Great Lakes food chain and asked them to identify the primary consumer [Science Practice 2 Visual Representations, Topic 1.9 Trophic Levels, and Topic 1.11 Food Chains and Food Webs]. In part (g) students were asked to describe what the arrows represented on the food chain [Topic 1.10 Energy Flow and the 10% Rule]. In part (h) students were asked to demonstrate an understanding of disturbance to the food chain by describing an impact to the Great Lakes chain by the introduction of the Asian carp [Topic 1.11 Food Chains and Food Webs].

In part (i) students were asked to describe how the overfishing of the Great Lakes endemic blue pike that led to their extinction is an example of the tragedy of the commons [Topic 5.1 The Tragedy of the Commons]. In part (j) students were asked to describe one disadvantage of aquaculture as a solution to overfishing [Science Practice 7 Environmental Solutions and Topic 5.16 Aquaculture].

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

Students were expected to be knowledgeable about food chains and food webs, invasive species, and the impacts invasive species can have on both ecosystems and ecosystems services.

- In part (a) most students correctly used the map provided to identify a body of water invaded by Asian carp, and in part (b) students earned a point using Science Practice 2 Visual Representations to describe how the distribution of Asian carp has “greatly increased” or “moved up the Mississippi” or “moved to the north and the west and even the south.”

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- In part (c) correct responses described an impact the introduction of carp had on an ecosystem service of the Great Lakes region. Students did not have to name the ecosystem service being impacted (regulating, supporting, cultural, or provisioning) but were required to describe how the introduction of the carp impacted one of them. Students earned a point for describing a positive impact such as “improved water clarity due to less algae so more people would swim,” or a negative impact such as “decreased oxygen production with less algae doing photosynthesis.”

- In part (d) correct responses proposed a realistic solution to help reduce the spread of carp. Students answered this question generally by saying you could physically stop the carp (“electric barriers,” “mesh fencing”), consume the carp (“educate on nutritional value,” “share recipes to encourage eating”), incentivize fishers to increase carp catch (“pay fishers to catch more carp,” “give tax breaks to fishers who also caught carp”) or limit bait or ballast water transfer from one body of water to another. The justification in part (e) had to be related to their answer in part (d). Students could earn a point in part (e) for justifying an incomplete, but not incorrect, response in part (d).

- In part (f) students applied Science Practice 2 Visual Representations to identify zooplankton as the primary consumer. In part (g) students earned a point for describing the flow of “matter,” “energy,” or “nutrients.” In part (h) students earned a point for either directly tying the lack of algae to a decrease in zooplankton, or for describing how an organism at the same trophic level on the food chain as the carp would be impacted.

- In part (i) correct responses described how the extinct blue pike was a demonstration of the Tragedy of the Commons. Students correctly described that the blue pike was a common resource that was overfished or exploited, leading to extinction or depletion. In part (j) students used Science Practice 7 Environmental Solutions to look at negative consequences of aquaculture. Students earned a point for describing the impact farm-raised fish would have if released into the environment, how density dependent population factors such as disease increased in fish farms, or the negative economic impacts on the fishing industry from the growth of aquaculture.

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What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Some students did not use the information given on the map to answer the question but instead made broad generalizations about where Asian carp might be found throughout the entire United States.	• "The carp has spread up the Mississippi River and into rivers that connect to it like the Missouri and the Ohio."
• Students confused an impact on an ecosystem with an impact on an ecosystem service. Students answered part (c) as an impact on the ecosystem rather than an impact on an ecosystem service.	• "Less fishing in the Great Lakes since the carp were outcompeting the fish that the fishermen wanted to catch." • "The carp ate the algae which made the water cleaner and better for drinking or swimming." • "The carp ate the algae … with less algae there was less carbon storage which led to an increase in global warming."
• A common knowledge gap was identifying a realistic solution to help stop the spread of Asian carp. Unrealistic answers included "damming the entire Mississippi river."	• "The government could pay fishermen to catch and kill the Asian carp."
• A misconception was understanding the flow of energy or matter in a food chain.	• "The arrows show the transfer of energy and nutrients in the aquatic food chain."
• Students confused aquaculture and agriculture.	• "Aquaculture contaminates water with excess waste from the fish."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Remind students of the differences required by the task verbs found in the question. "Identify" requires a very short response and does not require additional description or an explanation for a point. On the other hand, students should have practice explaining concepts and answers in preparation for the more detailed answer required from an "explain" task verb. Practice the task verbs.

- Students should practice adding detail to their writing. A response needs to demonstrate a level of understanding of environmental issues appropriate for an entry level college course and should not be vague. Practice peer grading. If another student reads their response and still has questions, have the original student go back and add more detail.

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- Question 2: Analyze an Environmental Problem and Propose a Solution requires students to make a claim and justify the solution in their constructed response. Students should feel comfortable with making claims that propose a solution to an environmental problem and then justifying that claim through additional information. These can be practiced in the classroom using CED topics.

- Students should focus on vocabulary taught in the CED. Students did not earn a point in their responses for not being able to distinguish between ecosystem service and ecosystem, or agriculture and aquaculture. Using AP vocabulary in lesson and assessment design allows students to practice these words throughout the year.

- The skills in Science Practice 2 Visual Representations ask students to analyze representations of environmental concepts and processes. These skills should be practiced in class so that students can practice how to read and interpret diagrams. They should have experience using a key and drawing conclusions based on provided information. Warm-up exercises with diagram interpretation can be used for quick practice on this skill.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

- Teachers will find sample student responses for this question on the exam information page on AP Central, along with commentary explaining why each point was or was not earned. Teachers can use these samples to better understand how each question was scored and to work with students to help practice writing correct responses.

- Teachers will find scoring guidelines for this question explaining how the question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.

- Teachers can have students practice with the examples of FRQ 2 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.

- Teachers can have students practice, score, and review the examples of FRQ 2 found on the three AP Environmental Science Practice Exams that can be accessed in AP Classroom.

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Question 3

Task: Analyze an Environmental Problem and Propose a Solution doing Calculations
Topic: Methane Landfills and Beef Calculations
Max Score: 10
Mean Score: 3.94

What were the responses to this question expected to demonstrate?

This question focused on topics related to the methane formation and emissions in landfills and cattle, as well as food production efficiency between beef and corn cultivation.

In part (a) students were expected to demonstrate understanding that methane is a greenhouse gas that leads to climate change/global warming [Science Practice 1 Concept Explanation, Topic 9.3 The Greenhouse Effect, and Topic 9.4 Increases in the Greenhouse Gases].

In part (b) students were asked to describe one factor that could affect the decomposition of solid waste in a landfill. Students could describe the content/makeup of the waste itself, or conditions in the landfill that would affect decomposition [Science Practice 1 Concept Explanation and Topic 8.9 Solid Waste Disposal].

In parts (c) and (d) students were asked to propose a solution to decrease the amount of methane released from landfills into the atmosphere and justify that solution by describing an additional advantage other than decreased methane release. Students demonstrated their understanding of which types of solid waste would contribute to methane production or that methane collections systems would reduce the amount of methane released from a landfill. To justify their solution, students described the potential for electricity or heat generation with incineration and methane collection systems [Science Practice 7 Environmental Solutions and Topic 8.10 Waste Reduction Methods].

In parts (e), (f), and (g) students were asked to calculate, showing work, the amount of methane produced by all beef cattle in the United States, the number of hectares needed to support all beef cattle in the U.S., and the difference between how many people could be supported between corn cultivated land and land used to raise beef cattle [Science Practice 6 Mathematical Routines and Topic 5.7 Meat Production Methods]. While dimensional analysis based on unit cancellation is recommended, a setup point was earned for responses showing correct values and mathematical operations.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

Students were expected to demonstrate knowledge of environmental problems associated with methane, impacts to decomposition rates in landfills, and ways to decrease methane in landfills. Students were also expected to calculate the amount of methane produced by all beef cattle in the U.S., the number of hectares needed to support all beef cattle in the U.S., and difference in how many people could be supported between corn cultivated land and land used to raise beef cattle.

- In part (a) correct responses applied Science Practice 1 Concept Explanation and their knowledge of Topic 9.3 The Greenhouse Effect and Topic 9.4 Increases in the Greenhouse Gases to describe an environmental problem associated with the release of methane into the atmosphere. Students had to first identify that methane is a greenhouse gas or that it warms the atmosphere. Then, students had

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to link that to an environmental problem like climate change. Responses that described, “methane is a greenhouse gas, and therefore contributes to climate change” earned a point in this section.

- In part (b) responses earned a point for applying Science Practice 1 Concept Explanation and their knowledge of Topic 8.9 Solid Waste Disposal to describe a factor that could affect decomposition of a solid waste in a landfill. Most students discussed either the make-up of the solid waste, e.g., the percentage of plastic or other nonbiodegradable solid waste, or a condition of the landfill such as the amount of oxygen present.

- In part (c) students applied Science Practice 7 Environmental Solutions and an understanding of Topic 8.9 Solid Waste Disposal and Topic 8.10 Waste Reduction Methods to propose a solution to decrease the amount of methane released from landfills. Students showcased their understanding of which types of solid waste would, if reduced, decrease methane production or that methane collections systems would reduce the amount of methane. Some students correctly answered that solid waste could be incinerated. Recycling or reduction of biodegradable solid waste also earned a point.

- In part (d) correct responses applied Science Practice 7 Environmental Solutions and understanding of Topic 8.9 Solid Waste Disposal and Topic 8.10 Waste Reduction Methods to justify the solution proposed in part (c) by describing an additional advantage other than decreasing the amount of methane released from the landfills. To justify their solution, many students described the potential for electricity or heat generation with incineration and methane collection systems. If students discussed composting or recycling of nonsynthetic organic waste, a point was earned by correctly discussing the advantage of fertilizer production or reduced need for new products, respectively. “Composting will not only reduce methane emissions, but also provide nutrient rich soil for gardens” earned a point in this section.

- In part (e) students applied Science Practice 6 Mathematical Routines to calculate the correct amount of methane released by all beef cattle raised in the United States in one year. One point was earned for showing their work, and one point was earned for the correct answer. Students were expected to show that there were 31.2 million cattle and not 31.2 cattle. Many students earned a point for showing a correct setup for part (e). “31.2 million cattle times 150 liters of methane times 365 days equals 1.7 x 10^{12} liters” earned a point in this section.

- In part (f) correct responses applied Science Practice 6 Mathematical Routines to calculate the number of hectares of pasture that would be needed to support all beef cattle raised in the United States in one day. Students could earn one point for the correct setup and one point for the correct answer. Student responses showed a wide variety of correct ways to set up the problem.

- In part (g) students applied Science Practice 6 Mathematical Routines to calculate how many more American people could be fed if 150 hectares of land was used to grow corn instead of raising beef cattle. Student responses earned one point for the correct setup of the problem and one point for the correct answer. Most student responses showed separate calculations for the number of Americans that could be fed by corn and by beef, followed by subtraction to calculate the difference. Students were required to show the subtraction if they chose this setup. While more complex than the other calculation questions, many students earned both the setup and answer point for this question.

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What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• A common misconception was that stratospheric ozone depletion is an environmental problem associated with the release of methane from landfills. • Another common misconception is that the greenhouse effect is not in and of itself an environmental problem. Only when it is significantly enhanced due to an excess amount of greenhouse gasses in the atmosphere is it considered an environmental problem.	• "Methane causes global warming since it acts as a greenhouse gas and traps infrared radiation."
• A common misconception was that plastic and other nonbiodegradable material contribute to methane production in landfills	• "Composting is a great way to reduce the amount of organic waste that goes into our landfills."
• A common misconception is that organic solid waste can be put on the ground and used directly as fertilizer instead of composting it first.	• "Composting will not only reduce methane levels, but also help to create nutrient rich soil great for growing crops."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve the student performance on the exam?

- Remind students to write numbers correctly and completely. In part (e) 13.2 million, 13.2×10^6, or 13,100,000 were all acceptable. Some students simply wrote 13.2, which was incorrect and did not earn a setup point.

- Students should be specific when discussing energy, for example "making electricity" or "making heat" instead of "making energy."

- Students should include the unit in the answer if it is not given in the question. For example, in part (e) responses should say 1.7×10^{12} Liters (or L), because the question asks for a volume and does not specify liters.

- Review scientific notation with students to ensure correct representation of calculations for large numbers. Some responses missed or added a zero, earning the setup point but not the answer point.

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What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

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- Teachers will find scoring guidelines for this question explaining how the question was scored on the exam information page on AP Central. Teachers can use and adapt these scoring guidelines throughout the course so that students become familiar with how their responses will be scored.
- Teachers can have students practice with the examples of FRQ 3 on the released 2021–2023 AP Environmental Science Exams found on the exam information page on AP Central. Student samples and scoring guidelines are also available for those questions.
- Teachers can have students practice, score, and review the examples of FRQ 3 found on the three AP Environmental Science Practice Exams that can be accessed in AP Classroom.
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