

## **2004 AP<sup>®</sup> ENVIRONMENTAL SCIENCE FREE-RESPONSE QUESTIONS**

2. West Fremont is a community consisting of 3,000 homes. A small coal-burning power plant currently supplies electricity for the town. The capacity of the power plant is 12 megawatts (MW) and the average household consumes 8,000 kilowatt hours (kWh) of electrical energy each year. The price paid to the electric utility by West Fremont residents for this energy is \$0.10 per kWh. The town leaders are considering a plan, the West Fremont Wind Project (WFWP), to generate their own electricity using 10 wind turbines that would be located on the wooded ridges surrounding the town. Each wind turbine would have a capacity of 1.2 MW and each would cost the town \$3 million to purchase, finance, and operate for 25 years.
- (a) Assuming that the existing power plant can operate at full capacity for 8,000 hrs/yr, how many kWh of electricity can be produced by the plant in a year?
- (b) At the current rate of electrical energy use per household, how many kWh of electrical energy does the community consume in one year?
- (c) Compare your answers in (a) and (b) and explain why you would or would not expect the numbers to be the same.
- (d) Assuming that the electrical energy needs of the community do not change during the 25-year lifetime of the wind turbines, what would be the cost to the community of the electricity supplied by the WFWP over 25 years? Express your answer in dollars/kWh.
- (e) Identify and explain TWO environmental benefits to West Fremont of switching from coal to wind power and TWO environmental costs to West Fremont of switching from coal to wind power.
3. Radioactive isotopes are widely used in the field of medicine, in the generation of electricity, and in the military. The use of radioactive isotopes has increased significantly over the past fifty years, leading to a corresponding increase in the amount of radioactive waste produced. The question of how to deal with radioactive waste is a topic of ongoing environmental concern.
- (a) Explain how the properties of low-level radioactive waste differ from those of high-level radioactive waste and how these properties lead to different storage requirements. For one of the two types of radioactive waste, give an example of a specific isotope that may be present in the waste, and explain how human activity generates the waste.
- (b) The United States Department of Energy recently chose Yucca Mountain in Nevada as the site for the deep underground burial of high-level radioactive waste. Describe THREE characteristics of an ideal deep underground storage site for high-level radioactive waste.
- (c) Identify TWO other options that have been suggested for the long-term management of radioactive waste. Discuss the feasibility of each method.
- (d) Exposure to high levels of ionizing radiation has adverse effects on human health and can result in immediate death. Identify one sublethal adverse effect on human health that can result from exposure to ionizing radiation, and explain how this effect is caused by the radiation.

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**Question 2**

- (a) Assuming that the existing power plant can operate at full capacity for 8,000 hours/yr, how many kWh of electrical energy can be produced by the plant in a year?**

**(2 points)**

1 point for correct setup.

1 point for correctly calculating the amount of electricity generated per year.

Answer must show calculations.

Student must correctly convert MW to kW.

Points may be earned if the student writes the answer as a word problem.

No points earned without showing or clearly stating calculations.

Solutions to the question that use alternate setups and arrive at a correct answer will also earn points.

$$12 \text{ MW} = 12,000 \text{ kW} \text{ or } 1.2 \times 10^4 \text{ kW},$$

$$12,000 \text{ kW} \times 8,000 \text{ hours/yr} = 96,000,000 \text{ kWh/year} \text{ or } 9.6 \times 10^7 \text{ kWh/year}$$

OR

$$\begin{aligned} 12 \text{ MW} \times 1,000 \text{ kW/MW} \times 8,000 \text{ hrs/yr} &= 96,000,000 \text{ kWh/yr} \\ &= 9.6 \times 10^7 \text{ kWh/yr} \end{aligned}$$

- (b) At the current rate of electrical energy use per household, how many kWh of electrical energy does the community consume in one year?**

**(2 points)**

1 point for correct setup.

1 point for correct calculation

Answer must show calculations.

Point may be earned if the student writes the answer as a word problem.

No points earned without showing or clearly stating calculations.

Solutions to the question that use alternate setups and arrive at a correct answer will also earn points.

$$3,000 \text{ homes} \times (8,000 \text{ kWh/home})/\text{year} = 24,000,000 \text{ kWh/year}$$

$$= 2.4 \times 10^7 \text{ kWh/year}$$

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**Question 2 (cont'd.)**

- (c) Compare your answers in (a) and (b) and explain why you would or would not expect the numbers to be the same.**

**(2 points, plus one possible elaboration point)**

1 point for comparing answers (a) and (b) with an explanation of why the numbers in parts (a) and (b) would be the same or different (must be a viable reason)

OR

1 point for a good explanation of why (a) and (b) are different even if the calculations were not attempted.

1 possible elaboration point for explanations that go into great detail on why the numbers differ.

Possible acceptable explanations as to why the electrical output of the power plant and the community's consumption are different:

- The plant must be able to supply power during peak demand periods, not just supply power for the average energy use of the community
- The power company must plan to provide power for future growth of the community
- The plant does not run at full capacity 24 hours a day
- Consumption is less/more during different times of day/week/month/year
- Loss of energy during transmission (line loss) from plant to consumer
- The plant supplies energy to businesses and industry, not just homes
- The plant exports some of its power to the grid for use elsewhere
- Households may be using alternative energy sources (solar, etc.), and may be returning unused energy to the grid
- If a student says (a) is less than (b) with a viable reason for the difference (e.g., community uses other energy providers), points will be earned

Note: If students say that (a) and (b) are the same, they must state that this can only occur if the households have backup systems that will produce energy for them if they exceed the power generated by the plant.

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**Question 2 (cont'd.)**

- (d) Assuming that the electrical energy needs of the community do not change during the 25-year lifetime of the wind turbines, what would be the cost to the community of the electricity supplied by the WFWP over 25 years? Express your answer in dollars/kWh.**

**(2 points)**

1 point for correct setup.

1 point for correct answer with calculations.

Solutions to the question that use alternate setups and arrive at a correct answer will also earn points.

If a student's answer in part (b) is incorrect but the student appropriately uses it as the basis for the calculations for answering the question in part (d), the student will receive full credit for answering part (d) if the setup and calculations are correct, even if the answer is not one of the ones listed below.

Solution A: Based on current community consumption of  $2.4 \times 10^7$  kWh/year [from part (b)]

$$\text{kilowatt-hours for 25 years} = 2.4 \times 10^7 \text{ kWh/year} \times 25 \text{ years} = 6 \times 10^8 \text{ kWh}$$

$$\text{direct cost for 25 years} = 10 \text{ turbines} \times (\$3 \times 10^6/\text{turbine}) = \$3 \times 10^7$$

$$\text{cost/kWh} = \frac{\$3 \times 10^7}{6 \times 10^8 \text{ kWh}} = \$0.05/\text{kWh}$$

Solution B: Based on power being generated at full capacity (students may use either the rounded value of 8,000 hours/year or the more accurate 8,760 hours/year)

$$8,000 \text{ hours/year} \times 12 \text{ MW} = 96,000 \text{ MWh/yr}$$

$$96,000 \text{ MWh/yr} \times 1,000 \text{ kW/MW} = 96,000,000 \text{ kWh/yr}$$

$$96,000,000 \text{ kWh/yr} \times 25 \text{ years} = 2,400,000,000 \text{ kWh} = 2.4 \times 10^9 \text{ kWh}$$

$$\text{cost/kWh} = \frac{\$3 \times 10^7}{2.4 \times 10^9 \text{ kWh}} = \$0.01/\text{kWh}$$

Note: Only one point earned for solution B, because it assumes the plants work at maximum output. The question asked for cost based on community consumption.

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**Question 2 (cont'd.)**

- (e) Identify and explain TWO environmental benefits to West Fremont of switching from coal to wind power and TWO environmental costs to West Fremont of switching from coal to wind power.**

**(4 points)**

1 point for identifying each environmental benefit and a suitable explanation **linked** to the benefit. Benefits and costs must be *environmental* and not *economic* (e.g., agriculture). Only the first **two** benefits and explanations will be graded.

Acceptable benefits with explanation for switching to wind power include:

ENVIRONMENTAL BENEFIT	EXPLANATION
Perpetual/renewable resource	If connected to a specific environmental benefit
Reduce SO <sub>2</sub> , SO <sub>3</sub> , or SO <sub>x</sub> emissions	Reduce acid deposition
Reduce CO <sub>2</sub> emissions	Slow global warming/global climate change
Reduce CO emissions	Must link increased CO <sub>2</sub> as cause

ENVIRONMENTAL BENEFIT	EXPLANATION
Reduce dust and airborne particulate matter	Reduce a specific health risk
Reduce NO <sub>x</sub>	Reduce photochemical smog; ground-level ozone and associated health risks
Multiple use of land	If connected to an environmental benefit
Reduce thermal pollution from coolant waters of coal-burning power plant	Thermal shock; decreased dissolved oxygen content of water
Eliminate/reduce Hg, Pb, Cd, radioactivity	Reduce a specific health risk
Reduce acid mine drainage from coal mines	pH change in aquatic habitats
Reduce the need for coal mining	Reduce adverse effects of mining – mine drainage, erosion, etc.

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**Question 2 (cont'd.)**

1 point for identifying each environmental cost and a suitable explanation **linked to** the cost. Only the first two costs and explanations will be graded. Costs must be *environmental* and not *economic* (e.g., agriculture)

Possible acceptable costs with explanation for switching to wind power include:

ENVIRONMENTAL COST	EXPLANATION
Negative aesthetic effect	Impairs view of natural landscape
Harmful to birds/migration	Birds die when they fly into spinning blades
Land requirement/alterations for wind farms	Such as: cutting down trees to construct turbines leads to increased soil erosion
Winds are not always steady	Require a backup generation system that may cause air pollution
Noise pollution from spinning blades and/or generator	Negatively impacts animal behavior
Ecosystem fragmentation	Reduction in species population