ENERGY CALCULATIONS

2011

You ***MUST*** show your work every time. On the AP exam, you are ***not*** allowed to use calculators, so try to get used to it now. Set up all equations to cancel out the units.

10 PTS.

Example:

Let's say we want to determine the amount of coal needed to heat a 500 ft^2 room. In order to do this we need to know a few things before we can complete the calculation. First, we need to know how much energy (in BTU's) is needed to heat 1 ft^2 of the room.

Let's say that it takes 200 BTU's to heat 1 ft^2 of space. We can write this as $\left(\frac{200BTU}{1ft^2}\right)$

Then we need to know how much energy is contained in a set amount of coal. Let's say that 1 pound of coal produces 5,000 BTU's. We can write this as $\left(\frac{5,000BTU}{1pound}\right)$ or $\left(\frac{1pound}{5,000BTU}\right)$

According to these simple conversions we can figure out the amount of coal need to heat the room by simply multiplying the two conversion factors by the size of the room.

$$\left(\frac{200BTU}{1ft^2}\right)\left(\frac{1pound}{5,000BTU}\right)(500ft^2) = 20pounds$$

Practice Problems:

1. A major coal fired electrical power plant produces 13,000 MW-hr of electrical energy per day.

CALCULATOR

a. Assuming that 1.0 MW-hr corresponds to 3,400,000 BTU's, how many BTU's are produced by the plant each day?

$13,000$ mwh $\times \frac{3,400,000 \text{ BTU}}{1.0 \text{ mwh}} = 44,200,000,000$ BTU

4.42×10^{10} BTU

b. Assuming that one pound of coal can produce 5000 BTU's, how many pounds of coal are used by the plant each day?

$44,200,000,000 \text{ BTU} \times \frac{1 \text{ lb. COAL}}{5,000 \text{ BTU}} = 8,840,000$ lb COAL

8.84×10^6 lb COAL

2. A major coal fired electrical power plant uses 4500 tons of coal each day. Each pound of coal can produce 5000 BTU's of electrical energy.
Given: 3400 BTU's are equivalent to 1.0 kW-hr of energy.

CALCULATOR

a. How many kW-hr of electrical energy are produced by the plant each day?

$\frac{4,500 \text{ TONS}}{\text{DAY}} \times \frac{2,000 \text{ lbs.}}{1 \text{ TON}} \times \frac{5,000 \text{ BTU}}{1 \text{ lb.}} \times \frac{1.0 \text{ kWh}}{3,400 \text{ BTU}} = 13,235,294$ kWh

1.32×10^7 kWh

3. Use the following conversion factors to answer the questions:

In 2008, the average American home used about 11,000 kWh of electricity.

Conversion Factors

1 kwh = 3.41×10^{3} BTU (British Thermal Units)
1 BTU = 2.93×10^{-4} kWh
1 BTU = 1,055 J (joules)
12,000 BTU = 3.52 kWh = 1.27×10^{7} J

1 pound bituminous coal = 12,000 BTU
1 barrel oil = 5.6×10^{6} BTU = 5.91×10^{9} J
1 ft³ natural gas = 1,030 BTU = 1.09×10^{6} J
1 g ^{235}U = 4.0×10^{7} BTU = 4.22×10^{10} J

a. Suppose the electricity in your region was supplied by the burning of natural gas. How many cubic feet of natural gas is needed to support your energy lifestyle?

$$11{,}000\ \text{kWh} \times \frac{3410\ \text{BTU}}{1\ \text{kWh}} \times \frac{1\ \text{ft}^3\ \text{GAS}}{1{,}030\ \text{BTU}} = \boxed{36{,}417\ \text{ft}^3\ \text{GAS}}$$

b. Suppose coal was used in the generators instead of natural gas. How many pounds of coal would need to be burned?

$$11{,}000\ \text{kWh} \times \frac{3410\ \text{BTU}}{1\ \text{kWh}} \times \frac{1\ \text{lb. COAL}}{12{,}000\ \text{BTU}} = \boxed{3125\ \text{lb. COAL}}$$

c. Suppose the electrical power was supplied by nuclear energy. How much uranium would be needed for your yearly consumption?

$$11{,}000\ \text{kWh} \times \frac{3410\ \text{BTU}}{1\ \text{kWh}} \times \frac{1\ \text{g}\ U^{235}}{40{,}000{,}000\ \text{BTU}} = \boxed{0.938\ \text{g}\ U^{235}}$$

d. The cost for Uranium Oxide (U_3O_8), the primary nuclear reactor fuel, is \$10.15 per pound or about \$0.022 per gram. What would be the cost of the uranium to generate your electricity?

$$0.938\ \text{g}\ U^{235} \times \$0.022/\text{g} = \boxed{\$0.02}$$

e. Coal costs about \$24.38 per ton. What would be the cost of the coal to generate your electricity?

$$3125\ \text{lb. COAL} \times \frac{\$24.38}{\text{TON}} \times \frac{1\ \text{TON}}{2{,}000\ \text{lbs.}} = \boxed{\$38.^{10}}$$

f. Natural gas averages about \$4.67 per 1,000 cubic feet. What would be the cost of the natural gas to generate your electricity?

$$36{,}417\ \text{ft}^3\ \text{GAS} \times \frac{\$4.67}{1{,}000\ \text{ft}^3} = \boxed{\$170.^{07}}$$

W/O CALCULATOR

4. A family is building a new home in Alaska which experiences severe winters.

Assume the following:

- The house has 4000 square feet
- 100,000 BTU's of heat per square foot are required to heat the house for the winter
- Natural gas sells for \$5.00 per thousand cubic feet
- One cubic foot of natural gas supplies 1000 BTU's of heat energy
- 1 kilowatt-hour of electricity supplies 10,000 BTU's of heat energy
- Electricity costs \$50 per 500 kWh

a. Calculate the number of cubic feet of natural gas required to heat the house for the winter

$$4000\ ft^2 \times \frac{100{,}000\ BTU}{1\ ft^2} \times \frac{1\ ft^3}{1000\ BTU} = \boxed{400{,}000\ ft^3\ GAS}$$

b. Calculate the cost of heating the house using natural gas

$$400{,}000\ ft^3\ GAS \times \frac{\$5.00}{1{,}000\ ft^3\ GAS} = \boxed{\$2{,}000.00}$$

5. Use the following conversion factors to answer the questions:

1 gallon of water = 8 lbs. of water
1 kWH = 3,400 BTU's
1 BTU = the amount of energy to raise 1 lb. of water 1°F
1 lb. of coal can produce 5,000 BTU's.
Coal is 5% sulfur by mass.
1 ton = 2,000 lbs.
1 cubic foot of natural gas can produce 1,000 BTU's.
Natural gas is available at \$5.00 per one thousand cubic feet.

a. An average coal power plant produces 10 million kWH of electricity each day, how many pounds of coal are required to power an average electric plant each day?

$$10{,}000{,}000\ KWh \times \frac{3{,}400\ BTU}{1\ KWh} \times \frac{1\ lb.\ COAL}{5{,}000\ BTU} = \boxed{6{,}800{,}000\ lb.\ COAL}$$

6.8×10^6 lb. COAL

b. How much natural gas would be required to produce the same amount of energy as a single day at the coal power plant?

$$10{,}000{,}000\ KWh \times \frac{3{,}400\ BTU}{1\ KWh} \times \frac{1\ ft^3\ GAS}{1{,}000\ BTU} = \boxed{34{,}000{,}000\ ft^3\ GAS}$$

c. How much sulfur is produced by the coal power plant each day?

$$6{,}800{,}000\ lb.\ COAL \times \frac{5\%}{lb.\ SULFER} = \boxed{340{,}000\ lb.\ SULFUR}$$

6. A typical home in the northern U.S. might require 120 MBtu of heat for the average winter. One cubic foot of gas yields 1000 BTU of heat. The abbreviation ccf stands for 100 cubic feet.

If this heat were supplied by a natural gas furnace operating at 60% efficiency…

a. How many BTU is needed to heat the home?

$$120 \text{ mBTU} \times \frac{1{,}000{,}000 \text{ BTU}}{1 \text{ MBTU}} \times \frac{1}{0.6 \text{ EFF}} = 200{,}000{,}000 \text{ BTU}$$

2.0×10^8 BTU

b. How many cubic feet of gas would need to be purchased?

$$200{,}000{,}000 \text{ BTU} \times \frac{1 \text{ ft}^3 \text{ GAS}}{1000 \text{ BTU}} = 200{,}000 \text{ ft}^3 \text{ GAS}$$

c. At a cost of $0.90/ccf, what would it cost to heat this house for the season?

$$200{,}000 \text{ ft}^3 \times \frac{1 \text{ ccf}}{100 \text{ ft}^3} \times \frac{\$0.90}{1 \text{ ccf}} = \$1{,}800$$

7. A new 80% efficient furnace is installed (at a cost of $4000) in the house mentioned in Question #5,

a. How many BTU is needed for the *new furnace*?

$$120 \text{ mBTU} \times \frac{1{,}000{,}000 \text{ BTU}}{1 \text{ MBTU}} \times \frac{1}{0.8 \text{ EFF}} = 150{,}000{,}000 \text{ BTU}$$

1.5×10^8 BTU

b. How many ccf for the *new furnace*?

$$150{,}000{,}000 \text{ BTU} \times \frac{1 \text{ ft}^3}{1000 \text{ BTU}} \times \frac{1 \text{ ccf}}{100 \text{ ft}^3} = 1{,}500 \text{ ccf GAS}$$

c. What would it cost to heat the house for the season with the *new furnace*?

$$1{,}500 \text{ ccf} \times \frac{\$0.90}{1 \text{ ccf}} = \$1{,}350$$

d. How long would it take to pay back the initial cost of this new furnace (assuming natural gas prices stay the same)?

$$\$1{,}800 - \$1{,}350 = \$450$$

$$\frac{\$4000}{\$450} = 8.9 \text{ YEARS}$$

AP® ENVIRONMENTAL SCIENCE FREE-RESPONSE QUESTION

8. 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.

(a) 12 mw = 12,000 kw

12,000 kw × 8,000 hr/YR = **96,000,000 kwh/YR**

9.6×10^7

(b) 3,000 ~~Homes~~ × 8,000 kwh/~~Home~~ / YR. = **24,000,000 kwh/YR**

2.4×10^7

(c)
- PLENTY OF EXTRA ENERGY FOR PEAK TIMES OF NEED
- PLANNING FOR GROWTH OF CITY
- SELL EXTRA ENERGY TO THE GRID

(d) 24,000,000 kwh/~~YEAR~~ × 25 ~~YEARS~~ = 600,000,000 kwh

10 TURBINES × $3,000,000 = $30,000,000

$30,000,000 / 600,000,000 kwh = **$0.05 kwh**

AP® ENVIRONMENTAL SCIENCE FREE-RESPONSE QUESTION

9. Answer the questions below regarding the heating of a house in the Midwestern United States. Assume the following.

- The house has 2,000 square feet of living space.
- 80,000 BTUs of heat per square foot are required to heat the house for the winter.
- Natural gas is available at a cost of $5.00 per thousand cubic feet.
- One cubic foot of natural gas supplies 1,000 BTUs of heat energy.
- The furnace in the house is 80 percent efficient.

(a) Calculate the following, showing all the steps of your calculations, including units.

(i) The number of cubic feet of natural gas required to heat the house for one winter

(ii) The cost of heating the house for one winter

(b) Identify and describe three actions the residents of the house could take to conserve heat energy and lower the cost of heating the house.

(a)(i)

$$2{,}000\ ft^2 \times \frac{80{,}000\ BTU}{1\ ft^2} \times \frac{1\ ft^3}{1000\ BTU} = 160{,}000\ ft^3$$

1.6×10^5

$$160{,}000\ ft^3 \times \frac{1}{0.8\ \text{EFF}} = 200{,}000\ ft^3$$ ← FINAL ANSWER

2.0×10^5

(ii) $$200{,}000\ ft^3 \times \frac{\$5.00}{1000\ ft^3} = \$1000$$

(b) VARIES