C1000 Problem Set 4 (**Draft** 10/16/03; Menke)

Frontiers of Science (C1000) Problem Set 4 on Energy Relevant to Green House Gases

Energy is one of the key concepts for individual organisms and for industrial societies. Humans require energy derived from food consumption to sustain life. Our cells metabolize compounds such as carbohydrates and produce CO^2 and H^2O as waste products. We also use large amounts of energy for transportation, electricity generation, heating and cooling. This industrial energy is now primarily derived from combustion of fossil fuels which also generate CO^2 and H^2O as waste products. Emission of CO^2 from combustion of fossil fuels appears to be one of the largest impacts of humans on global climate.

The purpose of this exercise is to examine a few energy concepts relevant to modern human life and impacts of possible changes in energy sources and use patterns. Selected unit conversions, definitions, and energy use statistics are compiled in four Tables A, B, C and D.

1. The daily intake of food recommended by the US National Research Council are 2300 kcal per day for 25 year old women and 3200 kcal per day for 25 year old men. These are "average" figures - body mass, age and activity level all affect food requirements.

In the first part of this problem, we will deal with the amount of energy used during the course of a year. For historical reasons, several different units of energy are in common use. We will need to become familiar with all of them.

A) Calculate the amount of food energy, in kcal, consumed in a year by an "average" Columbia student.
B) Express your answer in A) in kilojoules.
C) Express your answer in A) in Btu and in Quads (10^{15} Btu)
D) Express your answer in A) in kilowatt-hours.

2. Power is the rate at which energy is expended. Thus if you expend a given amount of energy in a short time, you are using a lot of power, but if you expend the same amount of energy over a long time, you are using less power.

A) Calculate the rate of food energy consumption by the average Columbia student in Quads per year.
B) Express your answer in A) kilowatts (kilojoules per second).
C) How does the amount of food energy consumed by an average Columbia student compare with that required to keep a 100 watt (0.1 kilowatt) light bulb burning continuously?

3. Data for population and energy consumption for a total of 21 countries or groups of countries were compiled (Table C) from an annual report available from the US Department of Energy (Energy Information Administration). Use data from this table,

together with a calculator or computer spreadsheet to answer the following questions. Please document the details of your calculations, with units.

A) What are the three countries or regions with the highest use of total energy? List the total annual energy use in Quads for each of these countries, as well as the percentage of global energy use represented by each.

B) What three countries or regions have the highest total emissions of CO^2? List the total CO^2 emissions for each of these countries, as well as the percentage of global CO^2 emissions represented by each of these countries or regions.

C) What percentage of global consumption of each of the 7 categories of energy use takes place in the United States? How does this percentage compare with the percentage of global population living there?

D) What is ratio of per capita (that is, per person) Total energy consumption to per capita Food energy consumption for the following countries or regions: United States, France, Germany, Japan, Former Soviet Union, China, India, and the World? Assume the same food consumption rate as for the USA. Use units of Btu for both parameters to simplify the calculation.

E) What is per capita emissions of CO^2 for each of the following countries or regions (in Tons of C equivalent per person per year): USA, France, Germany, Japan, Former Soviet Union, China, India and the world?

4. The following questions relate to energy consumption in individual states the United States during 1999. You should be able to answer most of the questions by inspection of Table D from the Energy Information Agency of the US Department of Energy (DOE).

A) What was the average per capita consumption of total energy in the USA in 1999 (in Btu)?

B) What was the average annual per capita cost (in dollars) of this energy?

C) What was the total annual cost (in dollars) of energy consumption for the entire USA during 1999?

D) What fraction of Gross National Product (GNP) does this represent? You will have to look up the 1999 US GNP – it's not in the table.

E) Which 5 states had the highest per capita consumption of energy in 1999? List a few plausible reasons why these states had relatively high per capita energy consumption.

F) Which 5 states had the lowest per capita consumption of energy in 1999? List a few plausible reasons why these states had relatively low per capita energy consumption.

4. In developed countries, about 1/3 of total energy use is for trransportation of people and goods. Motor vehicles (cars, trucks, buses, motorcycles, etc) account for about half of global oil consumption. For each of the following explain the basis of your estimates and show details of calculations, including units.

A) Passenger motor vehicles in the United States are driven about 12,000 miles per year. The average vehicle consumes 19 miles per gallon of fuel (that is, gasoline and diesel). How many liters of fuel are used by each vehicle in a year?

B) Assume that each vehicle has, on average, 1.5 persons onboard. How many liters per day of fuel does each person consume? How does this compare to the amount of beverages that you drink each day?

5. T the US Congress is currently debating to whether to open the Arctic National Wildlife Refuge (ANWR) for exploration drilling for petroleum and natural gas. Although the actual amount of petroleum there has not yet been established (no cannot be exploratory drilling has yet been allowed), several credible estimates of total recoverable petroleum reserves at ANWR are about 3 billion barrels (a barrel is 160 liters or 42 gallons).

A) Using the current consumption rate of petroleum in the USA (millions of barrels per day) for all purposes (Table C), how much time would be required to consume 3 billion barrels of petroleum in the USA?

B) By how much (in % and in miles per gallon) would the average motor vehicle mileage need to be increased (from 19 miles per gallon) to accomplish savings of 3 billion barrels of fuel during the next 20 years (approximately the time after exploration drilling was completed before the discovered reserves were exhausted by pumping).

C) What would you recommend that the US Congress do about exploration drilling at ANWR?

6. Fuel efficiency of private motor vehicles in the USA could be increased substantially. As an example, for several years Toyota and Honda have been selling hybrid gasoline-electric cars that use about 1/3 less gasoline per kilometer traveled. Currently there are about 100,000 hybrid cars in the USA, with recent sales of about 30,000 per year.

A) Assuming the same distance traveled per vehicle, how many liters of gasoline are "saved" each year by each hybrid gasoline-electric car?

B) How many liters are saved each year by the current national fleet of hybrid cars?

C) What fraction of the current national fuel consumption are currently saved by hybrid cars?
D) How significant does this motor vehicle engine innovation appear to be in terms of reducing current emissions of CO^2?

7. As a thought experiment, suppose that we were to convert the entire electricity generation system in the United States to solar energy using solar panels that directly transform the sunlight that reaches the Earth's surface to electricity. The USA demand for electricity during year 2000 was about 3600 billion kilowatt-hours. Sunlight delivers 1.35 kilowatts at the top of the atmosphere to each square meter at the equator, but the actual power that one can retrieve in practice at the Earth's surface is much less for a number of reasons:

i) The sun shines only half the time (day vs. night);
ii) Temperate latitudes, where many people in the United States live, receive only 75% of the sun light per square meter than does the equator;
iii) Clouds and dust in the atmosphere reduce sunlight reaching the surface by about half;
iv) Solar panels are only about 10% efficient in generating electricity from a given amount of solar radiation received at the Earth's surface;
v) In practice, it would probably not be feasible to cover more than about 50% of the land surface in a solar electricity farm with solar panels, given other space requirements for generation, transmission, access for repairs, etc.

A. Estimate the total amount of sun light (in watts per square meter) reaching the ground at temperate latitudes.

B. Estimate the amount of electrical power per square meter (in kilowatts per square meter) of that a solar electricity farm could generate if it were located in temperate latitudes.

C. During the year 2000, 3600 billion kilowatt-hours of electricity was consumed in the United States. What was the rate of power consumption (in kilowatts), presuming that the enery was generated at a constant rate during the year?

D. In practice, substantial additional generating capacity is required because of variable average demand during the different seasons of the year, and during the day and night. Furthermore, some generating plants under repair, or not operating at full capacity. As an approximation to account for these factors, assume that generation capacity installed should be about twice as much as the total demand averaged over the entire year. What power production capacity was needed to meet US demand in year 2000.

E.Calculate how much area of the USA would have to be covered by solar energy farms to equal US electrical energy demand? Put this number in context by comparing it with: 1) the size of one huge solar panel farm to a sunny state in the southwestern USA; 2) the number of solar roofs that would have to be installed compared to the number of people in the US; 3) The kilometers of roads that would have to be paved with solar cells to the kilometers of road available in the interstate highway system (~120,000 kilometers).

8. Could we, should we, convert to solar electric power?

A) How long would it take to switch over to an entirely solar electricity network? Siemens, a major manufacturer of solar cells, estimates that the world production was about 120,000 kilowatts per year in 1998, and that that figure might grow to 1,000,000 kilowatts per year by 2010. At the latter rate (1,000,000 kilowatts per year), how long would it take to install sufficient capacity to supply electricity to the USA at the rate consumed in the year 2000?

B) The sun shines only half the day. How could night-time electricity be provided?

C) What would be some of the ecological and national security impacts of major power installations in the American West (positive and negative)?

9) A) Worldwide generating capacity of solar electricity is currently about 500,000 kilowatts (electric). What percentage of global electricity generation (1.36×10^{12} kilowatt-hour per) does this represent?

B) The worldwide rate of growth of solar electricity generation for the period 1990-2002 was about 20% per year. If this rate of growth could be sustained for the next 30 years, what would the global solar electric capacity be in 2034?

C) What fraction of global electricity generation in 2000 would this represent?

10) The New York City subway system is the largest single user of electricity in New York State (1.74 billion kilowatt-hours per year for traction power). The total annual number of subway passengers in 2001 was 1.4 billion). We will assume that the average trip length was 20 km.

A) How many passengers per day were carried by the NYC subway?

B) What was the electrical energy required to move a subway passenger one kilometer (in kilowatt-hour)?

C) Energy consumed as electricity by the subway required approximately three times as much fossil fuel energy to be combusted, due to losses in electricity generation processes, transmission, and thermodynamic limitations. Thus the total energy associated with moving each passenger is actually three times greater than computed immediately above. What was the total energy required to move a subway passenger one kilometer (in kilowatt-hour)?

D) What is the energy required to transport one person by car, assuming 19 miles per gallon for a private motor vehicle? It would probably be easier to first convert fuel use to person-kilometers per Liter of fuel. The energy content of 1 Liter of petroleum is about 10 kilowatt-hour.

E) Which (private motor vehicle or subway) is more efficient in terms of energy use per kilometer traveled? By what factor?