Problem Set #4 AOSC 633

Due: Tuesday, 9 May 2017

120 points total.

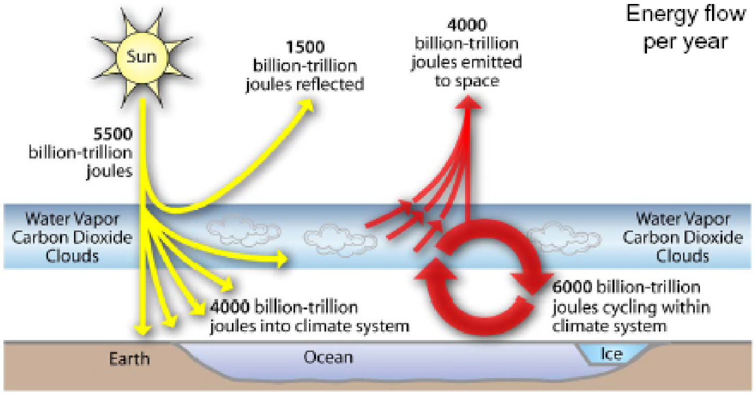
> **Late penalty**: ***<u>30 points per day late</u>***, unless there is a legitimate circumstance brought to our attention ***prior to the due date!***

1. Rising Sea Level and Earth's Energy Budget (40 points). Rising sea-level is one of the great concerns of global warming. If the entire Greenland Ice Sheet were to melt, global sea level would rise by about 7 meters.

a) (20 points) Estimate how much energy would be required to melt the Greenland Ice Sheet

> Hint: You can make a reasonable estimate of the volume of water contained in the Greenland Sheet given the information stated above and readily available additional information. Also, you can estimate the energy needed to melt the Greenland Ice Sheet using a physical constant that you should know about, but which has not been discussed in this class.

b) (10 points) This diagram shows the ***annual*** flow of energy into, out of, and within Earth's climate system:



This figure highlights the vast amounts of energy that flows through the climate system.

Assume it will take 100 years to melt the Greenland Ice sheet.

What fraction of the energy flow within the climate system (6000 billion-trillion joules) is needed to melt the Greenland Ice Sheet?

> Note: please remember to fold the 100 year time to melt the ice into your answer and *please use scientific notation* ☺

c) (10 points) Based on your answer to part b), should society be concerned about the possibility of a 7 meter rise in sea level, over a 100 year period of time?

2. Carbon capture and storage (40 points). The burning of fossil fuel within the United States presently releases about 5.8 Gigatons (5.8×10^9 tones) of CO_2 into the atmosphere per year. As we had worked out early in the semester, this is equal to 5.8×10^{15} grams of CO_2.

About half of this carbon remains in the atmosphere; the rest is absorbed by the world's oceans and forests.

Here we will estimate the land resource that would be needed to sequester atmospheric CO_2 into sodium carbonate Na_2CO_3, a stable (though caustic) way to store carbon. The physical properties of sodium carbonate are described at:

http://en.wikipedia.org/wiki/Sodium_carbonate

Our goal is to remove, on an *annual* basis, the amount of carbon released to the atmosphere ***that is not taken up by plants and trees***.

a) (10 points) What mass of sodium carbonate would be produced if the sequestered carbon is converted to sodium carbonate?

b) (20 points)

i) Using the density for sodium carbonate given at the above wiki page, what volume of sodium carbonate is consistent with the mass found in part a)?

ii) Assuming this sodium carbonate can be stored in a shelter of some type (it is caustic, and needs to be isolated from the environment) and that the shelter will be 4 stories high (i.e., 15 meters high), what would the area of the footprint of the building need to be to store this resulting "heap" of sequestered carbon?

iii) Assume, for sake of argument, that each state will house its share of sequestered carbon. Assuming Maryland gets to house 2% of the total US storage, what would be the "footprint" (surface area visible from Google Earth) of the needed structure?

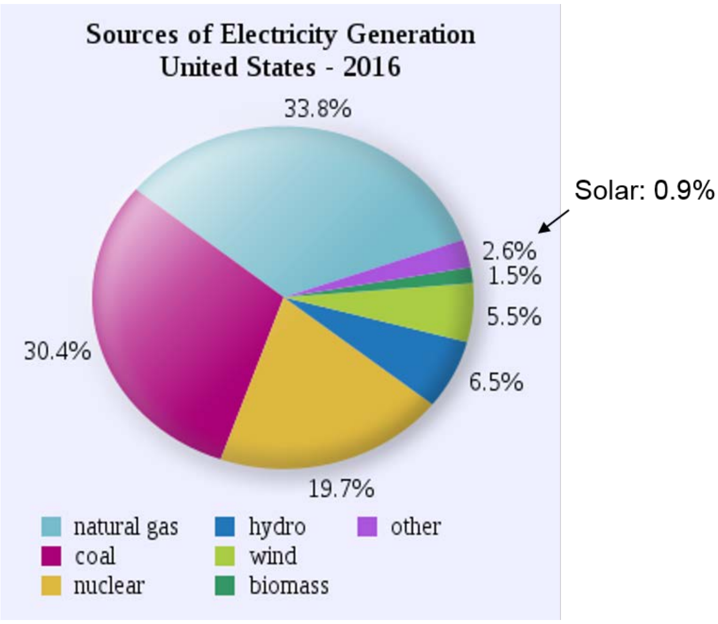
Do you believe a structure of this size is tenable to build?

c) (10 points) Now, assuming society decides to continue to rely on the combustion of fossil fuel to supply its energy needs for the next 50 years, what is the "footprint" needed to house the sequestered carbon for this period of time (you may assume fossil fuel emissions either stay constant with time, or grow at a reasonable rate of your choosing).

How does this "footprint" compare to the size of Maryland?

Is the use of this much surface area, for this need, tenable?

3. US Energy Needs and Solar Photovoltaics (40 points). The US currently consumes 4×10^{12} kilowatt-hrs in electricity per year, primarily from combustion of fossil fuels and nuclear energy, as shown in the figure below from Lecture 19:



Also:

$$1 \text{ kilowatt-hr} = 3.6 \times 10^6 \text{ J}$$
$$1 \text{ kilowatt} = 10^3 \text{ Watt}$$
$$1 \text{ W} = 1 \text{ J/s}$$

Here, we will explore the potential energy yield and cost of traditional solar photovoltaic (PV) arrays.

According to the 2010 census, the United States has 74 million single-family homes that house about 210 million people.

Assume that a decision is made to place a 5 kilowatt solar PV array on the roof of each single family home. ***5 kilowatt refers to the output of this system at noon (peak sun), for clear sky conditions.***

a) (15 points) What fraction of the US current electricity consumption would be provided if a 5 kilowatt solar PV system was placed on the roof of every US single family home?

> Note: in arriving at this estimate, please take into consideration the fact these systems only produce full energy under clear sky conditions, for overhead sun. We are looking for "reasonable estimates" of the annual electricity output from solar PVs, taking into consideration factors such as day vs night, clear sky vs cloudy sky, and that the sun sweeps through the sky each day (rough, "back of the envelope" estimates are needed for these factors).

b) (15 points) Assume each system costs $4.0 per watt of output (at full sun), as detailed at: http://costing.irena.org/media/8932/irena_costs_fig_511.jpg

i) How much would it cost to place a 5 kilowatt solar PV system on the roof of every single-family home in the United States?

ii) Assuming the gross domestic product (GDP) of the United States is the value given at the end of Lecture 19, what fraction of the US GDP would need to be expended, to place a 5 kilowatt solar PV system on the roof of every single-family home?

c) (10 points) If you were advising the United States government, would you recommend the government invest in the installation of a 5 kilowatt solar PV system on the roof top of every single-family home? Please support your reply with a sentence or two.