AOSC/CHEM 433 & AOSC 633 Atmospheric Chemistry and Climate

Problem Set #4

Due: Tuesday, 7 May 2019, at start of class

85 points

Please show all work. If you use a code to compute numerical values, attach a listing of the code, or if you use excel, attach (or email) the excel spread sheets.

Late Penalty: **10 points per day.**

Final deadline: Monday, 13 May 2019, 5:00 pm. ***No Credit*** for submissions after this deadline, because we will handout solutions at the review session held this time and date.

1. Assigned to 433 & 633. Carbon Capture and Storage (50 points). As we reviewed in Lecture 5, humans presently release about about 11 Gigatonnes (11×10^9 tonnes) of carbon into the atmosphere, due to combustion of fossil fuels, the manufacturing of cement, and biomass burning. As we had worked out early in the semester, this equals 11×10^{15} grams of carbon.

According to Table 2-1 of https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-chapter-2-trends.pdf the United States was responsible for release of 1.4×10^{15} grams of carbon into the atmosphere in 2017 (note this table gives mass of CO_2 released in units of million metric tons; we have converted to mass of carbon).

Here we will quantify the land resource 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. For the sake of this problem, assume there is a cost effective, environmentally friendly means to capture CO_2 and convert to Na_2CO_3.

Our goal is to calculate the land resource needed to sequester, on an *annual* basis, the carbon released to the atmosphere by the burning of fossil fuels. Since each nation will be responsible for sequestration of their own emissions, we will start with the total U.S. emissions for 2017.

a) (10 points) What mass of sodium carbonate would be produced for year 2017, if all of the carbon release by the U.S. could be converted to sodium carbonate?

b) i) (5 points) Using the density for sodium carbonate given at the wiki page cited above, what volume would be occupied by the mass of sodium carbonate found in part a)?

ii) (10 points) Because sodium carbonate is caustic, carbon sequestered in this manner must be stored in a shelter of some type. Assume that the shelter will be 4 stories high, about the height of the Atlantic building in which we meet. How much *surface area* (footprint of the buildings revealed on Google Earth) would be needed to store the resulting "heap" of sodium carbonate?

iii) (10 points) Assume that each state will be responsible for housing the carbon used by its residents: i.e., Maryland must house its share of the total U.S. storage. For simplicity, assume each state will be assigned to house a portion of the U.S. emission of carbon equal to the ratio of that state's population, relative to the total population of the U.S. Calculate the **surface area** "i.e., footprint that would appear on a 2-dimensional map" of the structure needed to house Maryland's carbon emissions for year 2017.

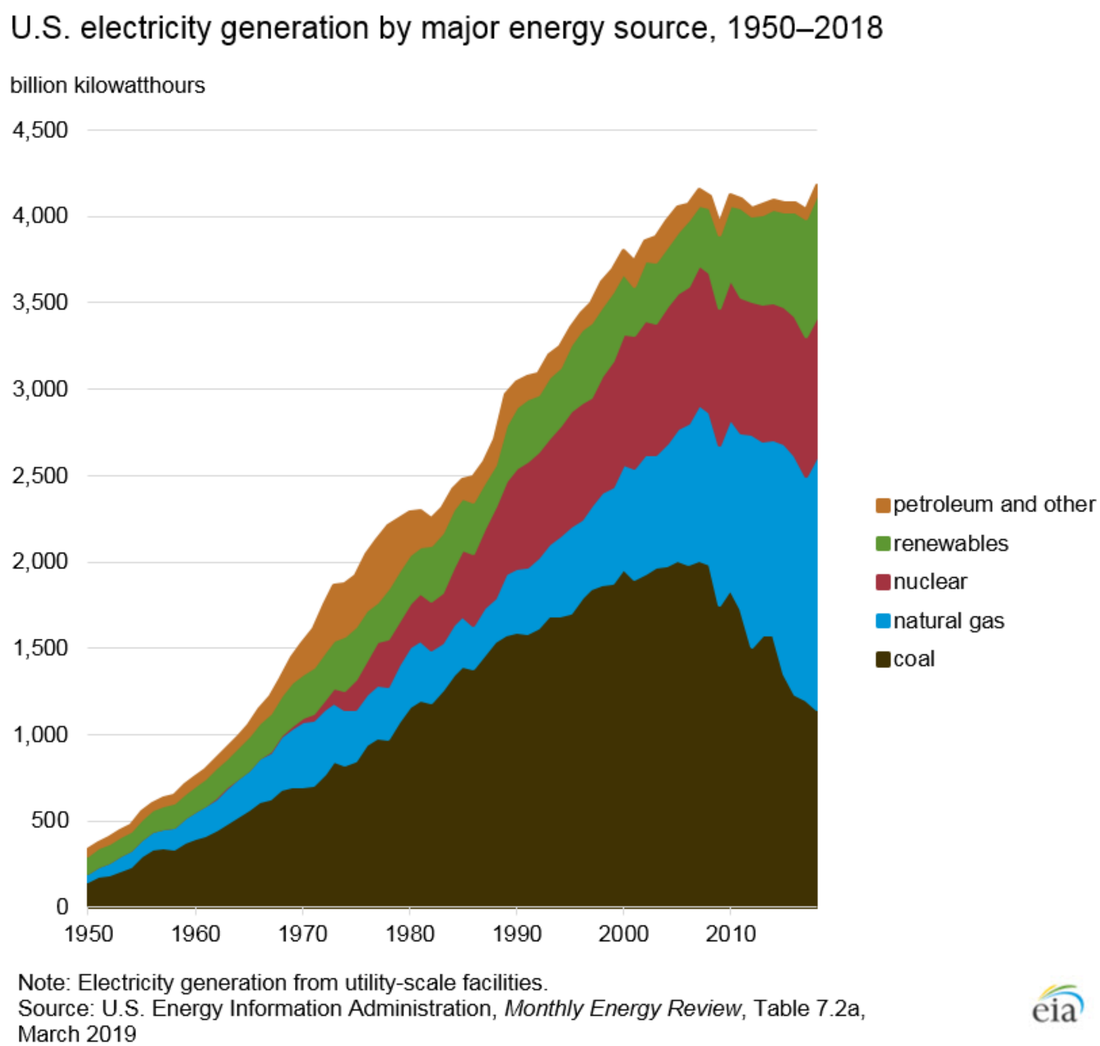
c) Assume for the next 50 years that society decides to continue to rely on the combustion of fossil fuel to supply its energy needs.

i) (5 points) What would the surface area "footprint" be, within Maryland, to sequester all of the carbon over the next 40 years, in the form of sodium carbonate? Make a ***reasonable assumption*** about how fossil fuel emissions will change over the next 40 yrs and ***describe your assumption***.

ii) (5 points) How does this surface area "footprint" compare to the size of Maryland?

iii) (5 points) In your opinion, is the use of this much land (i.e., your answer to ii) for carbon sequestration over a 40 year period of time "reasonable", from a pure land resource requirement? State a reply and support with a sentence or two.

2. Assigned to 433 & 633. US Energy Needs and Solar Photovoltaics (35 points). The U.S. currently consumes about 4.2×10^{12} kilowatt-hrs of electricity, with approximately 2.6×10^{12} kilowatt-hrs of electricity emanating from coal, natural gas, and petroleum, as shown on the chart below (from https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states and detailed in tabular form at https://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf).



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

According to https://www.statista.com/statistics/187576/housing-units-occupied-by-owner-in-the-us-since-1975/ , there are 79.4 million owner occupied homes in the U.S. that house 70% of the nation's population.

Assume that a decision is made to place a 6 kilowatt solar PV array on the roof of each single-family home. ***6 kilowatt refers to the output of this system at noon (peak sun), for clear sky conditions.***

Also:

1 kilowatt-hr = 3.6×10^6 J
1 kilowatt = 10^3 Watt
1 W = 1 J/s

a) (15 points) What fraction of the US current electricity consumption would be provided if a 6 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 at noon. 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) Assume each system costs \$3.00 per watt of output (at full sun), as detailed at:
https://news.energysage.com/how-much-does-the-average-solar-panel-installation-cost-in-the-u-s

i) (5 points) How much would it cost to place a 6 kilowatt solar PV system on the roof of each single-family home in the U.S.?

ii) (5 points) Using a gross domestic product (GDP) of \$20.5 trillion for the U.S. in 2018 as given at https://countryeconomy.com/gdp/usa, what fraction of the US GDP would be needed to place a 6 kilowatt solar PV system on the roof of every single-family home?

c) (10 points) If you were advising a U.S. Senator, would you recommend the government invest in the installation of a 6 kilowatt solar PV system on the roof top of every single-family home?

Please support your reply with a few sentences.