AOSC/CHEM 433 & AOSC 633 Atmospheric Chemistry and Climate

Problem Set #4

Due: Tuesday, 8 Dec 2020 (11:59 pm)

70 points

Late penalty: ***10 points*** per day late, unless there is a legitimate medical or extra-curricular circumstance that is brought to my attention ***prior to the due date!***

Final deadline: Thursday, 10 December, 2 pm: ***no credit*** will be given after this final deadline.

Please show all work!

1. Carbon Capture and Storage (35 points). As we discussed in Lecture 5, humans presently release about 12 Gigatonnes (12×10^9 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 12×10^{15} grams of carbon, or, equivalently, 44×10^{15} grams of CO_2.

According to Table 2-1 of https://www.epa.gov/sites/production/files/2020-04/documents/fastfacts-1990-2018.pdf the United States was responsible for release of 5.42×10^{15} grams of CO_2 into the atmosphere in 2018.

Many believe carbon capture and sequestration, on a grand scale, will be needed to avert climate catastrophe. An article on this topic is at https://www.iea.org/reports/direct-air-capture.

Here we will quantify the land resource needed to sequester atmospheric CO_2 into sodium carbonate Na_2CO_3, a stable (though caustic) means 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 either from exhaust plumes or even the atmosphere, and to convert the captured CO_2 to Na_2CO_3.

Your assignment 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 2018.

a) (5 points) What mass of sodium carbonate would be produced, if ***half*** of the CO_2 released to the atmosphere throughout the U.S. in 2018 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) (5 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 four stories high, about the height of the Atlantic Building on our Campus. How much *surface area* (*footprint* of buildings revealed on Google Earth images) would be needed to store the resulting "heap" of sodium carbonate?

iii) (5 points) Assume that each state will be responsible for housing its share of the captured sodium carbonate: i.e., Maryland must house its fair-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 that state's population divided by the total population of the U.S. in 2018. 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 2018.

c) Assume for the next 40 years that society decides to continue to rely on the combustion of fossil fuel to supply its energy needs.

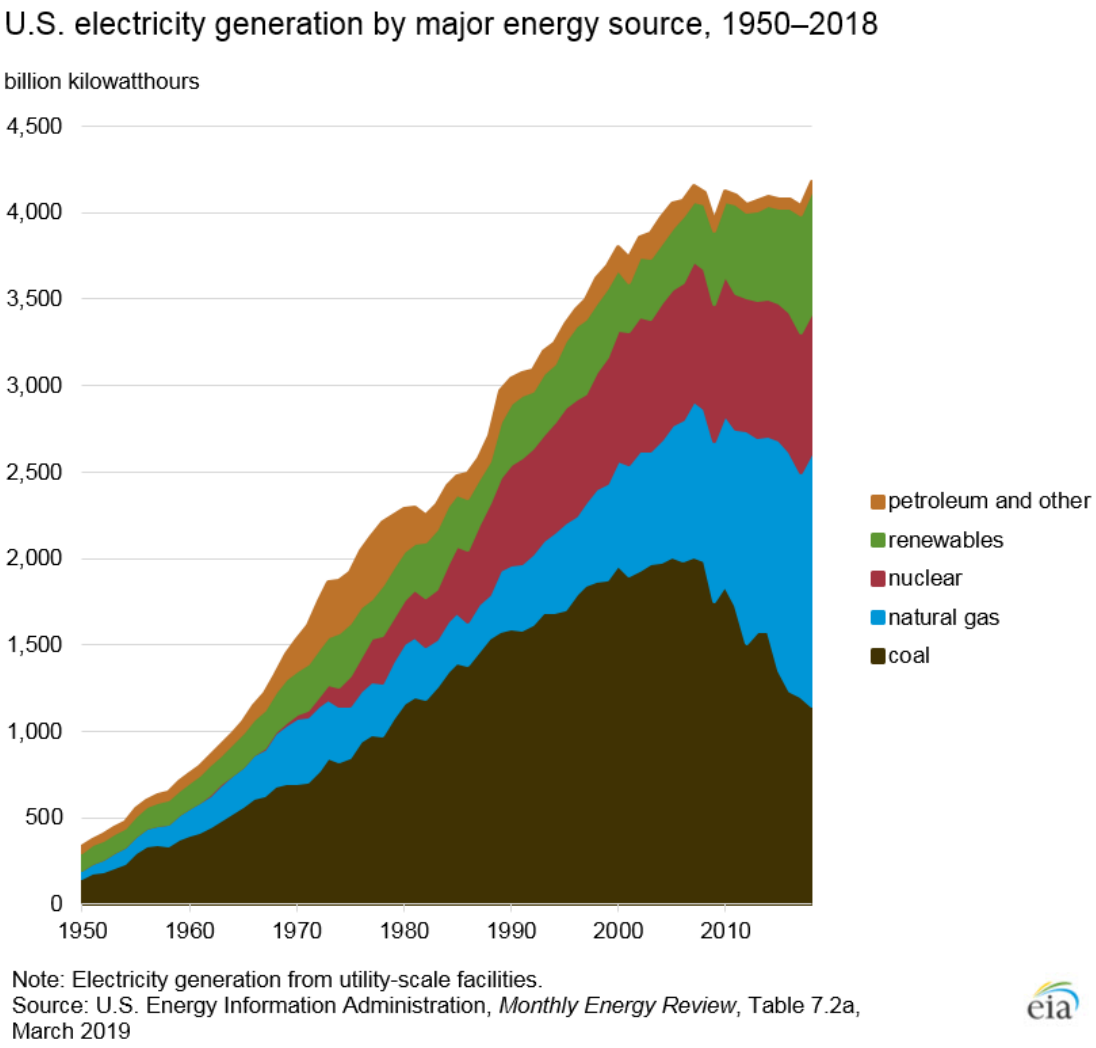
i) (5 points) What would the surface area "footprint" be, within Maryland, to sequester all of its share of our nation's CO_2 emissions over the next 40 years, in the form of sodium carbonate, if our country continues to capture ***half*** of our anthropogenic emitted CO_2, on an annual basis?

In answering this question, please make a *reasonable assumption* about how fossil fuel emissions will change over the next 40 yrs, and be sure to ***describe this assumption*** in your reply.

ii) (5 points) How does the surface area "footprint" needed to capture Maryland's share of our nations' sequestered CO_2 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? Please give your reply and support with a sentence or two.

2. 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, which is from https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states.



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 80.68 million owner occupied homes in the U.S.

Assume that a decision is made to place an 8 kilowatt solar PV array on the roof of each single-family home. ***8 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 an ***8 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 $2.91 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 an 8 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 $21.43 trillion for the U.S. in 2019 as given at https://countryeconomy.com/gdp/usa, what fraction of the US GDP would be needed to place an 8 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 that the government invest in the installation of an 8 kilowatt solar PV system on the roof top of every single-family home?

Please support your reply with a few sentences.