Problem Set #4 **AOSC 433 & CHEM 433**

Due: Tuesday, 9 May 2017

140 points total.

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

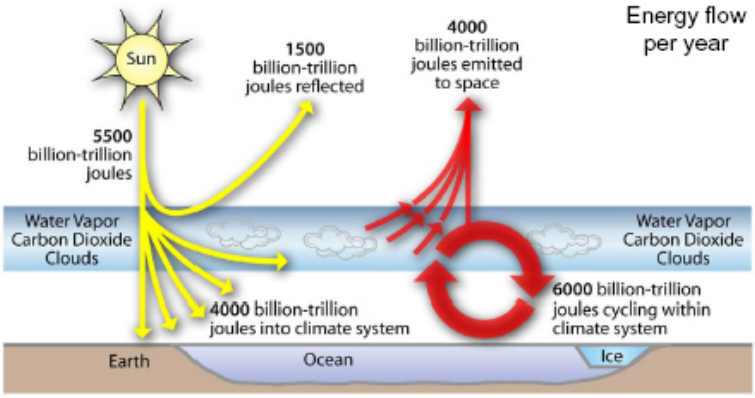
Please complete 2 of the first 3 questions (your choice). Everyone must complete question 4.

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 the latent heat of fusion required to melt water is 334 kJ/kg. Of course, you have to relate volume of the Greenland Ice Sheet to the mass of this Ice Sheet. If you have no idea how to proceed, please see Ross or Pam.

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. An analysis of the leakage of CH_4 from fracking (40 points).

a) (5 points) For each molecule of CO_2 released to the atmosphere, how much more energy is produced via the combustion of CH_4 compared to the combustion of coal?

Please express the answer as the ***ratio*** of the energy produced from the combustion of CH_4 divided by the energy produced via the combustion of coal.

Show your work: i.e., don't just write a ratio but rather describe how this ratio was found, and provide a source (could be lecture notes or readings) for your numbers.

b) (15 points). The extraction of CH_4 via fracking is notoriously leaky, at the few percent level. Here, we will calculate the fraction of CH4 leakage that would negate the climate benefit of using natural gas, rather than coal, to generate electricity.

First, compute the Global Warming Potential (GWP) of CH_4 on a 100 year time horizon, on a per molecule basis. Again, show your work and provide a source for your numbers.

Next, making use of your answer for a) above, compute the break-even point for the accidental release of CH_4 from fracking: i.e., if a certain **fraction** of CH_4 is released directly to the atmosphere rather than burned, at what fractional leakage amount will the climate penalty of direct release of CH_4 to the atmosphere balance the climate benefit of burning CH_4 rather than coal?

> Hint: A good way to start would be to assume that for the production of a certain amount of energy via combustion of CH_4, one CO_2 molecule is released to the atmosphere. Next, you should assess how many molecules of CO_2 would be released to the atmosphere, upon generation of the *same amount of energy* via combustion of coal. Then, set up an equation for the CO_2-equilament emission from your two processes: 1) the combustion of CH_4 plus the inadvertent release of an unknown amount of CH_4; 2) the release of CO_2 from the combustion of coal. Since the same amount of electricity should be provided by both processes, you can set the two CO_2-equivalent emission relations equal to each other, and solve for the unknown amount of CH_4 release. If you have no idea how to proceed, please see Ross or Pam.

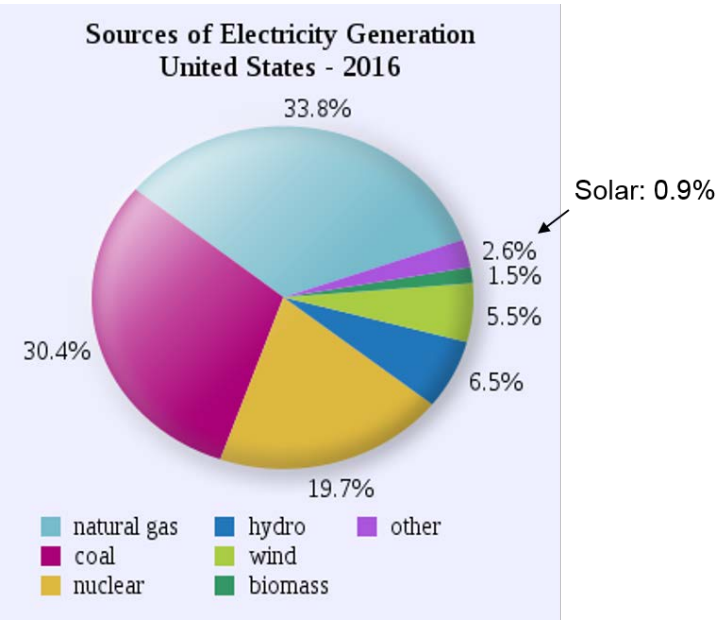
Express your answer as a fraction: i.e., what fraction of CH_4 can be released, rather than burned, such that combustion of natural gas *exerts the same toll on climate* as the combustion of coal.

c) (15 points) Repeat b), using the GWP of CH_4 on a 20 year time horizon.

d) (5 points) Suppose observations of CH_4 over an active fracking operation show that 4% of the gas leaks, relative to overall production. Is this a concern?

> Use your answers from b) & c) above to support your reply.

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.

4. Plan for The U.S. To Meet Its Future Energy and Needs (60 points)

Ross & Pam will read each reply carefully and make an assessment based on our view of how well material presented throughout the class, or perhaps gleaned from other sources, is integrated into a coherent, thoughtful reply. We look forward to learning from your replies ☺.

You are the Energy Advisor of a candidate for preparing for the 2020 election for President of the United States. The candidate has asked you to present a plan for the nation to meet its future energy needs, taking into account climate change, air quality, and the candidate's long-term vision for a high quality of life for US citizens. Specifically, the candidate has asked you to address the Nation's future *electricity supply* and *energy* needs in a manner that is both environmentally friendly and cost effective over the long–term, even if the plan requires significant initial investment.

The candidate's parting words when describing this request were "when dealing with energy, it is hard to separate the charlatan from the prophet".

As part of your plan to gain advocacy for your vision of America's energy future, you have decided to produce a "one page" briefing paper for the candidate that highlights the plan.

Please share your ***one-page*** plan for America's energy future. Your reply can take whatever format you'd like: i.e., paragraphs, bullet statements, etc are all fine. Your reply can be produced using Word, Powerpoint, etc. The only requirement is that your plan ***fit onto a single piece of paper (one side)*** ☺

Please write your name on the back, so that we can read your response without knowing by whom it was written (use a pencil if you think your name will show through the paper).

We will select a small number of responses for presentation in class on 11 May 2017.

If your response is selected, we will contact you prior to 5 pm on 10 May ☺