MAE 119 Winter 2015
Professor G.R. Tynan
FINAL EXAM
CLOSED BOOK CLOSED NOTES
NO ELECTRONIC DEVICES PERMITTED

PART I: MULTIPLE CHOICE. 5 points each.

1. Over the next 30-50 years global power demand (integrated over all end uses) is anticipated to grow to what rough value?
   a. 200-300 GW
   b. 2-3 TW
   c. 20-30 TW
   d. 200-300 TW

2. What fraction of energy demand is currently met by fossil fuels?
   a. 99%
   b. 80%
   c. 50%
   d. 30%

3. Which renewable energy source technology can most readily incorporate large-scale heat storage into the system design?
   a. Solar PV
   b. Wave power
   c. Wind
   d. None of the above

4. Which of these renewable technologies do not scale to meet at least 10% of human energy demand?
   a. Wave power
   b. Tidal power
   c. Conventional geothermal energy
   d. All the above

5. Historically, roughly how long has it taken in the past for primary energy sources to evolve from one source to another?
   a. 5 years
   b. 20 years
   c. 50 years
   d. There isn’t enough information given to answer

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PART II: Solve any 5 problems. All problems are 20 points each.
CLEARLY LABEL THE PROBLEM NUMBERS IN YOUR SOLUTIONS!

1. *Drivers of energy demand & expected future demand growth:* Suppose all of today's human population (about 7Billion) were to consume 4000 kW-hr of electrical energy per year.
   - *a.* If this energy is produced by burning coal, how much annual carbon emission results from this energy consumption? Assume coal releases 30 MJ/kg, and that coal is 100% carbon, and that the coal is converted into electrical energy with an efficiency of 30%. An answer to one significant figure is sufficient.
   - *b.* If the coal were to be replaced by natural gas (with an energy content of about 50 MJ/kG) at 50% net efficiency, what would be the new global carbon emission rate?
   - *c.* How does this compare to the current (2015) carbon emission rate? In 2015 annual CO_2 emissions are a little less than 40 Giga-Tonnes, or about 10 Giga-Tonnes of carbon)

2. *Climate change basics: Earth's heat balance:* Visible light with an intensity I uniformly illuminates a planet with an atmosphere. Due to clouds and ice crystals, the atmosphere reflects half of this radiation to space. The other half is absorbed by the ground which then emits infra-red radiation. The atmosphere contains greenhouse gas molecules and thus absorbs 50% of the IR radiation, half of which is emitted to space and the other half emitted towards the planet's surface.
   - *a.* Find an expression for the planet's surface and atmospheric temperatures.
   - *b.* If the greenhouse gas molecular density is doubled in the atmosphere, find new expressions for the surface and atmospheric temperatures.

3. *Climate change basics - Carbon balance:* Suppose we stop the growth of carbon emissions today, and manage to keep global carbon dioxide emissions into the atmosphere constant into the indefinite future. If the net exchange time-scale for carbon (in the form of CO_2) to be absorbed out of the atmosphere is 100 years, estimate the final steady-state carbon concentration in the atmosphere. (Hint: the pre-industrial atmospheric CO_2 concentration was about 250 ppm, which corresponds to a carbon mass of about 500 Giga-Tonnes. In 2015 annual CO_2 emissions are a little less than 40 Giga-Tonnes, or about 10 Giga-Tonnes of carbon)

4. *Deep geothermal energy:* Work out a conceptual design of a 100 MW deep geothermal "heat mine" that uses the Earth's heat gradient of 20 deg K/km of well depth to tap into the thermal energy of 1 km^3 of rock. Address the following elements of the conceptual design:
   - *a.* Assuming an ideal heat engine, how deep does the well need to be to have an initial conversion efficiency of at least 20%? Assume the cold reservoir is at 300 deg K.
   - *b.* If rock has a density of 10000 kG/m^3 and a thermal capacity of 1000 kJ/kG-deg K, how much total thermal energy can be removed before the rock temperature falls by 100 deg K?

   c. Once the ramp temperature has fallen by 100 deg K, what will the thermal conversion efficiency then be?
   d. Using the results from parts (b-c), estimate the lifetime of this "heat mine".

5. *Wind energy:* You have a wind turbine with a maximum power rating of 5 MW available for use in a wind farm. This turbine can operate in winds ranging from a minimum speed of 2 m/sec up to a maximum wind speed of 10 m/sec (which is when the turbine produces it's maximum power). You have two possible sites available: the first site has a steady wind that always blows at 6 m/sec. At the second site, the wind blows at 1 m/sec for 50% of the time, and at 10 m/sec for the other 50% of the time.
   a. If maximizing the peak power production is the most important consideration, which site should you choose? What will be that maximum power for a single turbine?
   b. If maximizing the average power production is the most important consideration, which site should you choose? What would be this average power for a single turbine?

6. *Solar Thermal:* The Ivanpah solar thermal power station has a maximum power capacity of about 400 MW of electrical power using a steam-based Rankine cycle, and covers a land area of about 16 km^2. The current design does not include any thermal storage and so the plant cannot produce power at night or when any clouds pass overhead. Assuming the sun shines 50% of the time, estimate the required volume for a molten-salt thermal storage system that would allow the plant to operate 24 hours a day with a constant power output. The peak molten salt temperature would be 800 deg K, and a maximum temperature drop of 200 deg K. The salt has a specific heat of 1 kJ/kG and a density of 2000 kG/m^3. If you cannot increase the collecting area of the plant, estimate the achievable steady-state power output if the plant thermal conversion efficiency is unchanged.

7. *Solar PV:* You have solar cells with an open circuit voltage V_{oc}=1 V and a short-circuit current I_{sc} = 0.1 Amps/cm^2 of cell surface area, and when you plot the current-voltage characteristic of the cell, you find that this particular design has a form factor FF=0.7. You have identified a site with land area equal to 10 km^2 and the solar intensity I=500sin(2pi t/T) (here I is measured in Watts/m^2) for 0<t<12 and I=0 for 12<t<24. Here pi=3.1415… and T = 24 hours is the duration of a day (note that here t=0 is the time when sunrise occurs).
   a. If you build a large scale PV power plant at this site using these cells, what is the power production vs. time for the site?
   b. What is the peak power production?
   c. Suppose you have an energy storage system available to allow the plant to produce steady-state electrical power. What would be the power output in that case? [Hint: consider the total energy input into the plant over a day and relate this to average power].
   d. If you can triple the minority carrier lifetime in the cell by improving the cell manufacturing process, estimate the effect on power output.