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SUSTAINABLE ENERGY

Spring 2004

MID-TERM EXAM

PROBLEM #1 (30%)

We desire to have a decommissioning fund of $500 million accumulated at the end of the 60-year lifetime of a photovoltaic power plant. The real estate interest is 5% per year.

QUESTIONS

A. What annualized rate of payments is needed in order to provide this fund?

i) In the absence of inflation.

ii) If the rate of inflation were equal to 5% annually.

B. How much of this money should be reserved for treatment of potential future environmental liabilities (e.g., due to toxic chemical residues) in order to provide compensation of $100 million for a fatality that occurs 100 years after shutdown?

PROBLEM #2 (35%)

A. Consider a pumped hydro system that is used for energy storage. During off-peak hours, excess electricity is used to pump water up to a storage reservoir. During peak demand periods the flow is reversed and electric power is generated by flowing the water through a hydraulic turbine. The storage reservoir is 100 m above the hydro turbine/pump units and the hydraulic turbine can accommodate up to 650 kg/s of flow (taking into account the full flow-based power capacity of the turbine). Estimate the theoretical energy and power density of the system that stores water during the times that power is generated. Express your answer in J/m^3 for energy density and W/m^3 for power density. Is it possible to plot your estimate on the Ragone plot shown in Figure 16.5? Explain. Data are given below.

B. What is the maximum energy per square meter of water surface area that could be obtained from a tidal power station located at the Bay of Fundy where the mean tidal height range is 5 m high? [Hint: Consider that the tide brings a volume of water that covers a basin area, A, and varies the height of the water surface from 0 to 5 m.]

C. What additional energy could be extracted if the mean flow velocity of water through the tidal basin is 1 m/s throughout the year? [Background: Consider that a river flow into a tidal estuary. At the location of the dam impounding the water, where the power turbine is located, the steady mean flow velocity (imposed by the riverine flow) is superimposed by an oscillating flow due to the tidal rise and fall.]

Data
- Density of water is 1000 kg/m^3
- Acceleration of gravity is 9.8 m/s^2
- Heat capacity of water is 4200 J/kgK
- Viscosity of water is about 1 centipoise
- Width w = 1000m
- Depth d = 5m

PROBLEM #3 (35%)

The Earthday ecological footprint quiz you did in problem set 1 showed that the average American has a "footprint" of 24 acres. If you travel by airplane 100+ hours per year, the footprint quiz estimates that you use up about 6 acres of land equivalent. Is this a reasonable estimate based on the associated CO_2 emissions?

QUESTIONS

A. Calculate the biomass energy (BTU) and weight (ton) yields per acre of average U.S. land using the data below.

B. Calculate the amount of carbon emissions from 100 hours of air travel a year and the amount of land required to sequester that amount of carbon, based on typical data given below.

C. How much land (acres) would be required to produce methanol fuel that would substitute in energy content for the jet fuel used?

D. Write your comments on the footprint quiz estimate for air travel based on your above analyses. What do you think is the most reasonable estimate?

Data
- Typical energy use per passenger mile for commercial aircraft is 4100 BTU/mile
- Typical average speed of commercial air trip is 400 mph
- Assume jet fuel is about 85% carbon by weight, has a density of about 40 lb/ft^3 and a heating value of about 11 kcal/g
- Solar constant is 1.94 cal/cm^2-min
- U.S. average solar incidence is 13.6% of solar constant
- Conversion to high yield biomass energy crops is about 0.5% of solar incidence
- Assume that about 50% of the biomass crop weight is carbon and that it has a heating value of about 8000 BTU/lb
- Production of methanol from wood yields about 700 liters per ton of dry wood
- Heating value of methanol is about 1.58×10^4 MJ/m^3