ER120 *Renewable Energy*, Spring, 2002: Problem Set 1

Due in class March 14, 2002

1. Consider two biomass power plants with an output of 20 MW_e. The first is a conventional steam-cycle plant burning woodwaste from a variety of sources like urban woodwaste, orchard trimmings, and timber offcuts and sawdust (all common fuels in California's biomass power plants). The second is gasifier with a gas turbine that uses the heat from its exhaust to raise steam that is then fed into a steam turbine (this is a biomass integrated gasifier combined cycle system or BIG/CC for those of you who are trying to follow the acronyms). The gasifier uses willow trees grown on a dedicated short rotation energy plantation. For this exercise you will compare the emissions from the two power plants with different assumptions about the conditions of combustion.

   You should work with the following assumptions for each part of the problem. The steam-cycle plant is 25% efficient and the BIG/CC is 45% efficient. The heat content of both fuels is roughly 16 GJ/ton. In both cases, the biomass can be represented by the chemical formula $C_6H_{12}O_6$. *Be sure to state clearly any additional assumptions that you make and cite sources where applicable.*

   a) Under ideal conditions, burning a hydrocarbon fuel like biomass produces water vapor CO_2 and heat. If this is the case for both of our plants, estimate how much carbon as CO_2 is released per kWh of electricity produced in each plant.

   Now lets assume the combustion isn't ideal so that you actually get various mixtures of CO_2, CO, gaseous hydrocarbons, particulate matter (PM) and ash.

   b) First for the steam-cycle plant - Typically a boiler for a steam turbine might be 90% efficient, which means that 90% of the energy content of the input fuel is converted to heat. The remaining 10% of the fuel's energy remains "trapped" in PICs. If we assume that PICs consist of only CO and PM, this means that roughly 40 gm-C as CO and 1 g-C as PM are emitted for every kg of biomass burned in the boiler. With this in mind, estimate the emissions in g-C per kWh of electricity for CO_2, $CO_,$ and PM in this slightly more realistic model of a steam-cycle biomass plant.

   c) Now, for the gasifier - A gasifier partially pyrolizes biomass feedstock in the presence of air. The cleaned "producer" gas generally consists of a mixture of N_2, CO_2, CO, H_2, and CH_4 in a range of proportions given in the table below. This gas is then sent to a turbine where it is cleanly combusted to yield CO_2 and water vapor. See the notes from lecture 3 for the gory details of the combustion reactions and remember that volume and mole number are directly related for ideal gases.

	N_2	CO_2	CO	H_2	CH_4
% by volume (and moles)	50-54	17-22	9-15	12-20	2-3

Out of the constituent gases in this table, identify what burns and what doesn't? Assume that 99% of the combustibles in our producer gas are cleanly combusted in the turbine so that they are emitted as CO_2 and water vapor. This means 1% of our producer gas escapes out the stack, what are the emissions of CO_2, CO, and CH_4 in g-C per kWh of electricity produced? Ignore the H_2 and assume there is no PM. How does the more realistic BIG/CC compare to the ideal case and to the boiler/steam-cycle combo?

2. Now that we've examined biomass electricity production at the level of two hypothetical plants, lets think about the land area required to actually get a substantial portion of the world's energy supply from biomass. A lot of forecasts, including ones in Reddy et al, estimate that biomass could provide a significant fraction of the world's energy supply midway through this century. Taking a nice round figure of 100 EJ (a tad less than a quarter of the world's *current* primary energy consumption), estimate how much land is needed to provide 100 EJ *primary energy* (that is, energy measured before conversion into a useful fuel or electricity).

   The hint here is that there are no hints. Make your own assumptions based on information you find in the readings, on the web, or elsewhere. Be sure to state your assumptions clearly, cite your references, and show all of your work. There is no exactly correct answer because the numbers depend strongly on the assumptions you make so try to come up with a reasonable range of values. To get an idea of what this range of means, compare it to the area of your home state or country…is it much bigger or smaller? What is the likelihood of an industrialized country or the entire world generating ¼ of its primary energy from biomass? Remember that in many countries, the proportion of primary energy that comes from biomass is actually much higher than 25% and some exceed 90%, but this isn't what the forecasters had in mind…

3. Using the internet as a resource, try to find data for the monthly insolation in your hometown (or as close as possible). This data is typically reported as the average daily solar radiation in kWh/m^2 (energy per unit area) that falls on a flat surface facing south (or north in the southern hemisphere) and tilted above the horizontal at the angle the location's latitude.

   For a fun comparison, if you're from a temperate area in the US or Europe, choose a site from the tropics to compare to your hometown. Pick a place that you've been to or that you've always wanted to visit (Timbuktu, Fiji, Mumbai, La Paz, you decide…). If you're from a country in the tropics, choose a temperate location to make your comparison. Of course, pick a place with data that's available on the web or in some reference you have on hand. How do the two locations compare? Are there any aspects of the solar irradiation at the two locations that surprise you? Why?