Renewable Energy II

Biomass

Other Renewables

Biomass

- Biomass is any living organism, plant, animal, etc.
- 40×10^{12} W out of the $174{,}000\times10^{12}$ W incident on the earth from the sun goes into photosynthesis
  - 0.023%
  - this is the fuel for virtually all biological activity
  - half occurs in oceans
- Compare this to global human power generation of 12×10^{12} W, or to 0.6×10^{12} W of human biological activity
- Fossil fuels represent *stored* biomass energy

Photosynthesis

- Typical carbohydrate (sugar) has molecular structure like: $[CH_2O]_x$, where x is some integer
  - refer to this as "unit block": $C_6H_{12}O_6$ (glucose) has x=6
- Photosynthetic net reaction:

$$xCO_2 + xH_2O + \text{light} \rightarrow [CH_2O]_x + xO_2$$

1.47 g 0.6 g 16 kJ 1 g 1.07 g

- Carbohydrate reaction (food consumption) is essentially photosynthesis run backwards
  - 16 kJ per gram is about 4 kilocalories per gram
- Basically a "battery" for storing solar energy
  - usage just runs reaction backward (but energy instead of light)

Photosynthetic efficiency

- Only 25% of the solar spectrum is useful to the photosynthetic process
  - uses both red and blue light (reflects green), doesn't use IR or UV
- 70% of this light is actually absorbed by leaf
- Only 35% of the absorbed light energy (in the useful wavelength bands) is stored as chemical energy
  - the rest is heat
  - incomplete usage of photon energy just like in solar PV
- Net result is about 6%

Realistic photosynthetic efficiency

Location	Plant Production (g/m^2 per day)	Solar Energy Conversion Efficiency
Potential Maximum	71	5%
Polluted stream (?!)	55	4%
Iowa cornfield	20	1.5%
Pine Forest	6	0.5%
Wyoming Prairie	0.3	0.02%
Nevada Desert	0.2	0.015%

How much biomass is available?

- Two estimates of plant production in book come up with comparable answers:
  - 10^{17} grams per year
  - 320 grams per m^2 averaged over earth's surface
  - consistent with 40×10^{12} W photosynthesis
- U.S. annual harvested mass corresponds to 80 QBtu
  - comparable to 100 QBtu total consumption
- U.S. actually has wood-fired power plants: 6,650 MW-worth
  - burn wood equivalent of 1,000,000 barrels of oil *per day*
  - about a fifth of this for electricity production

Ethanol from Corn

- One can make ethanol (C_2H_5OH: a common alcohol) from corn
  - chop; mix with water
  - cook to convert starches to sugars
  - ferment into alcohol
  - distill to separate alcohol from the rest

Why are we even talking about Ethanol?!

- We put more energy into agriculture than we get out (in terms of Caloric content) by about a factor of 2–10
  - at least in our modern, petrol-based mechano-farming
  - sure, we can do better by improving efficiencies
- Estimates on energy return from corn ethanol
  - controversial: some say you get out 0.7 times the energy out that you put in (a net loss); others claim it's 1.4 times; often see numbers like 1.2
  - 1.2 means a net gain, but 83% of your total budget goes into production; only 17% of crop is exported as energy

Ethanol, continued

- Right now, using tons of fossil fuels to get ethanol
  - and not clear we're operating at a net gain
- Why on earth are we trying?
  - corn has worked its way into many of our foods
    - high fructose corn syrup
    - cow feed
    - corn oil for cooking
  - powerful presence in the Halls of Power
    - the corn lobby is responsible for pervasiveness of corn in our diet (soft drinks)
    - are they then implicated in U.S. health/diet problems?

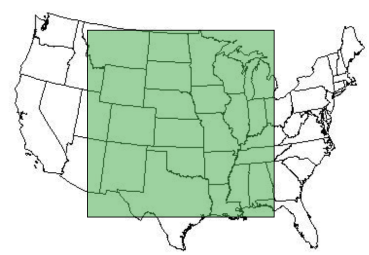
Ethanol problems, continued

- Energy is a high-payoff business, especially when the government helps out with subsidies
  - thus the attraction for corn ethanol (which *does* get subsidies)
- Can supplant actual food production, driving up price of food
  - there have been tortilla shortages in Mexico because corn ethanol is squeezing the market
  - after all, we only have a finite agricultural capacity
  - both land, and water are limited, especially water
- Ethanol from sugar cane can be 8:1 favorable
  - Brazil doing very well this way: but corn is the wrong answer!
  - but lookout rain forests: can actually increase CO_2 by removing CO_2-absorbing jungle

Quantitative Ethanol

- Let's calculate how much land we need to replace oil
  - an Iowa cornfield is 1.5% efficient at turning incident sunlight into stored chemical energy
  - the conversion to ethanol is 17% efficient
    - assuming 1.2:1 ratio, and using corn ethanol to power farm equipment and ethanol production itself
  - growing season is only part of year (say 50%)
  - net is 0.13% efficient (1.5% × 17% × 50%)
  - need 40% of 10^{20} J per year = 4×10^{19} J/yr to replace petroleum
  - this is 1.3×10^{12} W: thus need 10^{15} W input (at 0.13%)
  - at 200 W/m^2 insolation, need 5×10^{12} m^2, or (2,200 km)^2 of land
  - that's a square 2,200 km on a side

What does this amount of land look like?



We don't *have* this much arable land!
And where do we grow our food?

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The lesson here

- Hopefully this illustrates the power of quantitative analysis
  - lots of ideas are floated/touted, but many don't pass the quantitative test
  - a plan has to do a heck of a lot more than sound good!!!
  - by being quantitative in this course, I am hoping to instill some of this discriminatory capability in you

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Other renewables

- We won't spend time talking about every conceivable option for renewable energy (consult text and other books for more on these)
- Lots of imagination, few likely major players
- As a way of listing renewable alternatives, we will proceed by most abundant
  - for each, I'll put the approximate value of QBtu available annually
  - compare to our consumption of 100 QBtu per year

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Renewables list

- Solar (photovoltaic, solar thermal)
  - get 100 QBtu/yr with < 2% coverage of U.S. land area
- Wind
  - maybe 180 QBtu/yr *worldwide*, maybe 25 QBtu in U.S.
  - but some estimates are far less optimistic
- Biomass
  - if we divert 10% of the 40 TW global budget into energy, would net 4 TW, or 120 QBtu worldwide; maybe 7 QBtu in U.S., given about 6% of land area
- Hydroelectric
  - 70 QBtu/yr feasible *worldwide*: twice current development
  - 5 QBtu/yr max potential in U.S.

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Renewables, continued

- Geothermal: run heat engines off earth's internal heat
  - could be as much as 1.5 QBtu/yr *worldwide* in 50 years
  - limited to a few rare sites
- Tidal: oscillating hydroelectric "dams"
  - a few rare sites are conducive to this (Bay of Fundy, for example)
  - up to 1 QBtu/yr practical *worldwide*
- Ocean Thermal Energy Conversion (OTEC)
  - use thermal gradient to drive heat engine
  - complex, at sea, small power outputs

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Assignments

- Read Chapter 6 on nuclear energy for Monday 5/17
- Optional from Do the Math:
  - 34. Alternative Energy Matrix
  - has overview of all the options, post fossil fuels
- Homework #6: due Friday, 5/24
- Power Plant tours: sign-up sheet up front for tours (optional) Tuesday or Wednesday 2:00–2:50
  - must wear long pants and closed-toed shoes for safety
  - check box to indicate you understand, and *don't forget*