Lec #19: Fossil Fuels, II.

LAST TIME: Coal, Gas, and Oil (Chapter 7)
- Sources and Production
- Discussion of Fossil Fuels: Hidden Costs
- The Combustion Process and its Byproducts

TODAY: Environmental Impacts (Chapter 8)
- Air/Water/Thermal Pollution
- Mitigation Strategies and Technologies
- Global Environmental Impacts of FF Burning

NEXT TIME: Global Climate Impact (Chapter 9)

Principal Pollutants
- Products of combustion:
  - useful energy (heat)
  - waste heat (50% or more)
  - waste steam or hot water (to cool steam)
  - benign gasses (H₂O and CO₂)
  - gaseous pollutants
  - bottom ash (non-combustible solids)
  - heavier-than-air particulates (fly ash) that are temporarily suspended ("aerosols") in air

- e.g. the brown cloud
  - NO₂ + sunlight --> NO + O
  - absorbs blue sunlight -> reddish air
  - O + O₂ --> O₃ ("Ozone")
  - this is nasty stuff by itself; doesn’t last long, b/c it reacts with everything (and produces tertiary pollutants)
  - O₃ + NO --> NO₂ + O₂ and the process repeats!
  - photochemical smog
    - NO₂, HC’s, oxidants (like O₃) + atmospheric conditions (esp. thermal inversions)
    - HCNO complex molecules (PAN, PAH)

What’s the Good News?
- Good news? Why should there be any?
  - problems became acute in 50’s & 60’s
  - e.g. London disaster
  - Clean Air Acts; esp 1970 amendments
  - pollution control technology
- Despite growth, most air pollution concentrations have actually gone down
- There are still major problems in cities, especially in the West (Denver, LA, etc.)
- There are still other problems that are not yet being addressed (e.g. Acid Rain)
Carbon Monoxide in Denver

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CO diurnal variation

Problems reduced by oxygenated fuels, automobile inspections, semi-mandatory 4-day/5wk driving schedules, etc.

Seldom exceeds 8h standards any more but it still stinks!

Emission Control Technology

- Electrostatic Precipitator
- Bag House (fabric filters)
- Cyclone Collector
- Wet scrubber for Flue Gas Desulfurization
- Pre-Wash coal
- Fluidized Bed Combustion

Note: Most of these take energy to run, which means we have to burn even more coal.
Solid Waste, Waste Heat, and Hot Water

- Mining, Processing, Transportation
- Solid Waste
  - fly ash “fallout”
  - bottom ash and captured fly ash
  - sludge
- Waste Heat from stack (TD efficiency)
- Waste Heat from condenser water
  - streams and lakes
  - cooling towers
  - water loss must be replenished with treated water

What About The Solid Waste?

- There’s a whole lot of it! It’s now our 3rd largest mineral resource, after crushed stone and sand/gravel
- 122 million tons in 2003; 40% used; rest landfilled
- captured fly ash, bottom ash, FGD sludge
- It can be pretty darn useful stuff
- But is it toxic?

Environmental Limitations

- Haven’t we seen enough?
  - invasive exploration (and decreasing supplies)
  - messy extraction; health risks
  - transportation (coal dust; oil spills; pipeline explosions)
  - air pollution (can be limited, with big energy cost, which means more fuel; but can it be zeroed out?)
  - thermal pollution
- Even if that were the whole story, it should be enough to cause us to change our ways.
- But of course it’s not the whole story!

<table>
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<th>Trace Elements in Coal</th>
<th>Concentration (ppm by weight)</th>
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<td>Tellurium</td>
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</table>

Source: National Bureau of Standards, Standard Reference Material

It’s mostly the heavy metals in coal that don’t burn. Some are useful, some can be toxic. Some of it is radioactive (much more than can ever be emitted from a Nuclear Power plant).
The Facts About Global Warming

1. Greenhouse Effect is Real
   - well understood, natural phenomenon
   - it can be beneficial
   - but non-linear, subject to feedbacks, therefore it is hard to predict changes

2. Global Warming is Real
   - Earth is warming up at a measurable rate
   - rate corresponds to...

3. CO₂ Concentration is Increasing
   - huge growth corresponds to history of fossil fuel burning

4. Earth has always been either heating up or cooling off, and the behavior has been (quasi) cyclic
   - astronomical causes
   - geological activity cycles?
   - solar activity or luminosity cycles?

5. Amplitude of natural cycles exceeds current warming trend, but

6. Timescale of current trend is shorter than any natural cycles

The Greenhouse Effect

- ENERGY IN = ENERGY OUT
  - otherwise, Temperature changes
  - radiant energy only possible mechanism
- IN:
  - solar radiation (mostly visible)
- OUT:
  - reflected sunlight (visible)
  - thermal emission from surface and atmosphere (infrared, microwave)
  - Earth’s interior cooling (infrared; 2700 times less)
- H₂O, CO₂, CH₄, etc. “absorb” infrared
  - block a fixed fraction from escaping
  - tiny changes in composition can change temperature

“Blackbody Radiation”: Electromagnetic Radiation emitted by a dense object in thermal equilibrium

energy emitted at all wavelengths

higher temperature emits more at all wavelengths

total energy emitted = (area) x cT⁴

peak wavelength proportional to temperature

[play with Spectrum Explorer]
Earth’s Equilibrium Temperature

- Solar Luminosity \( L_s = 4\pi R_s^2 \sigma T_s^4 = 10^{26} \text{ W} \)
  \(- T_s \sim 5800 \text{ K} \)
- Intensity of electromagnetic radiation decreases as square of distance
- “Flux” at Earth: \( F = L_s/4\pi d^2 = 1356 \text{ W/m}^2 \)
  \(- “albedo” = \text{ fraction not reflected} \sim 0.5 \)
- Radiant Energy IN = flux x albedo x \( \pi R_e^2 \)
- Earth Luminosity \( L_E = 4\pi R_E^2 \sigma T_E^4 \)
  \(- \text{must equal energy IN} \)
  \(- T_E \text{ will adjust to make it so} \)
- Without atmosphere, \( T_E \sim 250 \text{ K} \) (brrr!!)
- With atmosphere, \( T_E \sim 300 \text{ K} \) (mostly b/c \( \text{H}_2\text{O} \))