PS9.1: Carbon Taxes

A. A tax of \$50 per ton of CO_2 is equivalent to:

$$\left[\frac{\$50}{t_{CO_2}}\right]\left[\frac{44\ g_{CO_2}}{mole_{CO_2}}\right]\left[\frac{mole_{CO_2}}{12\ g_C}\right]=\frac{\$183}{t_C}$$

B. \$100/tC would increase the price of coal by:

$$\left(\frac{\$100}{t_C}\right)\left(\frac{0.65\ t_C}{t_{coal}}\right)\approx\frac{\$65}{t_{coal}}$$

PS9.1: Carbon Taxes

C. The price of coal for electric utilities given at http://www.eia.doe.gov/cneaf/coal/page/acr/table34.html is \$27.30/short ton (national average.

$$\left(\frac{\$27.30}{\text{short ton}}\right)\left(\frac{1.102\ \text{short ton}}{t}\right)=\frac{\$30.08}{t_{coal}}$$

A tax of \$100/t_C would add \$65/t to the price of coal; if demand remained constant, the price of coal would more than triple, from \$30 to \$95.

PS9.1: Carbon Taxes

D. From part B, \$100/t_C = \$65/t_{coal}. The energy content of coal is 25 MJ/kg = 25 GJ/t. The plant is 32% efficient in converting heat to electricity.

$$\left(\frac{\$65}{t_{coal}}\right)\left(\frac{t_{coal}}{25\cdot 10^9\ J_{th}}\right)\left(\frac{J_{th}}{0.32\ J_e}\right)\left(\frac{3.6\cdot 10^6\ J}{kWh}\right)=\frac{\$0.029}{kWh}$$

Compare to the average wholesale price is \$0.05/kWh, so a \$100/t_C tax would increase the wholesale price by almost 60%.

PS9.1: Carbon Taxes

E. Gasoline is 85% C; density is 0.75 kg/L. How much would a \$100/tC tax add to the price of a gallon of gasoline?

$$\left(\frac{\$100}{t_C}\right)\left(\frac{0.85\ t_C}{t_{gas}}\right)\left(\frac{0.75\ t_{gas}}{m^3}\right)\left(\frac{m^3}{264.2\ gal}\right)=\frac{\$0.24}{gallon}$$

This is comparable to the fluctuations that have occurred over the last few months.

PS9.2: Carbon Sequestration

A. Goggle “tree spacing” or “tree density”. Average for US forests ≈ 500/acre ≈ 1200/ha.

Another approach: assume a canopy 10 feet in diameter (think spruce, not oak), area = $\pi(5\text{ ft})^2$ = 80 ft² = 7 m²/tree = 1400/ha.

$$\left(10\cdot 10^9\text{ trees}\right)\left(\frac{\text{ha}}{1200\text{ trees}}\right)=8\cdot 10^6\text{ ha}=21\cdot 10^6\text{ ac}$$

Existing areas: 290 Mha forest, 240 Mha pasture, 190 Mha cropland, 200 Mha “other”.

PS9.2: Carbon Sequestration

B. Compare steady-state carbon storage of forests and the ecosystem types that might be replaced with forests (use table in notes or table XII.2 in SC).

Temperate forest stores (146+118) = 264 t_C/ha or (12270 + 12000) = 24270 g_C/m^2 = 243 t_C/ha

Trees would likely be planted on cropland (132 or 81 t_C/ha) or grassland (199 or 243 t_C/ha). The difference ranges from (243 – 81) = 162 t_C/ha to (243 – 243) = 0 t_C/ha. If we assume 150 t/ha, increased storage of 8 Mha is:

$$\left(\frac{150\ t_C}{\text{ha}}\right)\left(8\cdot 10^6\text{ ha}\right)=1200\cdot 10^6\ t_C$$

C. Compare to emissions of 1500 MtC/y.

Ecosystem type	area (Mha)	biomass (t_C/ha)	dead (t_C/ha)	NPP (t_C/ha·yr)
Tropical forest	**2450**	**188**	**104**	**8.3**
Temperate forest	**1200**	**146**	**118**	**5.6**
Boreal forest	**1200**	**90**	**149**	**3.6**
Swamp and marsh	**200**	**68**	**686**	**11.3**
Wood/shrub land	**800**	**27**	**69**	**2.7**
Tropical savanna	**1500**	**18**	**37**	**3.2**
Temperate grassland	**900**	**7**	**192**	**2.3**
Cultivated land	**1400**	**5**	**127**	**2.9**
Tundra/alpine meadow	**800**	**3**	**216**	**0.65**
Desert scrub	**1800**	**3**	**56**	**0.32**
Rock, ice, and sand	**2400**	**0.1**	**1**	**0.15**
Lake and stream	**250**	**0.1**		**2.3**
Open ocean	**33200**	**0.014**		**0.57**
Upwelling zone s	**40**	**0.1**		**2.3**
Continental shelf	**2660**	**0.05**		**1.6**
Algal bed and reef	**60**	**9**		**9.0**
Estuaries	**140**	**4.5**		**8.1**

Terrestrial Ecosystems

Ecosystem	Area (10^{12} m²)	NPP (g_C/m^2y)	Plant C (g/m²)	Soil C (g/m²)	Res. Time Plant	Res. Time Soil
Forest, tropical	14.8	925	16500	8300	18	9.0
Forest, temperate	7.5	670	12270	12000	18	18
Forest, Boreal	9	355	2445	15000	6.9	42
Woodland, temperate	2	700	8000	12000	11	17
Chaparral	2.5	360	3200	12000	8.9	33
Savanna, tropical	22.5	790	2930	11700	3.7	15
Grassland, temperate	12.5	350	720	23600	2.1	67
Tundra, arctic/alpine	9.5	105	630	12750	6.0	121
Desert and scrub	21	67	330	8000	4.9	119
Desert, extreme	9	11	35	2500	3.2	227
Perpetual ice	15.5					
Lake and stream	2	200	10		0.05	
Wetland	2.8	1180	4300	72000	3.6	61
Peatland	3.4			133800		
Cultivated	14.8	425	200	7900	0.5	19
Human area	2	100	500	5000	5.0	50
TOTAL	150.8	391	3220	13640	8.2	35

PS9.2: Carbon Sequestration

D. Cost can be calculated easily as:

$$\frac{\left(\frac{\$500}{\text{acre}}\right)\left(21\cdot 10^{6}\ \text{ac}\right)+\left(\frac{\$1}{\text{tree}}\right)\left(10^{10}\ \text{trees}\right)}{1200\cdot 10^{6}\ t_C}=\frac{\$17}{t_C}$$

Of course, if you buy large amounts of land the price goes up…

PS9.3: Million Solar Roofs

A. Assuming 500 ft^2 per house for mounting PVs:

$$\left[10^{6}\ \text{roofs}\right]\left[\frac{500\ \text{ft}^2}{\text{roof}}\right]\left[\frac{\text{m}^2}{10.76\ \text{ft}^2}\right]\left[\frac{6\cdot 10^{9}\ J_s}{\text{m}^2\cdot \text{y}}\right]\left[\frac{0.15\ J_e}{J_s}\right]\left[\frac{\text{kWh}}{3.6\cdot 10^{6}\ J_e}\right].$$

$$\approx 10\ \text{billion kWh/y} = 10\ \text{TWh/y of electricity}$$

B. Compare to U.S. electricity generation (2002) of roughly 3800 billion kWh/y. Thus, 10 billion kWh/y ≈ 0.3% of current total electricity generation.

PS9.3: Million Solar Roofs

C. Solar electricity costs \$0.25/kWh. If this replaces coal-fired electricity, what is the cost in dollars per ton of carbon emission avoided?

Coal-fired electricity costs \$0.05/kWh, so the net cost of solar is \$0.20/kWh. From 9.1D:

$$\left(\frac{t_{coal}}{25\cdot 10^{9}\ J_{th}}\right)\left(\frac{0.65\ t_C}{t_{coal}}\right)\left(\frac{J_{th}}{0.32\ J_e}\right)\left(\frac{3.6\cdot 10^{6}\ J}{\text{kWh}}\right)$$

$$=\frac{0.00029\ t_C}{\text{kWh}} \qquad \left(\frac{\$0.20}{\text{kWh}}\right)\left(\frac{\text{kWh}}{0.00029\ t_C}\right)=\frac{\$680}{t_C}$$