Inconvenient Issues

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We dig carbon (i.e. fossil fuels—such as coal, oil, gas, etc) out of the ground and burn it to provide energy [1]. See Fig.(1). Burning of fossil fuels injects carbon dioxide into the atmosphere, and carbon dioxide is a major greenhouse gas. Increased greenhouse effects of the atmosphere can warm the earth.

The global warming (or climate change) problem is very much in the news. The following is a succinct summary of current public discourse:

1. The people are ready to do something right now, but the politicians are cowards, ... Special interest groups are blocking actions; big oil is making unconscionable profits; fine the companies that emits the greenhouse gases! China has to do her share; ...

2. Conservation! Use fluorescent bulbs, better insulations for buildings, ... Energy efficiency! Higher federal gas mileage standards for cars, hybrid cars, ...

3. Biofuels (e.g. ethanol), windmills, solar energy, ... No fission nuclear energy (this is slowly changing). Carbon capture and sequestration! More research! Something will turn up ...

4. The impact on the economy is tolerable—the global GDP may drop by about 1% ...

Suppose we arrive at the conclusion that we should do something. What should we do [2]? Is the public being adequately informed?

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What is the current situation?

Before the industrial revolution, the earth's atmospheric carbon level had been relatively constant at approximately 600 billion tons for many centuries. At the present moment (2008), the annual global carbon emissions rate (in the form of carbon dioxide from burning of fossil fuels)—to be denoted by E here—is roughly 8 billion tons of carbon per year. Historically, about half of the annual global carbon emissions stays in the atmosphere. The effective residence time of atmospheric carbon is approximately 200 years. The world population is rising, and the average global per capita energy usage is also rising. In the past few decades *E has been rising with time at the rate of about* 0.16 *billion tons of carbon per year each year*. Currently, about one-third of carbon emissions into the atmosphere is from the electricity generation sector, about one-third is from the transportation sector, and about one-third from the home heating/industrial sector. The United States and China each accounts for about one-fourth of the global annual carbon emissions. The rest of the world accounts for the other half.

What do we do?

In order to avoid the atmospheric carbon dioxide level breaching twice the pre-industrial revolution level, E has to decrease from the current level to an *allowed* value of less than 3 billion tons of carbon per year *within a finite time window* [3]. The needed decrease from the current value is *more than 60%*. The first task is to *stop the increase* of E, the next task is to *decrease* E toward the low allowed value, and the final task is to *maintain* E at the low allowed value [4].

No single *current* non-carbon energy technology can solve the problem (even with the most optimistic help of improved conservation and energy-use efficiency). A "portfolio" of economically viable non-carbon energy technologies is needed [5]. At the present time, non-carbon energy is more expensive than fossil fuels energy (except for hydroelectric power generation which is already nearly fully exploited globally). In order to make non-carbon energy more competitive in the future, governments must intervene:

Carbon tax : Impose a carbon-based tax. The rationale is that the "market mechanism" will encourage the energy users (working on the demand side) to reduce the consumption of fossil fuels-based energy. The tax money is then available as subsidies to provide incentives for innovations in new non-carbon energy technologies (there is much PR talk on the importance of this tax being "revenue neutral.")

Cap and trade : Impose an annual carbon emissions "cap" on major emission sources. Trading of the allowance is permitted. The rationale is that the "market mechanism" will (working on the supply side) *automatically* favor the most efficient technologies for carbon emissions reduction. The good past experience in reducing sulfur dioxide emissions is usually quoted to support this strategy.

The basic premises of both of the above strategies are:

- In the future, energy users must pay for the predicted damage to the environment when they buy fossil fuels energy.
- With firm assurance of long term public support and sufficient profit incentives, *entrepreneurs and engineers will come up with innovative technologies to solve our energy problems in the future* (using new technologies which may be beyond our wildest current imaginations).

Both strategies assume:

- Every sovereign government will enact national laws to impose the appropriate (and internationally coordinated) carbon tax and/or the emission cap, and will strictly enforce the laws to achieve the emission reduction goals. The governments which impose carbon tax also have the extra responsibility of *somehow* deciding how to funnel the money as subsidies to provide profit incentives for the development of new non-carbon energy technologies. The cap and trade option leaves this job to the "market-mechanism." Both strategies assume *somehow something technologically wonderful will turn up* before it is too late.
- The issue of *fairness between nations* can be settled.

But life is more complicated. The first bullet is problematical. The second bullet is even more problematical. Let's focus on the second bullet.

What is fair?

In what follows, we shall use round numbers which are appropriate for the start of the 21st century. The total global population is approximately 6 billion. Since the current annual global carbon emissions from fossil fuels burning is approximately 8 billion tons per year, every living person on earth thus currently emits on average about 1.3 tons of carbon into the atmosphere per year. The current average American per capita annual carbon emissions is approximately 7 tons of carbon per year[1]. The current average Chinese per capita annual carbon emissions is approximately 1.5 tons of carbon per year[2].

Now, the amount of allowed annual carbon emissions to honor the so-called doubling atmospheric carbon dioxide target ceiling is estimated to be less than 3 billion tons of carbon per year [3, 4] (in the maintenance period.). Assuming that the global population stays flat at 6 billion, then for this target the future global annual per capita carbon emissions into the atmosphere is only about 0.5 tons of carbon per year.

Let us preface the discourse on *fairness between nations* by quoting from the universally admired American *Declaration of Independence*:

> ... We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty, and the Pursuit of Happiness. ...

Starting from this bedrock statement of modern democracy, what would be the obviously *inconvenient answer* to the obvious (per capita) question?

All would readily agree that the global warming problem is an international problem. Since all countries of the world will soon need to meet and work out who is to do *what, how much*, and *by when*, there ought be be some talk on the inconvenient answer in the public discourse now.

Suppose we also accept the following "truths" to be self-evident:

- If the new (future) non-carbon energy technologies are economically fully competitive with fossil fuels in a free market, the global warming problem is solved.

[1] Computed by dividing 25% of 8 billion tons per year by 300 million people.
[2] Computed by dividing 25% of 8 billion tons per year by 1.3 billion people.

- If the new (future) non-carbon energy technologies remain economically non-competitive with fossil fuels in a free market but are nevertheless adopted by government decrees because of global warming, *the incremental costs is eventually paid* by you and me—the energy users.

How much is the "incremental cost?" Suppose the operating cost to avoid emitting one ton of carbon emission (e.g. carbon sequestration) is US \$100. This translates to approximately US \$0.25 per gallon of gasoline, or US \$500 billion per year to lower annual global carbon emissions from 8 to 3 billion tons per year (or US \$83 per person on earth per year). The capital costs of installing the new carbon-free technologies would be extra.

Everybody knows that the world's energy demand will continue to rise, but nobody knows what is the maximum level of atmospheric carbon dioxide the world can tolerate. If the atmospheric carbon dioxide level reaches twice its pre-industrial revolution level, the best IPCC estimate of the global average temperature rise (from the pre-industrial revolution value) is roughly 3^o Celsius [6]. So far the atmospheric carbon level has already risen one-third of the way to doubling since the industrial revolution, and the observed average global temperature rise is less than 1^o Celsius. At the present moment, nobody really knows whether there is a "tipping point" for atmospheric carbon level that the world must not cross. The "doubling" target level is merely a convenient talking point—not a scientifically validated tipping point.

How to decrease carbon emissions?

Global carbon emissions can decrease in the future only if *more existing fossil fuels powerplants are being de-commissioned than newly built fossil fuel powerplants* (e.g. new coal-fired powerplants without carbon capture and new automobiles with conventional gasoline engines) starting from this time forward. To pick up the "slack" of energy supply, the *business* of building "green" powerplants must somehow be made *profitable*. Conservation and improved efficiencies alone cannot do the whole job [2, 5]—they can play significant roles only if they are economically compelling. The debate on how to apportion the world's allowed carbon emissions among all living persons on earth must be settled. The incremental costs must be shared fairly. International coordination is crucial.

Governments must provide leadership for their people, and all endeavors must get started before it is too late [3, 4].

It is a long haul. Before the eventually (successful) stabilization, the atmospheric carbon level will continue to rise, and the earth will continue to warm. How should the official year-end report card to the world be written to justify the effort? What did the hundreds of billion dollars spent last year on carbon mitigation buy?

References

[1] "Climate change and the greenhouse effect," Hadley Centre, 2005.
http://www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/

[2] See the official webpage of the *Environmental Protection Agency* (EPA):
http://www.epa.gov/climatechange/wycd/index.html

[3] Socolow, R. H. and Lam, S. H., "Good enough tools for global warming policy making," in Energy for the Future, *Phil. Trans. Royal Society, Series A,* **365** 697-934, 2007. Available at
http://www.princeton.edu/~lam/documents/GoodTools.pdf

[4] Lam, S. H., Interactive *Mathematica* demonstration of carbon cycle response to various anthropogenic emissions strategies. Available at
http://www.princeton.edu/~lam/documents/BestEffortDemo.htm

[5] Pacala, S. and Socolow, R., "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science*, vol. 305, no. 5685, pp. 968-972, August, 2004.

[6] The direct "radiative forcing" consequence of doubling the atmospheric carbon dioxide level is only approximately 1^o Celsius. The additional 2^o Celsius warming is attributed to the so-called water vapor positive feedback.

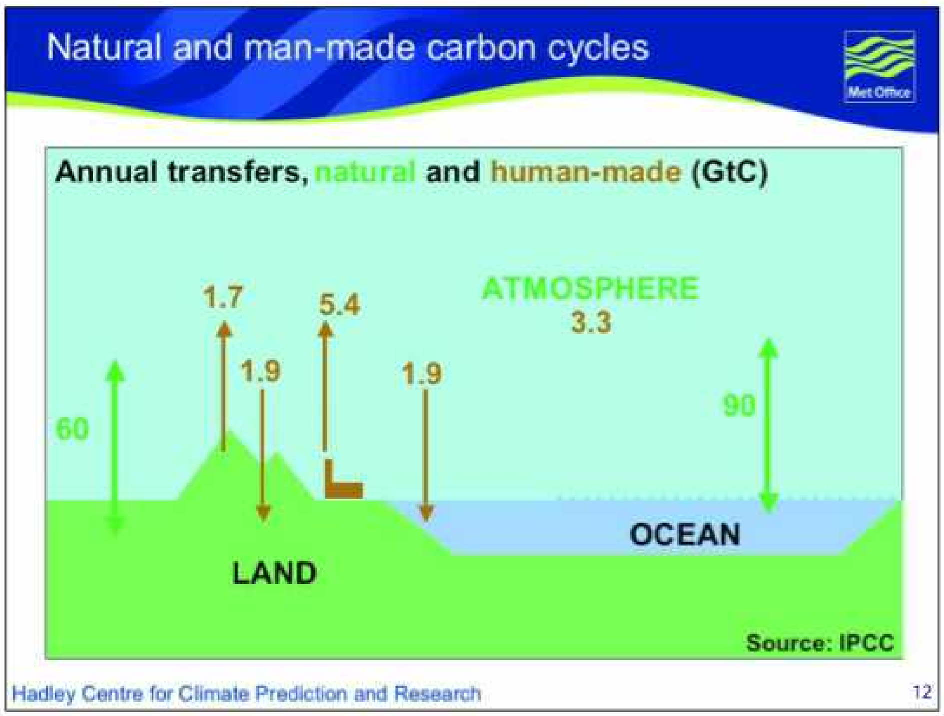

Figure 1: A cartoon of the earth's carbon cycle at start of 21st century. GtC is gigatons (billion tons) of carbon (each ton of carbon equals 3.7 tons of carbon dioxide). Arrows represent approximate fluxes in billion tons of carbon per year to and from the ATMOSPHERE (double-headed green arrow means the net natural flux is zero). It is assumed that the 5.4 billion tons per year of anthropogenic carbon emitting out of the smoke stacks into the atmosphere were previously fossil fuels buried underground and thus were previously isolated from the carbon cycle. In this cartoon, the amount of carbon in the ATMOSPHERE increases by about 3.3 billion tons of carbon per year (3.3=(1.7+5.4)-(1.9+1.9)). This (human-made) increase is the main driving force of the global warming problem. The (human-made) *incremental* amount of carbon being sequestered by LAND (as trees and soil detritus) is approximately 0.2 billion tons per year (0.2=1.9-1.7), and the (human-made) *incremental* amount being sequestered by OCEAN is estimated to be approximately 1.9 billion tons per year. So, approximately 2.1 billion tons of carbon (2.1=0.2+1.9)—out of 5.4 billion tons being emitted into the ATMOSPHERE by fossil fuels burning—are absorbed by LAND and OCEAN per year. At 2008, all the human made numbers are slightly larger.