More Inconvenient Truths

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The media have recently paid much attention to the global warming problem.[1] Most people now know that carbon dioxide is a major greenhouse gas, and that its emissions from the burning of fossil fuels since the Industrial Revolution have sharply increased the carbon dioxide content in the atmosphere. If the rate of global fossil fuels energy usage continues at the present level (or above) for a long time, the greenhouse effect can significantly—and probably adversely—affect the climate of the earth. There is much talk in the media of "doing something about it right now."

Is the general public being adequately informed by the media?

The following are critiques of the current public discourse:

- *There is inadequate recognition of the magnitude of the total job to be done.* How much less fossil fuels burning do we need? It is *not* a 10% or 20% problem.

- *There is inadequate coordination of the proposals.* Because of the lack of appreciation of the magnitude of the total job, most proposals being discussed are piecemeal, *uncoordinated* single options.

Some non-controversial and verifiable facts are:

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[1] *An Inconvenient Truth, the Planetary Emergency of Global Warming and What We Can Do About It*, Al Gore, Viking Juvenile, 2007. And a Paramount Vantage movie with the same name, directed by Davis Guggenheim, 2006.

1. Before the Industrial Revolution, the earth's atmosphere had about 600 billion tons of carbon[2]. This number had not changed significantly for several millenniums until the 19th century. The amount of carbon emissions from fossil fuels burning until then was essentially negligible.

2. At the beginning of the 21st century, the earth's atmosphere had about 800 billion tons of carbon. The burning of fossil fuels currently emits about 8 billion tons of carbon annually, and the atmospheric content of carbon is currently increasing by about 4 billion tons per year. Historically, about half of the emissions stays in the atmosphere. The global average temperature has risen by slightly less than one degree Celsius since the Industrial Revolution.

3. For the past half century, the annual fossil fuels carbon emissions has been increasing by about 160 million tons/yr each year. This annual increase can be attributed to newly built fossil fuels powerplants and more output from existing fossil fuels powerplants during the year.

4. If the atmospheric carbon content were to reach 1200 billion tons (double the preindustrial value), scientists estimate that its greenhouse effect could increase the average global temperature by between 2 and 4.5 degrees Celsius. At such levels, severe adverse climate change consequences are likely.

5. Currently, about 25% of the fossil fuels carbon emissions is by the United States, about 25% by the People's Republic of China, and the remaining 50% by the rest of the world (including the European Union which is responsible for about 15%). Both the world population and the average per capita emissions are expected to continue to rise in the near future.

6. The three major sources of fossil fuels carbon emissions are the electricity generation sector, the industrial use and heating sector, and the transportation sector (automobiles, airplanes, ships).

[2]Usually, atmospheric carbon dioxide content is represented by ppm (parts per million). The conversion factor is: 1 ppm of carbon dioxide=2.1 billion tons of carbon. Thus, 600 billion tons of carbon in the atmosphere is approximately 286 ppm of carbon dioxide. There is one ton of carbon in 3.7 tons of carbon dioxide. When we say "carbon emissions," we mean "carbon dioxide emissions from the burning of fossil fuels" expressed in terms of the annual amount of carbon emitted.

The 2007 IPCC Paris report[3] attributes most of the observed increase in global atmospheric carbon content to the burning of fossil fuels. The science which predicts the resulting adverse greenhouse effects (droughts, floods, sea level rises, etc.) is somewhat speculative (because unequivocal observational validations are not yet available), but is judged credible by many. Most people agree that the carbon content of the atmosphere should have a *target ceiling*. No one really knows what it should be, but "doubling" of the pre-industrial value is often used as the default.

What actions should we take to slow the observed increase of the atmospheric carbon content, and to ensure that it never breaches the chosen target ceiling? Websites in support of Mr. Gore's movie[4] say that everyone can help to "stop" global warming. The recommended actions are:

- use fluorescent light bulbs,
- drive less,
- recycle more,
- check your tires,
- use less hot water,
- avoid products with a lot of packaging,
- adjust your thermostat,
- plant a tree,
- turn off electronic devices.

This action list gives the impression that stopping global warming is not that hard a task. When interviewed on television, Mr. Gore explicitly and emphatically ruled out nuclear energy as an option. It is widely reported that many actions-now advocates are against windmills off Cape Cod because windmills ruin the scenic views. Many novel technologies and innovative ideas

[3] *Climate Change 2007: The Physical Science Basis*, WG1 of the IPCC, Paris, 2007. http://www.ipcc.ch

[4] See http://www.climatecrisis.net/pdf.10things.pdf, and the U.S. Congressional *Environment and Public Works Committee* official webpage at http://www.senate.gov/public; click on the "Act Now to Stop Global Warming" icon.

have been put forth as possible "solutions" to the problem: solar cells, ethanol from corn or sugar or switchgrass, hybrid automobiles, carbon sequestration, etc. Economists advocate carbon tax and emissions trading (... perhaps the global GDP might drop one percent ...). A message often being conveyed by the media is: global warming can be stopped right now if we only have the will..., giving the impression that there are many options available, scenic views need not be ruined, and life can go on with only minor inconveniences.

The impressions conveyed above are misleading. The job is much bigger than the media lets on. Immediately "stopping" the increase of atmospheric carbon content is totally out of the question. We can only aim for slowing down the annual increase, and settle for some significantly higher-than-now target ceiling level. The world will continue to warm each year until the atmospheric carbon content is finally stabilized at the chosen target ceiling level—after the emissions from the burning of fossil fuels are reduced to the allowed lower value by exploiting all credible options.

What is the allowed annual emissions value for a chosen target ceiling, and how fast do we need to get there? Answers to such common sense questions have been known to the global warming research community for a long time, but the media has paid inadequate attention to them and has not kept the public fully informed.

To deal with the first question, Socolow and Lam[5] recently examined many science-based computer simulations published in the past decade, and found that the predicted amount of allowed annual carbon emissions after stabilization, to be denoted by E_{stab}, can be correlated by the following simple formula:

$$E_{stab}(t) = \frac{C_{stab} - C_{pre}}{\tau_L(t)} \text{ billion tons of carbon per year,} \qquad (1)$$

where C_{Stab} and C_{pre} are respectively the chosen target ceiling level and the pre-industrial level of atmospheric carbon dioxide (in billion tons of carbon), and $\tau_L(t)$ is an effective "residence time" (in years). The value of C_{pre} is approximately 600. The value of $\tau_L(t)$ depends on the science of the carbon cycle, and is a slowly increasing function of time. Numbers extracted from different simulations in the past decade are roughly consistent with each other. For the next few centuries, $\tau_L(t) \approx 200$ years. For example, if the

[5]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** 897-934, (2007). DOI: 10.1098/rsta.2006.1961.

target ceiling level is the "doubling" level (1200 billion tons or 570 ppm), $E_{stab}(t)$ is less than 3 billion tons per year (and decreases slowly with time). More definitive science could narrow the uncertainty of this number, but its order of magnitude is unlikely to change. The total emissions reduction job (for the doubling target ceiling) is to go from the current annual emissions value—which is presently still rising with time—to less than 3 billion tons per year. We are not talking about 10% or 20% reductions! *We would need more than 60% reductions*—even though the world population and the per capita energy usage are both expected to increase in the future. For example, even if all electricity generation and all industrial use/heating could somehow be made carbon neutral, the 1200 billion tons (doubling) target ceiling would still be a formidable challenge. The Gore-inspired list of citizen actions could indeed play a starring role in the effort to make the U.S. independent from foreign oil—but it has only a relatively small part in the long term global warming show. *No single option is likely to be able to do the whole job.* All options should stay on the table, together with emphasis on higher efficiencies and conservation. It is highly likely that the whole job can only be done by summing the coordinated contributions from many credible 5% and 10% options. The (fission) nuclear option should not be preemptively excluded and kept off the table. Keep in mind that the required per capita emissions reduction is a more depressing number.

How fast do we need to drop the current annual emissions value to the allowed value after stabilization? We define the (average) future pace of the mitigation efforts to be the total amount of unfinished emissions reduction divided by the total number of years allotted to do the unfinished task. Too slow a pace (e.g. doing very little each year) would fail to honor the chosen target ceiling, while too fast a pace (e.g. doing the whole job in this decade) could incur unnecessary efforts and costs. Thus *there must be a critical pace—and thus a critical number of allotted years* to do the unfinished task. Using only simple mathematics, Socolow and Lam show that this special critical number of allotted years at any time t is:

$$\tau_{CPM}(t) \equiv \frac{2(C_{stab} - C(t))}{C(t) - C(t-1)} \text{ years}, \tag{2}$$

where $C(t)$ is the current global atmospheric carbon content in billions of tons. The recommended emissions reduction pace for next year is calculated using $\tau_{CPM}(t)$ as the number of allotted years to finish the job. They call this recommendation the *Constant Pace Mitigation* (CPM) strategy. They

also show—under very general conditions—that the recommended emissions reduction pace is approximately constant if the strategy is strictly implemented, and thus requires the least maximum annual effort among all possible strategies which can guarantee honoring of the chosen target ceiling without overshooting (*ibid.*).

Note that this pragmatically interesting τ_{CPM}—as derived by Socolow and Lam—is totally *independent of the science of the global carbon cycle*, and can be computed at any time using actual observed data regardless of whether the CPM strategy is being implemented or not. However, the actual amount of annual emissions reduction needed to implement the CPM strategy next year *does* depend on the science of the global carbon cycle—since it involves the estimate of the post-stabilization allowed annual emissions. Note that the total emissions reduction job, the τ_{CPM} and the CPM pace should all be updated annually, and these numbers can be used to monitor the status of the mitigation task. If we are on course with the CPM strategy, τ_{CPM} will decrease by one year each passing year.

At the start of the 21st century, for a target ceiling at 1200 billion tons, τ_{CPM} is 200 years, and the needed CPM pace is approximately 25 million tons/yr per year for each of these 200 years (*ibid.*). If the target ceiling is 1000 billion tons, then τ_{CPM} is about 100 years, and the needed CPM pace is approximately 60 million tons/yr per year (*ibid.*).

The above numbers say we have plenty of time (200 years) to do the job for the 1200 billion tons target ceiling case if we start now, and that the needed CPM pace is not such a daunting number. However, procrastination can drastically change the picture. Each year of inadequate emissions reduction effort drops the τ_{CPM} by more than one year—so the unfinished reduction job will need to be done in a shorter time. For example, if nothing is done for the next 50 years, in 2056 we will have less than 30 years (instead of 200) to do the job for the doubling target ceiling case (*ibid.*). *The later we begin the mitigation, the shorter the τ_{CPM}, the higher the CPM pace—thus the harder the remaining mitigation task.* It goes without saying that a transition buffer period is needed to slow down and reverse the currently rising annual emissions rate before a CPM strategy can begin, and continued annual emissions reduction is needed even after stabilization since $E_{stab}(t)$ decreases slowly with time.

It is not widely appreciated that technology alone can not solve the whole problem. *Economics and polities must play their roles.*

If new energy can be made less expensive than fossil fuels, the invisible

hand of free market capitalism would move the world away from fossil fuels. No prodding would be needed. *The world only needs to be prodded when fossil fuels continue to be less expensive than all the alternatives.* In a free market, fossil fuels prices would respond to technological breakthroughs to defend its market share. Thus the challenge of the biomass ethanol producers is not merely to be competitive with crude oil at $60 per barrel, since crude oil producers could remain profitable at $20 per barrel or lower, if pressed.

Thus so long as fossil fuels energy remains the least expensive, the invisible hand of free market capitalism will resist carbon emissions reduction. Consequently, *this invisible hand must be removed and replaced* by a covenant endorsed by the informed citizenry of the world. People must agree to forego the less expensive fossil fuels energy, pay more for the new green energy, and allow some of the scenic views to be ruined—from now on. Political leaders around the world must tilt the playing field of world energy supplies in favor of this universal covenant, however intrusive (carbon tax, etc). Entrepreneurs and innovative engineers need a stationary price target and firm assurances of long term public support. Technological advances can modulate the amount of tilting needed, but can do little for the economic dislocations caused by the absence of a free market. The year-end report card for a totally successful year can celebrate that the earth is less warm by several hundredth of a Celsius degree because of the mitigation efforts, but must nevertheless concede that it is still warmer than last year. *All citizens of the world must be sufficiently sophisticated to appreciate this report card.* All must understand that the intrusive convenant is a long term (international) commitment. Short term (low-hanging-fruits based) or uncoordinated piecemeal efforts, *however heroic*, will not do. The payback is not to us but to our grandchildren and their grandchildren. The agreed premise must be that their energy options in the future must not be limited by what we do now in some irreversible way.

The brave new world in which more than 60% of its energy comes from alternative (and most probably more expensive) sources will be more than slightly different from the world dominated by (inexpensive) fossil fuels. This deserves special media attention alongside the well-publicized Inconvenient Truth.