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# How to Reverse Global Warming: 21st Century Climate Blueprints

## Perspectives from the Recent History of the Atmosphere

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The Earth surface temperature reflects the net balance between incoming solar (shortwave) radiation and outgoing terrestrial (long wave) radiation (Kiehl and Trenberth, 1997 [1]). The severe disturbance of the energy balance of the atmosphere ensuing from the emission of over 320 billion tons of carbon since 1750 threatens a shift in the state of the atmosphere/ocean system to ice free greenhouse Earth conditions. Based on the recent Copenhagen Synthesis Report [2], climate change trends at the top range of IPCC 2007 projections [2], and the identification of tipping points in the recent history of the atmosphere/ocean system (i.e. at 14 – 11 and 8.2 thousand years-ago [3]), the scale and pace of 21st Century climate changes [4] require re-consideration of mitigation and adaptation strategies.

1. The combined CO2 and methane level in the atmosphere is fast tracking toward a level of 500 ppm, which defines the approximate onset of the East Antarctic ice sheet [5], the upper climate range which allowed the development of habitats where large mammals flourished from about 40, and in particular 34 million years ago, and hominids appeared from about 7 million years ago [6] (Figure 1). Feedbacks from the carbon cycle, including release of methane from permafrost, polar sediments and bogs, and feedbacks from ice melt/warm water interaction dynamics, accelerate this process. In view of the cumulative nature of CO2 in the atmosphere, at current growth rates of about 2 ppm per-year, rising above the combined CO2 + methane level of 450 ppm [7], the atmosphere/ocean system is fast tracking toward conditions similar to those of an ice-free Earth.

2. The scale of such greenhouse event may, or may not, bear an analogy to the PETM (Paleocene-Eocene Thermal Maximum) event about 55 million years ago [8], including release of large volumes of methane. Recent methane release from Siberian permafrost, lakes and shallow sediments [9].

3. Due to hysteresis (retardation of effect after cause), the effects of temperature rise, superposed ENSO (El Nino Southern Oscillation) cycles (Figure 2), melting of Greenland and the west Antarctic ice sheets [10], sea level rise [11], possible collapse of the North Atlantic Thermohaline Circulation [12], and potential tipping points (Figure 3), lag behind CO2 rise by as yet little-specified periods. A shift of the climate system through a transitional stage is occurring at present and is associated with extreme weather events [13].

4. With a mean global temperature rise of about 0.8 degrees C since 1750, plus a rise of about 0.5 degrees C masked by sulfur aerosols emitted by industry [14], plus temperature rise due to ice albedo loss and infrared absorption by water [10], in particular the Arctic Sea, global warming is potentially near 1.5 degrees C. At this rate, conditions which existed on Earth about 2.8 million years ago (mid-Pliocene +2 to 3 degrees C; Sea level rise of 25+/-12 meters) [6] could be reached within time frames of a few decades.

5. The unique nature of the "experiment" Homo sapiens is conducting with the atmosphere through the emission of 319 billion tons of carbon by 2007 [15], and the consequent extreme rise in atmospheric CO2 of about 2 ppm/year, two orders of magnitude faster than during the last glacial termination [16], counsels caution.

John Holdren, Obama's science advisor, compared global warming to "*being in a car with bad brakes driving toward a cliff in the fog.*"

Should humanity choose to undertake all possible mitigation and adaptation efforts in an attempt at slowing global warming down, or even reversing it, steps need to include:

1. Urgent deep reductions in carbon emissions, on the scale of at least 5 percent of emissions per year, relative to 1990 (Anderson and Bows, 2008 [7]).

2. Global reforestation efforts in semi-arid and drought-effected regions, among other providing employment to millions of people.

3. Construction of long-range water conduits from flood-affected to drought-stricken regions (an even more important task than designing Broadband networks…).

4. Urgent development of atmospheric CO2 draw-down methods, including CO2-sequestering vegetation, soil carbon enrichment, sodium-based CO2 capture (a technology no more complex than space projects technologies and financially not more expensive than military expenditure).

5. Rapid transition to clean energy (solar-thermal, hot-rock, hydrogen, wind, tide, photovoltaic) and transport systems (electric vehicles).

It is possible that, in order to gain time, some governments may opt for geo-engineering efforts, including stratospheric injection of sulfur aerosols (simulating volcanic eruptions) [17], likely over polar regions, meant to temporarily raise the Earth albedo while other measures are undertaken.

The alternative to urgent fast tracked mitigation efforts does not bear contemplation.

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