S4-1 The Low Carbon Scenario Global Energy Technology Strategy

James Edmonds,
Pacific Northwest National Laboratory, USA

Extended Abstract

We draw on results from our participation in the Stanford Energy Modeling Forum Exercise 22, on Transition Scenarios. This exercise explores a rich suite of potential future worlds in which climate change is limited to a variety of radiative forcing levels[1], with various of the world's regions beginning emissions mitigation at various times. Three radiative forcing limits are examined: 4.5, 3.7, and 2.6 W/m^2. Of these, 2.6 W/m^2 is by far the most ambitious as it limits anthropogenic climate change to 450 ppm CO_2-equivalent. CO_2 equivalent should not be confused with atmospheric CO_2. The former includes the radiative effects of all Kyoto gas emissions to the atmosphere. Thus, observed atmospheric CO_2 concentrations are smaller. Our analysis is reported more fully in Calvin, et al. (2009). In this paper we find that 450 ppm CO_2-e is associated with an atmospheric CO_2 concentration between 383 ppm and 385 ppm depending on the policy regime ("Not-to-Exceed" versus "Overshoot"; "Immediate Accession" versus "Delayed Accession"), compared with a preindustrial CO_2 concentration of approximately 280 ppm and a 2007 atmospheric concentration of 384 ppm.

Limiting radiative forcing to low levels is attractive as an environmental goal in that it limits anthropogenic climate changes. But lower limits on radiative forcing imply greater and more rapid changes to human systems—energy, industrial, and land-use. The magnitude and timing of the required changes have only begun to be explored. Van Vuuren et al. (2007) introduced the idea of limiting radiative forcing to 2.6 W/m^2. The 2.6 W/m^2 was selected as the low scenario in the new suite of four "Representative Concentration Pathway" (RCP) scenarios[2] being developed by the integrated assessment modeling community for climate modelers. Subsequently Rao et al. (2008) took up the problem of finding scenarios that were consistent with the 2.6 W/m^2 limit.

We examine the technical and policy challenges—including the role of technology availability, particularly energy technology, and land-use policy—of limiting radiative forcing to 2.6 W/m^2 in 2100. Wise et al. (2009) have shown that land-use policy is important in climate change limitation scenarios. In this paper we explore the implications of alternative land-use change policies in the context of both idealized international cooperation, and in scenarios of delayed accession.

Radiative forcing, measured in terms of the Kyoto gases, is estimated to have been 2.4 W/m^2 in 2005, leaving little room for further growth without exceeding 2.6 W/m^2. Delays on the part of major emitting regions to limit emissions can increase total radiative forcing beyond 2.6 W/m^2, and eclipsing even the most dramatic emissions reductions by other regions. No modeling team that participated in the EMF22 exercise was able to hold radiative forcing below under 2.6 W/m^2 in all years in the delayed accession scenario[3].

Relaxing the condition that radiative forcing never exceeds 2.6 W/m^2 makes the problem easier, but it remains a major technical and political challenge as outlined in Table 1.

[1] Radiative forcing is measured in terms of the "Kyoto" gases, anthropogenic CO_2, methane, nitrous oxide, the HFC's, PFC's, and SF_6. The measure does not include the effects of other gases such as the CFCs, sulfur, black carbon, organic carbon, and the reactive gases such as CO, NO_X, and non-methane hydrocarbons. These distinctions are important near the beginning of the 21st century when the cooling effects of sulfur aerosols are significant. By the end of the 21st century sulfur emissions are sufficiently reduced that the distinction between the "Kyoto" gases and the full suite of greenhouse gases is less significant.

[2] The other levels are 4.5, 6.0 and 8.5 Wm^{-2}. See Moss et al. (2008).

[3] See Table 1.

Table 1. The challenges associated with limiting radiative forcing to 2.6 W/m^2 in the MiniCAM model

	Not-to-Exceed	Overshoot
Immediate Accession[4]	1) Includes immediate participation by all regions 2) Includes dramatic emissions reductions, 70% by 2020 3) Includes substantial transformation of the energy system by 2020, including the construction of 500 new nuclear reactors, and the capture of 20 billion tons of CO_2 4) Includes a carbon price of \$100/tCO_2 globally in 2020 5) Includes a tax on land-use emissions beginning in 2020 6) Includes advanced technologies, including some means of decarbonizing the transportation sector or achieving negative emissions in other sectors to compensate for the inability to decarbonize transportation.	1) Includes immediate participation by all regions 2) Includes the construction of 126 new nuclear reactors and the capture of nearly a billion tons of CO_2 in 2020 3) Includes negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies 4) Carbon prices escalate to \$775/tCO_2 in 2095 5) Possible without a tax on land-use emissions, but would result in a tripling of carbon taxes and a substantial increase in the cost of meeting the target.
Delayed Accession[5]	Not attainable given the assumptions in MiniCAM	1) Includes dramatic emissions reductions for Groups 2 and 3 at the time of their accession, 2) Includes negative emissions in Group 1 by 2050 and negative global emissions by the end of the century, and thus requires broad deployment of bioCCS technologies 3) Carbon prices begin at \$50/tCO_2, and rise to \$2000/tCO_2 4) Results in significant land-use leakage, where crop production is outsourced to non-participating regions resulting in a substantial increase in land-use change emissions in these regions

Source: This table is taken from Calvin, et al. (2009).

Delay on the part of major emitting parties to limit greenhouse gas emissions creates another potential problem, "leakage" in both energy and land-use. That is, emissions reductions in energy in one region may result in higher emissions in another region because emissions-intensive industries may move off shore. Similarly, expansion of land for forestry to store carbon in terrestrial systems can in turn lead to deforestation elsewhere to compensate for the reduced availability of land for agriculture and livestock.

Other modeling groups participating in the EMF22 international exercise also found the 2.6 W/m^2 scenarios challenging. Six of the ten modeling teams could develop a scenario that limited radiative forcing to 2.6 W/m^2 if all regions of the world participated immediately and emissions could exceed 2.6 prior to the year 2100. Four teams could not find a solution. But,

[4] Immediate accession scenarios assumed that all regions of the world begin coordinated emissions mitigation efforts in which all emissions are reduced with perfect where, when and what flexibility beginning in 2012.

[5] Delayed accessions scenarios assume that OECD begin emissions mitigation in 2012. Brazil, China, India, and the Russian Federation are assumed to impose formal emissions limitations between 2030 and 2050, and the rest of the world impose formal emissions limitations between 2050 and 2070.

Table 2. Number of EMF 22 Modeling Teams Participating in the International Study that were able to provide a scenario that did not require an initial carbon price greater than $1000 per ton CO_2.

2.6 W/m^2 Radiative Forcing Limit in 2100	Not-to-Exceed	Overshoot
Immediate Accession	2	6
Delayed Accession	0	2

only two teams could create a scenario that limited 2.6 W/m^2 under more limiting conditions, Table 2. And, no modeling team was able to hold CO_2-e concentrations below 2.6 W/m^2 in all periods if emissions mitigation was delayed in major emitting regions.

References

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