Implementing AB-32:

Effective Verification of California's Greenhouse Gas Emissions Reductions

The California Global Warming Solutions Act of 2006 (AB-32) mandates substantial reductions in California's emissions of a wide range of "greenhouse gases" (GHGs), including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. This pioneering legislation has also served as a template for similar GHG emissions reduction legislation in other US states and in other countries. Under AB-32 the California Air Resources Board (ARB, or in the legislation the "state board") is charged with the responsibility for implementing the required emissions reductions so as to ensure that: "The greenhouse gas emission reductions achieved are real, permanent, quantifiable, verifiable, and enforceable by the state board" (Section 38562).

The AB-32 implementation proposals which have so far been advanced by the ARB, including those in the current comprehensive discussion draft of the *Climate Change Scoping Plan* [1], rely on "bottom-up" emissions inventory methods developed by the Intergovernmental Panel on Climate Change (IPCC) [2] that depend on accurate reporting and in many cases on the use of algorithms to convert industrial, agricultural and land-use practices into estimated GHG emissions. While such bottom-up inventories are useful in quantifying some industrial and transportation GHG emissions, atmospheric researchers in the broader scientific community as well as in the ARB have shown that such inventories are often surprisingly inaccurate for many types of GHG emissions, especially those of biogenic origin. Furthermore, bottom-up inventories are vulnerable to under-reporting abuses that are difficult to identify at their sources. Because of their significant uncertainties, emissions reduction regulations based solely on bottom-up assessments may also be vulnerable to legal challenge on the basis of the above AB-32 requirement that California's reductions be "real" and "verifiable".

An important additional source of information on emissions is contained in the atmosphere itself, where GHGs are accumulating. By measuring this accumulation, an alternative approach to assessing emissions is possible. In this "top-down" approach, continuous measurements of GHGs at a few well-chosen ground-based measurement stations are analyzed with computer models of regional atmospheric transport based on weather observations. As weather systems move over the state, the air masses reaching these stations sweep over ever-changing trajectories and accumulate emissions as they move. As emissions accumulate they raise the concentrations of each of the GHGs in these air masses by measurable amounts above their "background" values that would be present without these added emissions. Over time, emissions from wide geographic regions are sampled at each station. Stations near the coast also allow background concentrations to be measured. By combining this information with the analysis of air trajectories, a map of regional GHG emissions is created which is completely independent of the bottom-up inventory approach and is not vulnerable to the uncertainties cited above.[3-4]

Top-down emissions assessment based on regional measurements of the accumulation of GHGs in the atmosphere is an active and rapidly developing area of research. Nevertheless, the evidence is already clear that for many of the GHGs covered by AB-32 the top-down approach holds a greater promise of reliably quantifying regional emissions than do the bottom-up methods currently in use. In some applications, regional and global top-down approaches have been used to identify errors as large as a factor of two or more in the bottom-up assessments.[5-6]

In view of the current state of the science and the verification requirements of AB-32, we believe it is both prudent and urgent for the ARB to expand its current emissions quantification efforts to include both bottom-up and top-down assessments. This necessarily would begin by establishing the requisite observational network of continuous atmospheric measurement stations. At present there are only two stations in California that are capable of making continuous measurements of all the GHGs covered by AB-32: at Trinidad Head in Northern California and at La Jolla in Southern California (both are operated by the Scripps Institution of Oceanography under federal support). Preliminary estimates by atmospheric modelers suggest that by increasing the number of observing stations by a factor of two or three and investing in improved atmospheric models it should be possible to quantify emissions with spatial resolutions on the order of tens to a hundred kilometers and on seasonal time scales, and thus to significantly reduce the large verification uncertainties that are currently associated with AB-32. The highest priorities are therefore: 1) to formalize these estimates by enlisting leading atmospheric transport modelers to optimize the locations and numbers of additional GHG measurement stations that will be needed to quantify emissions with the required temporal and spatial resolutions, and 2) to begin to build and install the instruments and train the personnel that will be required to make the measurements. Modeling studies can always be improved retrospectively, but everything must be done to begin high-quality measurements as quickly as possible.

Because air masses move freely across political boundaries, the expansion of this observational and modeling program as a shared effort extending into other parts of western North America would strengthen the quantification of California emissions, and vice versa. Within California, we envision the required expansion of the atmospheric observational and top-down emissions modeling capabilities to be a joint effort between the ARB and the academic and federal research communities. We estimate that the annual cost of this program for California would be on the order of $2-3M.

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References and Notes:

1. California Air Resources Board, *Climate Change Draft Scoping Plan*, June 2008 Discussion Draft, 77 pp., 2008.

2. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, National Greenhouse Gas Inventories Programme, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds), in five volumes, www.ipcc-nggip.iges.or.jp/public/2006gl/, IGES, Japan, 2006, and predecessors.

3. Reimann, S., A.J. Manning, P.G. Simmonds, D.M. Cunnold, R.H.J. Wang, J. Li, A. McCulloch, R.G. Prinn, J. Huang, R.F. Weiss, P.J. Fraser, S. O'Doherty, B.R. Greally, K. Stemmler, M. Hill and D. Folini, Low European methyl chloroform emissions inferred from long-term atmospheric measurements, *Nature*, 433, 506-508, 2005.

4. Manning, A., and R.F. Weiss, Quantifying regional GHG emissions from atmospheric measurements: HFC-134a at Trinidad Head, unpublished manuscript, 2007. This is a short "demonstration" paper showing the power of combining continuous atmospheric measurements from a single observing station with an atmospheric transport model to identify and roughly quantify western North American emissions of the new automotive refrigerant HFC-134a (GWP 1300).

5. Bergamaschi, P., M. Krol, F. Dentener, A. Vermuelen, F. Meinhardt, R. Graul, M. Ramonet, W. Peters and E.J. Dlugokencky, Inverse modeling of national and European CH_4 emissions using the atmospheric zoom model TM5. *Atmos. Chem. Phys.*, 5, 2431-2460, 2005. These results showed up to 50-90% higher anthropogenic methane emissions than those reported under IPCC guidelines [2] for several European countries, and led to a substantial increase in the reported German national methane emissions.

6. Unpublished bottom-up estimates of global aluminum industry emissions of the PFC carbon tetrafluoride (the longest-lived GHG regulated by AB-32, GWP 6000) from the International Aluminium Institute account for only about half of the measured global atmospheric increase of this gas after minor contributions from the electronics industry are subtracted. There are only several hundred aluminum smelters in the world, so this should be a relatively easy bottom-up calculation.