exists on the solvation properties of a wide range of hydrocarbons. Readers interested in detailed analyses of the solvation properties of benzene and other hydrocarbons may wish to review recent seminal contributions (*1*). These studies, as well as several of the references in our report, identify potential energy surfaces to be used in molecular simulations of the aqueous environment. All invoke a hydrogen bond interaction of individual water molecules with the benzene π cloud. The major differences between the models concern the geometry of the potential minimum and the degree of anisotropy in the benzene-water pair potential, which can be unambiguously determined by looking at the far-infrared spectrum of the dimer. We thank Faust and other researchers for bringing these important points to our attention.

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1. See, for example, W. J. Jorgensen and D. L. Severance, *J. Am. Chem. Soc.* **112**, 4768 (1990); C. J. Cramer and D. G. Truhlar, *Science* **256**, 213 (1992); A. W. Garrett and T. S. Zweir, *J. Chem. Phys.* **96**, 3402 (1992).

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Carbon Budget Estimates

P. E. Kauppi *et al.*, in their article "Biomass and carbon budget of European forests, 1971 to 1990" (3 Apr., p. 70), estimate "an annual accumulation of 70 to 105 million tons of carbon in European forests in the 1970s and 1980s." These numbers are consistent with the earlier estimate of about 80 million tons by one of us (R.A.H.) and colleagues (*1*). However, the assertion by Kauppi *et al.* that this (plus a 15-million-ton increase in wood products) "represents 8 to 10% of the 'missing' flux in the global carbon budget" indicates that their interpretation of the land-use term in the global budget is different from ours.

The net flux of carbon resulting from changes in land use (the land-use term) is not considered to be the gross flux of carbon from deforestation. On the contrary, the land-use term includes not only the release of carbon to the atmosphere from deforestation but the accumulation of carbon from reforestation, afforestation, and regrowth of forests after logging or abandonment of farmland. The term also includes the longer term decay of plant material left on site at harvest, the oxidation of harvested products, and the oxidation and subsequent recovery of soil carbon after logging. Thus, the assumption criticized by Kauppi *et al.* "that nontropical forests are in [near] equilibrium with the atmosphere" is not an assumption at all but a result of analyses accounting for all of the carbon originally contained in the forest.

In the budget of Kauppi *et al.*, the "buildup of wood in unexploited forests makes only a minor contribution to the observed trends of increase in standing stock and growth." Thus, virtually all the storage is the result of regrowing forest and should be included in the land-use term of the global budget. However, their budget does not account for the decay of plant material left on site after harvest or for the oxidation and recovery of soil carbon. These two factors will substantially reduce their estimates of net carbon storage.

Kauppi *et al.* cite an annual rate of "138 million cubic meters of sawed wood and wood-based panels" used in Europe, 58 of which replace old wood products (no net storage) and 80 (or 15 million tons of carbon) of which is new storage. The plant material left (both above- and belowground) from harvest can be three to four times as large as the actual harvest (*1*, appendix 1). Using a more conservative factor of two and using their volume-to-carbon conversion factor of 1/5, we estimate the decay contribution to the land-use term to be about 55 million tons of carbon ($138 \times 2 \times 1/5$). This would reduce the storage rate of Kauppi *et al.* to between 15 and 50 million tons per year. (Houghton *et al.* estimate 28 million tons per year) (*1*). To this is added the 15-million-ton increase in wood products for a net storage of 30 to 65 million tons of carbon per year.

Can this 30 to 65 million tons of carbon per year be tallied against the "missing" carbon in the global budget? As we have pointed out, this flux is more properly attributed to the land-use term. To contribute to the "missing" flux, the 30- to 65-million-ton flux would have to be greater than the land-use flux already accounted for in the global budget. Houghton *et al.* (*1*) estimate a net sink in Europe of 28 million tons of carbon per year. The difference between the Kauppi *et al.* and the Houghton *et al.* estimates of this sink is between 2 and 37 million tons of carbon per year. This difference can reasonably be tallied against the "missing" sink, but it accounts for no more than 0.2 to 3% of the missing flux. As pointed out by Daniel B. Botkin *et al.* (Letters, 10 July, p. 146), the errors in estimating terrestrial carbon fluxes are large. The additional flux in the budget of Kauppi *et al.* is well within these errors.

A more important indicator of increased carbon storage in terrestrial ecosystems, which might help explain the "missing" flux of carbon, would be an increase in the rate of forest growth. Kauppi *et al.* state that the annual increment of stemwood volume "increased by about 30% between the early 1970s and the late 1980s." However, they also cite a greater than twofold increase in the rate of use of forest products since 1949. Therefore, the increase in growth may simply reflect a younger average forest age. If so, there may be no net effect on carbon storage because of the decay associated with previous harvests. That is, this increase in growth rate is also accounted for in the land-use term of the global budget.

To account for the "missing" carbon in the global budget, the rate of forest regrowth would have to be faster now than it was for the forests used to estimate regrowth in the original global budget. Kauppi *et al.* cite a German study (*2*) in which "present stands were observed to grow faster than the stands of earlier rotations on the same plots," resulting presumably from favorable climate and increased nitrogen deposition. This is indeed compelling evidence of increased storage in terrestrial ecosystems which might help explain the "missing" sink of carbon in the global budget, but Kauppi *et al.* do not distinguish between the original estimate of carbon accumulation in regrowing forest and any enhanced accumulation estimate. It is that difference that can be attributed to the "missing" flux.

We join with Kauppi *et al.* and Botkin *et al.* in urging that the carbon budget of the terrestrial biosphere be given high research priority. The evidence for a terrestrial sink is growing. Until we understand this sink and its dynamics, predictions of the future ramifications of increased carbon dioxide are difficult to justify.

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Response: Houghton *et al.* estimated that European forests accumulated 28×10^{12} grams of carbon in the year 1980 which acted as a weak sink in the global carbon budget (*1*). The suggested reason was the abandonment of croplands. We estimated a higher rate of annual buildup, 70 to 105 $\times$ 10^{12} grams of carbon, and attributed it mainly to an increase in the biomass of existing middle-aged and mature stands (*2*). Either one or both of these estimates must be revised.

Soil carbon in our analysis was assumed

to be proportional to vegetation biomass. In Europe, biomass formation (of trees) has exceeded removal and natural wood decay, and stands on average have become denser and older. The buildup of soil carbon in areas that have not been harvested has counteracted the carbon flux on harvested forest land from soils into the atmosphere. Rastetter and Houghton point out that we did not take into account the intensive decay rate after harvest. However, this has only a small impact on the carbon budget (*3*), especially as total removal in Europe has not increased (*4*).

Although removal has been stable, the fraction of biomass used for sawed wood and panels has increased. This has prolonged the average decay time of harvested wood and has contributed to carbon sequestration from the atmosphere. The flux, 15×10^{12} grams of carbon per year according to our estimate (*2*), was added to the (independent) estimate of carbon accumulation in forests thus obtaining the total flux estimate of 85 to 120×10^{12} grams of carbon per year. This is three to four times higher than the respective estimate of carbon sequestration by Houghton *et al.* (*1*).

The area of forests in Europe is about 2.5 million square kilometers, less than 7% of the global forest area. We agree that estimating carbon fluxes in Europe alone will not be able to balance the global budget. R. Sedjo has recently estimated carbon sequestering of temperate forests in all northern continents (*5*). His estimate for Europe is consistent with ours.

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5. R. Sedjo, *Ambio* 21, 274 (1992).

Corrections and Clarifications

The photograph of Thomas Caskey that accompanied the News & Comment article "DNA fingerprinting: Academy reports" by Leslie Roberts (17 Apr., p. 300) should have been credited to Baylor College of Medicine, not Baylor University.