seawater also alter the oceanic isotopic composition but do not affect sea level. If limits can be put on floating ice-cap effects during the last interglacial, then we can calculate ocean temperature changes by using our measured sea level changes from the raised reef data. Earlier workers (*23, 24*) have overestimated isotopic effects from a floating ice cap because they used an incorrect volume for the Arctic Ocean. Menard and Smith (*26*) have given a more reliable value of 12.6×10^6 km^3. Calculations based on the use of their depth and area distribution reveal that a floating ice cap to a depth of 1 km would occupy 5.4×10^6 km^3. This is equivalent to a change of only 0.14 per mil in mean oceanic $\delta^{18}O$ composition [if we assign a value of −35 per mil (*23*) for the ice].

Williams *et al.* (*24*) assumed that a floating Arctic ice cap 1 km thick formed during glacial substage 5d and remained until the present interglacial. If so, 0.14 per mil must be subtracted from the 0.7 per mil $\Delta\delta^{18}O$ between interglacial Nicolas and Mole or Saint. From the known sea level change of 18 m, a bottom temperature change of 1.6°C can be calculated (*27*). If, more reasonably, no floating ice cap accumulated during these interstadials, the full 0.7 per mil benthic $\Delta\delta^{18}O$ is used and the temperature change is 2.2°C. In the latter case temperature accounts for 70 percent and continental ice volume for 30 percent of the effects.

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$$\delta^{18}O = \left[\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{standard}} - 1\right] \times 10^3$$

where the standard is standard mean ocean water.
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27. Assuming a conservative estimate of mean glacial ice of -45 $\delta^{18}O$, a mean ocean depth (MOD) of 3729 m, a change in sea level (ΔSL) of 18 m, and a $\Delta\delta^{18}O$ of benthic forams of either $0.7 - 0.14 = 0.56$ per mil or 0.7 per mil (the latter value based on the assumption that there is no floating Arctic ice cap), the temperature change (ΔT) in ocean deep water between substage 5e (Nicolas) and substage 5a or 5c (Mole or Saint) can be calculated from the formula

$$(\delta^{18}O_{glacial\ ice})(\Delta SL) + (\Delta\delta^{18}O_{benthic\ foram} - 0.22\,\Delta T)(MOD - \Delta SL) = 0$$

28. We have used these parameters to be consistent with the dating of other reef material. There is a large uncertainty for the half-life of ^{230}Th; a value of 8.03×10^4 years has also been reported in *Table of Isotopes* [C. M. Lederer and V. S. Shirley, Eds. (Wiley, New York, ed. 7, 1978)].
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Residential Firewood Use in the United States

Abstract. *An empirical relation between residential firewood use and population density was developed from survey data for 64 counties in New England and was corroborated by data from other states. The results indicate that usage is concentrated in urbanized areas of the Northeast and north central states and that about 9.0 to 11.0 percent of U.S. space heating input is from firewood. No constraints due to the supply of wood were apparent in 1978–1979. These findings have implications for effects on air quality.*

Uncertain oil supplies and steep price increases for petroleum and natural gas have led to increased use of alternative fuels for home heating. Sales of wood stoves and efficient fireplaces are estimated to be about 1 million units per year (*1*). Although wood smoke is generally regarded as benign by the public, there is concern about effects on ambient air quality and health that might result from widespread use of wood fuel (*2*) and about accidents from harvesting the wood (*3*). To assess these effects data on firewood usage, and in particular, estimates of the spatial density of wood use (cords per square mile or kilograms per hectare) are needed.

Most surveys of the use of firewood for space heating have reported data for states, with occasional breakdowns to regions of a state. The New England Fuelwood Survey (*4*), however, provided data for counties in New England for the 1978–1979 heating season. These survey data were used to develop the following equation for the 64 mainland counties, excluding islands.

$$\text{Cords used per household per } 10^4 \text{ degree days} = 3.087 \pm 0.25 - (0.322 \pm 0.05)\ \ln(\text{population density}) \quad (1)$$

where population density is expressed as persons per square mile with the 95 percent confidence interval shown (*5*). Equation 1 was then applied to all counties in the conterminous United States to develop estimates of wood usage based on the number of households in the county (1970 census) and the 30-year average heating degree days (*6*). Spatial patterns of usage throughout the country on the basis of Air Quality Control Regions (*7*) (Fig. 1) show concentrations in

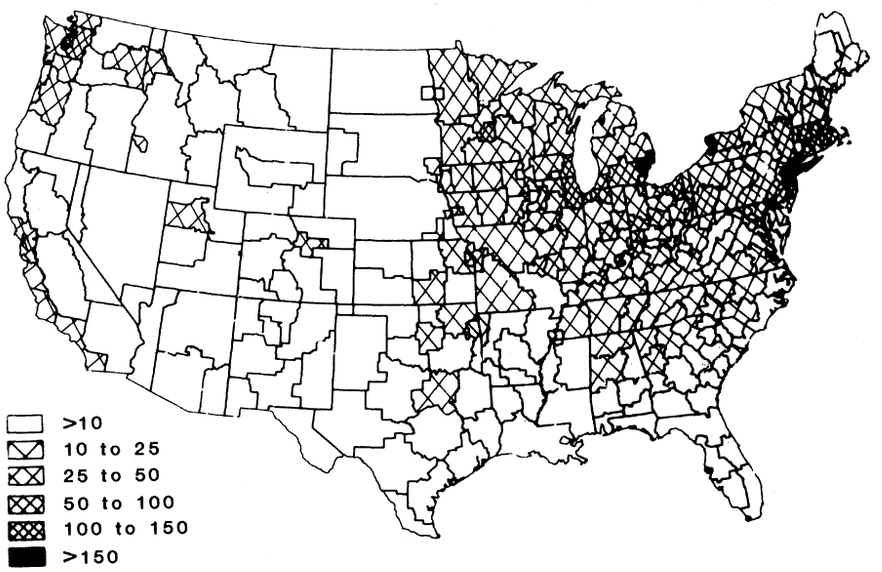

Fig. 1. Fire wood usage (cords per square mile) in the United States, 1978.

northern urban areas. The U.S. national total was estimated to be 34.7×10^6 cords for the 1978–1979 heating season or about 0.8 quad of energy per year (1 quad = 10^{15} Btu) (*8*). This is about 10 ± 1.0 percent of the energy input for space heating; the percentage of delivered heat would be substantially less because of the relatively low thermal efficiencies of stoves and fireplaces. This national estimate is higher than a previous estimate (*9*), but lower than an estimate from a Gallup poll (*10*).

To check on the validity of this extrapolation of the data from the 64 counties in New England to the rest of the country, state totals were compared to the survey data from 12 other states (Fig. 2). (The six New England states are also shown on Fig. 2) (*11*). Oregon used substantially more wood than Eq. 1 would predict; this may be because of the ready availability of waste from the logging and forest products industries. Montana and Minnesota used less wood than expected, but no reasons are readily apparent (*12*). In general the states surveyed used firewood in the same manner as New England. No constraints on supply were apparent at the observed level of usage.

Demographic data on users of wood fuel, where available, indicate that use of wood for space heating is no longer concentrated among the rural poor. For example, in a wood-scarce state like Kansas, nearly 31 percent of households in the five largest cities burned some wood (*13*), and 33 percent of the households in rural farm and rural suburban households in three counties in upstate New York burned some wood (*14*).

The important parameter in assessing the effect of wood burning on air quality is the density of usage, so that air pollutant emissions may be estimated per unit area for use with an atmospheric dispersion model. Equation 1 may be transformed to cords per square kilometer by multiplying by population density and dividing by persons per household and then differentiating with respect to population density to display the sensitivity of usage density to population density (Fig. 3). Wood usage density peaks at a population density of about 5000 persons per square mile (*15*) in this example. Population exposure (the product of population times air pollution dose) would peak at an even higher density, about 8800 persons per square mile. These are urban population densities and include major cities in the northern United States (*16*).

The emphasis on urban firewood usage is a direct result of the regression analysis leading to Eq. 1, which is not sensitive to low values of cords per household. Small changes in the coefficients of Eq. 1 can result in relatively large changes in wood usage, since the cords per household figures for urban areas are multiplied by such large population bases.

Our analysis indicates that there is an upper limit to the density of firewood use (Fig. 3) at the county level and thus to the resulting air pollution emission density. This finding should permit more realistic simulation of the resulting effect on air quality through the use of conventional dispersion models. It appears that emissions of particulate matter from woodburning in Northern cities may contribute the major portion of all space heating particulate emissions (*17*).

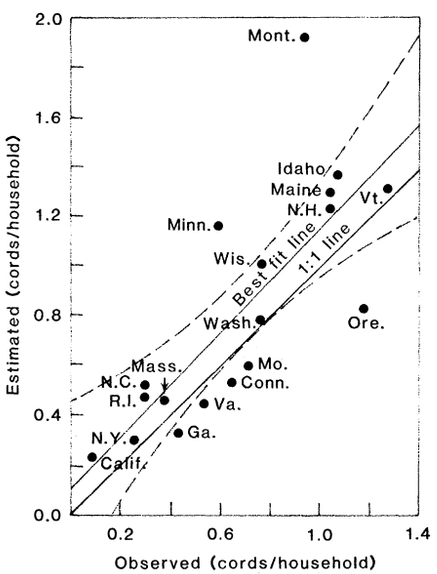

Fig. 2. State level wood use correlation (*11*).

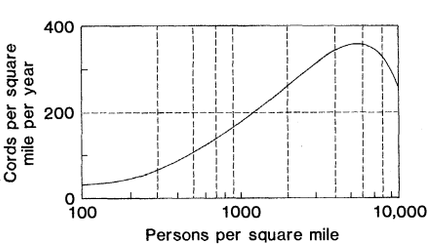

Fig. 3. Typical wood fuel use density at 6500 degree days, 1978–1979 (*15*).

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2. Wood smoke is high in polycyclic organic compounds, some of which have carcinogenic properties. See J. A. Cooper, *J. Air Pollut. Control Assoc.* **30**, 855 (1980); National Academy of Sciences, *Particulate Polycyclic Organic Matter* (Washington, D.C., 1972); G. J. D'Alessio and K. E. Kawaoka, "Health effects of residential wood combustion: survey of knowledge and research" (Department of Energy, Washington, D.C., March 1980).
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5. The data used to develop Eq. 1 could support a number of alternative relations since many other attributes of New England counties, such as percentage of urbanization, percentage of land in forest, retail price of wood, and perhaps family income, relate to population density. Since the main purpose of this inquiry is to develop models for subsequent air quality analysis, population density is the preferred parameter.
6. Census data from 1970 were used to establish the relation between population density and wood usage per household and also to project national total wood consumption. Thus, this estimate may be in error (probably low) because of population shifts since 1970. However, when individual states were considered (Fig. 2), esti-

mated 1978 figures on the numbers of households were used to arrive at state totals, consistent with the survey totals. Any errors so introduced are probably not serious in comparison to the uncertainties involved in many of the surveys. The error introduced by the use of 30-year average heating demands should tend to average out across the nation; the 1978–1979 winter was colder than normal in some areas and warmer in others, for example.

7. There are 238 Air Quality Control Regions designated by the Environmental Protection Agency. The regions are usually groups of counties and vary considerably in size and population.
8. The uncertainty in this total estimate of 35 million cords can be derived as follows: for 18 states, usage figures are available from surveys or from local estimates; these total 14,364,000 cords, a figure taken as accurate for the purpose of statistical model development. The uncertainty thus derives from the estimates for the other 30 states. There are several levels of uncertainty involved. First, Eq. 1 contains uncertainty as to how well it represents the 64 New England counties from which it was derived. However, this uncertainty is not relevant to the problem of applying this particular equation (or any other equation) to other states; the uncertainty derives from how well the equation fits the state data. Figure 2 displays this uncertainty at the state level. The standard error involved in the regression of predicted wood usage against observed wood usage may be derived in two different ways, either from use of cords per household in each state as the measure or else from just the total state estimate in cords. The goodness of fit was about the same in each case, with about 65 percent of the variance explained and a standard error of about 37 percent. Since the average predicted state usage for the 48 states (about 736,000 cords) is comparable to the average prediction for the 18 states (787,000 cords), the 18-state sample is regarded as representative of the whole country, including the error of prediction for each state (about 306,000 cords). Thus, assuming that all states have the same probability distribution of prediction error, the error for the sum of the 30 nonsampled states is given by 306,000 $\sqrt{30}$ or 1.68×10^6 cords. The 95 percent confidence limits for the U.S. total would be from 31.1 to 38.2 million cords. This would be equivalent to about 0.70 to 0.86 quad, or from 9.0 to 11.0 percent of U.S. space heating input. The error involved in basing fuel usage on degree days referenced to 65°F may be more important, since it is doubtful that homeowners in climates where only occasional space heating is required would make the investment required for wood heating systems.
9. D. G. DeAngelis, D. S. Ruffin, J. A. Peters, and R. B. Reznik ["Source assessment: Residential combustion of wood" (EPA-600/2-80-042b, Environmental Protection Agency, Washington, D.C., March 1980)] estimated that about 16.6×10^6 metric tons of wood were burned in the residential sector in 1976; this corresponds to about 0.3 quad of energy.
10. J. O. Davies III and P. Cohen, "Wood as a viable home heating alternative" (Gallup Organization, Princeton, N.J., June–July 1979).
11. Figure 2 shows the best fit regression line for all 18 states; it has a slope of 1.06 ± 0.4. The 1:1 correspondence line falls within these 95 percent confidence limits. If the three most outlying states (Oregon, Montana, and Minnesota) are dropped, the slope is 1.11 ± 0.10. Thus, the relation between observed firewood usage and the usage predicted by Eq. 1 appears to be satisfactory.
12. Survey data from Missoula County, Montana (J. McNairy, "Energy use in Missoula," report prepared for Missoula Valley Energy Conservation Board, June 1981) agree quite well with Eq. 1: 0.8×10^{12} Btu and 0.87×10^{12} Btu, respectively. The statewide survey may not be representative.
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15. Data used in Fig. 3 are based on a typical average number of persons per household (3.1) and 6500 heating degree days per year. At about 3.1 persons per household, this population density level corresponds to about 2.7 houses per acre. Since Eq. 1 yields 0.209 cord per household at this density and the average household depending entirely on wood uses about 5 or 6 cords annually, this peak value corresponds to about 4 percent of urban households heating exclusively with wood. Casual use of wood by others would reduce this figure. The uncertainties in the parameters of Eq. 1 result in a large uncertainty in Fig. 3, which should be viewed as an example.
16. Small cities often have population densities higher than 2000 persons per square mile. But many entire counties also have densities in the range of maximum air quality impact; for example, Denver (5100); Suffolk, Mass., which includes Boston (12,907); and suburban New York and New Jersey counties (4000 to 7000).
17. Particulate emissions from wood burning are 20 to 60 times higher per input (Btu) than emissions from liquid or gaseous fuels [F. W. Lipfert, in *Residential Solid Fuels, Environmental Impacts and Solution*, J. A. Cooper and D. Malik, Eds. (Oregon Graduate Center, 1981)]. The substitution of wood fuel for 10 percent of the heat input may result in the doubling or tripling of the total emissions of particulate matter.
18. We thank our colleagues at Brookhaven for helpful discussions and assistance with computations, J. Martino for manuscript preparation, and an anonymous reviewer for statistical suggestions. Supported by the Department of Energy contract DE-AC02-76CH00016.

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Activation of 2-Aminofluorene by Cultured Plant Cells

Abstract. *Cultured tobacco plant cells activated 2-aminofluorene to an agent mutagenic to* Salmonella typhimurium *strain TA98. The plant activation of 2-aminofluorene is heat-inactivated and may not involve solely cytochrome P-450. The kinetics of activation demonstrated both time- and concentration-dependent responses.*

Environmental mutagens constitute a threat to public health (*1*). A relatively new topic in genetic toxicology is the activation of chemicals into mutagens by green plants. A promutagen is a chemical that is not mutagenic in itself but can be biologically transformed into a mutagen. Plant activation is the process by which a promutagen is activated into a mutagen by the biological action of a plant system. Plant activation is analogous to the mammalian microsome activation systems that are used routinely in most short-term microbial mutagen assays. In order for an agent to be defined as a plant promutagen, it is necessary that the plant activation process be distinct from the genetic end point used to assay for mutagenicity (*2*).

We provide here evidence for the metabolic activation of 2-aminofluorene (2-AF) to a mutagen by plant cells in culture. Aromatic amines such as 2-AF and 2-acetylaminofluorene are well-characterized mammalian promutagens and procarcinogens (*3*). Their carcinogenicity and in vivo reactivity are dependent upon metabolic activation. The first step in the mammalian metabolic activation of these agents is *N*-hydroxylation (*3, 4*). In the presence of mammalian hepatic microsomes, the *N*-hydroxylation of aromatic amines is dependent upon the cytochrome P-450 enzyme system that functions as a terminal monooxygenase (*4*). Plant cells contain exceedingly little cytochrome P-450 (*5*).

Our discovery of plant activation of 2-AF is based on a new technique in which cultured tobacco cells *(Nicotiana tabacum)* were coincubated with the bacterial genetic indicator organism *Salmonella typhimurium* strain TA98 (*6*). The *N. tabacum* and *S. typhimurium* cells were coincubated in a culture medium with 2-AF, after which the plant cells were removed by centrifugation. Induction of reverse mutation at the *his* locus in TA98 was determined by plating on a minimal medium.

A liquid suspension culture of *N. tabacum* cell line TX1 was grown aseptically at 28°C in Murashige and Skoog medium containing 0.4 mg of 2,4-dichlorophenoxyacetic acid per milliliter (*7*); 50-ml aliquots of plant cells were harvested from logarithmic-phase cell suspensions by centrifugation at 50*g*. The cell pellet was resuspended in 10 ml of fresh cell culture medium and used immediately.

A single colony isolate of TA98 was inoculated into nutrient broth and incubated at 37°C overnight. The bacterial cell pellet was resuspended in a standard S-9 buffer (*8*). For incubation studies requiring mammalian microsomal activation, an Aroclor-induced rat hepatic fraction (S-9) was used to prepare a standard activation mix (*8*). The bacterial cells were maintained according to established practice (*8*).

The coincubation experiments were conducted such that either the time of coincubation with 2-AF or the concentration of 2-AF was the variable. The coincubation and the incubation tests were conducted while shaking at temperatures of 25°C and 37°C, respectively. The solvent controls consisted of 50 μl of dimethyl sulfoxide (DMSO) added to each different control suspension. The experimental test suspensions contained 2-AF in 50 μl of DMSO. A heat-inactivated control consisted of either plant cells or S-9 mix, killed or denatured by incubation at 70°C for 15 minutes prior to their use in the suspension tests. Samples (1 ml) were withdrawn at the designated times, diluted in 9 ml of 0.5 percent NaCl at 4°C, and mixed vigorously. The