Incineration of municipal waste is most commonly used in metropolitan areas where high population density often prevents the use of landfill, and where high total population results in the generation of high quantities of refuse. From 20 to 25 percent of commercial and domestic waste collected in urban areas (10 percent of the total waste generated in the United States) is incinerated (Sittig 1975). Plastics and plastic-containing wastes are most often put into landfills. The advantages of placing wastes into landfills are that it is easy and has low capital cost, and landfills accept any waste. The disadvantages are that there is no recovery, and there are a variety of environmental problems. Other methods have been used or suggested, such as recycling and more use of incineration; each has its advantages and disadvantages (Bridgewater and Mumford 1979).

Because plastics do not decompose readily, they theoretically release no odors in sanitary landfills or gasses or liquids that pollute surrounding land, air, or water. They do not contribute to settlement. They could be considered the equivalent of an inert material such as broken concrete. Some decomposition does occur, however; in one study, different levels of biodegradation of thin plastic films, polyethylene, and PVC had occurred after 5 years (Sittig 1975).

Aluminum

Extraction - Aluminum is the most abundant metal in the crust of the Earth, and alumina is the principal raw material used for aluminum production. Only bauxite rock qualifies as a commercial source of alumina under current economic conditions (Bravard and others 1972). Bauxite is mostly imported and therefore controlled by other countries. The United States imports about 85 to 90 percent of its bauxite needs, mainly from Suriname, Jamaica, and Guyana. The remainder is mined domestically in Arkansas (Talley and Ongerth 1974). Shortages have been projected within a few decades, but the technology exists for extracting aluminum from clay (Midwest Research Institute 1974). Recovery efficiencies can be increased somewhat, and leaner and less accessible ore must be used. Leaner ore means more material must be processed, which requires more energy and produces more environmental degradation (National Academy of Sciences .1975).

Open pit mining accounts for most of the bauxite refined in the United States (Bravard and others 1972, U.S. EPA 1974b). Vegetation, soil, and water effects of pit mining operations are similar to the most extreme effects found in timber harvesting. In addition, the handling and relocation.of solid waste from mining is a problem in any mining industry. The rate of solid waste produced increases annually as the depth of ore bodies increases and the grade decreases. Stream sedimentation may occur from runoff from solid-waste piles depending on the nature of the solid waste and the climate. Runoff can be minimized with proper waste management, revegetation, or landscaping (Williams 1975).

Manufacture--Aluminum oxide (alumina) is the compound extracted from bauxite. Bauxite is hydrated aluminum oxide with impurities including iron oxide, various silicates, and quartz. Bauxite is the residuum of strata high in alumina. The Bayer process or the combination process dissolves the impure alumina in the ore with caustic soda (NaOH) to form soluble sodium aluminate. The solution is cooled, diluted, and hydrolyzed to precipitate aluminum hydroxide, which is filtered and

The major solid-waste disposal problem in the mining industry is the handling and relocation of overburden and gangue. Acid mine drainage is a problem in coal mining areas, and coal is used to fuel some cement kilns (Williams 1975).

Manufacture–The production of hydraulic cement involves (1) proportioning a lime-containing substance and material containing silica, alumina, and iron; (2) grinding these to a slurry or powder; (3) "burning" the mixture in a rotary kiln, until fused; and (4) grinding the "clinker" that comes out of the kiln with gypsum into a fine powder (The Ford Foundation 1974).

All raw materials must be ground to an impalpable powder and intimately mixed before burning. Blending of the rock may begin in the quarry and continue as the raw materials flow into each crusher or mill. In the dry process, all grinding and blending operations are done with dry materials, and the final mixing is accomplished chiefly in the grinding mills. In the wet process, the final grinding and blending are brought about in a water slurry, and mixing is done both in the grinding mills and by stirring in large vats. The wet process requires 15 percent more energy, but is mandatory to use in many cases because of technological and ecological reasons. The water can be removed by various processes or allowed to evaporate in the kiln. The kiln is heated with ignited powdered coal and air, or less commonly with fuel oil or gas. The charge drops from the end of the kiln and is ground with gypsum (Popovics 1979).

Water use in the cement industry varies from 0 to 730,000 gallons per day. Ready-mix concrete plants use a great deal of water (U.S. EPA 1978). Water **is** used as mixing water, for curing, washing aggregate, and cleaning equipment. The disposal of waste water can be a problem. Solutions include the reduction of solids and other impurities to an acceptable level by sedimentation, chemical means, or other methods before disposal, or recycling; reducing contamination so the water can be reused for mixing, curing, or washing (Popovics 1979). Wash water is the greatest source of waste water. Low pressure steam curing of cement blocks leaves suspended solids, COD, oil, greasei, and high pH in the water. The EPA selected total suspended solids, oil and grease, and pH as major water pollution parameters. Oily wastes include light and heavy hydrocarbons, lubricants, and cutting fluids. Dissolved solids may be present in significant amounts, but there is no treatment other than no discharge to practicably reduce them. Chemical oxygen demand can be controlled by controlling oil and grease. Suspended solids are removed in settling basins, tanks, or ponds. Sulfuric acid is used to adjust pH. Oil is removed by skimming from the tank or pond surface. Waste-water discharge from plants manufacturing concrete products are relatively small. Some recycle is practiced, and the use of evaporation or percolation ponds is widespread (U.S. EPA 1978).

Solid waste includes cement dust, waste concrete, scrap block, and brick. Dust is returned to cement storage silos, and solid wastes are used as fill. Some companies crush broken block for reuse as aggregate. Miscellaneous wastes come from equipment washoff, accidental spill washdown, and aggregate moisture control (U.S. EPA 1978).

The use of precalcining cement kilns has created a unique problem in both cement kiln process and environmental control. Precalciner cement kiln operation, because of the nature of the fuel combustion process, establishes a specific pattern of CO generation. Because of the CO generation, automatic explosion protection systems deenergize the electrostatic precipitators (ESP) used to control particulate matter emissions from the kilns. The number, duration, and frequency of deenergizations is highly variable and is source specific depending on the manufacturer of the kiln, the process operation, and the associated monitoring system. Because of the high frequency of excess emissions at several plants, the EPA funded a study to evaluate the extent and possible causes of excess emissions. Several plants have recognized the severity of CO problems and have taken steps to reduce the frequency of events. These efforts have involved changes in fuel firing methods, monitor location, and operating procedures (Hawks and Chadburn 1986).

Use—Radon is radioactive and causes lung cancer. Although it has been recognized as a heatth problem for 20 years, public attention has reached a new high with the discovery of high levels of radon inside homes. Radon-222 comes through the uranium-238 cycle and occurs to some extent everywhere. It is produced by the radioactive decay of radium-226, which is estimated to be present at levels of about 1 picocurie per gram in ordinary soil and rock. Radon has a half-life of 3.8 days, but it is not really the problem; its decay products have short half-lives, and if they decay in the lungs, cancer can be a result. Because it is an inert gas, the radon generated is free to migrate through rocks, soil, slab, and floor into the structure above. There, it will accumulate. The total accumulation of radon and its decay products in a house depends on the rate of infiltration into the building and on the degree of outside ventilation into the house (Hanson 1985).

Different types of construction materials have been identified as sources of hazardous materials. Typical radium-226 levels in rock, clay, and sand products have been developed. The diffusion of radium-226 from building materials is influenced by moisture content of the material, density, the presence of sealants, the nature of the material itself, and the nature of the substance it is mixed with (Wadden and Scheff 1983). The exhalation rate of radon from concrete decreases drastically after forced drying by heating. Flyash is commonly used in concrete manufacture. Increasing the flyash content in concrete up to 35 percent gives no increase in exhalation rate. Using flyash with lower radium contents gives a decrease in the radon exhalation rate (Van DerLugt and Scholten 1985).

DIsposal—Settled solids from settling basins are disposed of in landfills. The major amount of solid-waste disposal is on land.

Conclusions

Much attention has been paid to the environmental ramifications of forest products, particularly with regard to harvest. One should be careful of doing a partial analysis, in that a change in one market has marked consequences for environmental effects in other markets. When steel, aluminum, concrete, or plastics are substituted for forest products, there are many types of impacts on the environment that need to be considered before forest policy is made.

Empirical evidence supports the general hypothesis that wood and other materials (steel, aluminum, concrete, and plastics) are substitutes in many end uses. The advantages and disadvantages of this substitution depend on the environmental effects associated with each commodity. This study has indicated that changes in the softwood timber market could increase prices, thereby creating increased demands for steel, aluminum, and concrete. In turn, soil, air, and water quality could be adversely affected in the short run through increased extraction and manufacturing activities in the other sectors. In the long run, a whole new set of disposal issues could surface. Research efforts in the future should quantify the effects summarized in table 1 so that it is possible to quantify environmental impacts in a precise manner to enable policy makers to make informed decisions.

Literature Citations

The Aluminum Association. 1967-83. Aluminum statistical review. Washington, DC: The Aluminum Association. Annual.

American Iron and Steel Institute. 1962-85. Annual statistical report. Washington, DC. Annual.

Bravard, J.C.; Flora, H.B., II; Portal, Charles. 1972. Energy expenditures associated with the production and recycle of metals. Oak Ridge, TN: Oak Ridge National Laboratory. 87 p.

Bridgewater, A.V.; Mumford, C.J. 1979. Waste recycling and pollution'control handbook. New York: Van Nostrand Reinhold Co. 706 p.

Bye, J.C. 1983. Portland cement; composition, production and properties. Oxford, England: Pergammon Press. 149 p.

Cannon, James S. 1974. Environmental steel; pollution in the iron and steel industry. In: Halloran, Jean M., ed. New York: Prager Publishers. 521 p.

Dyer, Jon C.; Mlgone, Nicholas A. 1983. Handbook of industrial residues. Park Ridge, NJ: Noyes Publications. 453 p.

Eldredge, Richard W. 1977. Industrial solid waste management. In: Wilson, David G., ed. Handbook of solid waste management. New York: Van Nostrand Reinhold Co.: 466-519.

The Ford Foundation. 1974. Energy consumption in manufacturing. Cambridge, MA: Ballinger Publishing Co. 610 p.

Franklin, Arnold J. 1976. Cement and mortar additives. 2d ed. Park Ridge, NJ: Noyes Data Corp. 308 p.

Groah, William J.; Gramp, Gary D.; Garrison, Scott B.; Walcott, RIchard J. 1985. Factors that influence formaldehyde air levels in mobile homes. Forest Products Journal. 32(2): 11-18.

Hanson, David J. 1985. High radon levels in homes spark moves to combat pollutant. Chemical and Engineering News. 63(46):18-19.

Hawks, Ronald L.; Chadburn, John. 1986. Modifications to precalciner combustion systems to prevent carbon monoxide electrostatic precipitator trips. In: Record of conference papers: The Institute of Electrical and Electronics Engineers 28th IEEE cement industry technical conference; 1986 May 19-22; Salt Lake City, UT. New York: The Institute of Electrical and Electronics Engineers Inc.: 1-42.

Haynes, R.W.; Adams, D.M. 1985. Simulations of the effects of alternative assumptions on demand-supply determinants on the timber situation in the United States. Forest Resource Economics Research publication. Washington, DC: U.S. Department of Agriculture, Forest Service. 113 p.

Meyer, Beat; Hermanns, Karl. 1985. Formaldehyde release from pressed wood products. In: Turoski, Victor, ed. Formaldehyde analytical chemistry and toxicology. Washington, DC: American Chemical Society: 101-116.

Mldwest Research Institute. 1974. Resource and environmental profile analysis of plastics and competitive materials. Kansas City, MO: Midwest Research Institute. Final report, MRI project 3714-D.

National Academy of sciences. 1975. Mineral resources and the environment. Washington, DC: National Academy of Sciences. 348 p.

Nlessen, Walter R. 1977. Properties of waste materials. In: Wilson, David G., ed. Handbook of solid waste management. New York: Van Nostrand Reinhold Co.: 10-62.

Nordman, Henrlck; Kesklnen, Helena; Tuppuralnen, Matti. 1985. Formaldehyde asthma-rare or overlooked? The Journal of Allergy and Clinical Immunology. 75(1): 91-99.

Popovics, Sandor. 1979. Concrete-making materials. Washington, DC: Hemisphere Publishing Corp. 370 p.

Schnelder, Mary Jane. 1979. Persistent poisons; chemical pollutants in the environment. New York: The New York Academy of Sciences. 67 p.

Shasma, M.P. 1985. Effect of aqueous leachates from polyvinyl chloride on seed germination and growth of various crop species. Canadian Journal of Botany. 63: 1072-1075.

Stttlg, Marshal. 1975. Pollution control in the plastics and rubber industry. Park Ridge, NJ: Noyes Data Corp. 305 p.

Soclety of the Plastlcs Industry. 1985. Facts and figures of the U.S. plastics industry. New York: Society of the Plastics Industry, Inc. 132 p.

Talley, Ronald J.; Ongerth, Rlchard H. 1974. Aluminum as a component of solid waste and a recoverable resource..PB-235 770. EPA-670/5-74-005 Cincinnati, OH: National Environmental Research Center.

Turoskl, Victor, ed. 1985. Editor's preface. In: Formaldehyde analytical chemistry and toxicology. Washington, DC: American Chemical Society: ix-x.

US. Environmental Protection Agency. 1974a. Addendum to development document for proposed effluent limitations guidelines and new source performance standards for the synthetic resins segment of the plastics and synthetics materials manufacturing point source category. EPA 440/1-74/036-a. Washington, DC. 110 p.

U.S. Envlronrnental Protection Agency. 1974b. Development document for effluent limitations guidelines and new source performance standards for the bauxite refining subcategory of the aluminum segment of the nonferrous metals manufacturing point source category. EPA 440/1-74-019-c. Washington, DC. 99 p.

U.S. Environmental Protection Agency. 1974c. Development document for effluent limitations guidelines and new source performance standards for the primary aluminum smelting subcategory of the aluminum segment of the nonferrous metals manufacturing point source category. EPA 440/1-74-019-d. Washington, DC. 143 p.

U.S. Environmental Protection Agency. 1976a. Interim final supplement to the development document for the petroleum refining industry existing point source category. EPA 440/1-76/083A. Washington, DC. 115 p.

U.S. Envlronmental Protection Agency. 1976b. Supplemental for pretreatment to the interim final development document for the secondary aluminum segment of the nonferrous metals manufacturing point source category. EPA 440/1-76/081-c. Washington, DC. 132 p.

U.S. Environmental Protection Agency. 1976c. Development document for interim final effluent limitations guidelines and proposed new source performance standards for the oil and gas extraction point source category. EPA 440/1-76/055-a. Washington, DC. 154 p.

U.S. Environmental Protectlon Agency. 1978. Guidance development document for effluent limitations guidelines and new source performance standards for concrete products point source category. EPA 440/1-78/090. Washington, DC. 157 p.

U.S. Department of Agriculture, Forest Service. 1958. Timber resources for America's future. FRR-14. Washington, DC: U.S. Department of Agriculture, Forest Service. 713 p.

U.S. Department of Agriculture, Forest Servlce. 1965. Timber trends in the United States. FRR-17. Washington, DC: U.S. Department of Agriculture, Forest Sepice. 235 p.

U.S. Department of Agriculture, Forest Service. 1974. The outlook for timber in the United States. FRR-20. Washington, DC: U.S. Department of Agriculture, Forest Service. 367 p.

U.S. Department of Agriculture, Forest Service. 1982. An analysis of the timber situation in the United States 1952-2030. FRR-23. Washington, DC: U.S. Department of Agricultre, Forest Service. 499 p.

U.S. Department of Agrlculture, Forest Servlce. [In press]. An analysis of the timber situation in the United States, 1989-2040. Forest Resource Report. Washington, DC.

Van DerLugt, G.; Scholten, L.C. 1985. Radon emination from concrete and the influence of using flyash in cement. The Science of the Total Environment. 45: 143-150.

Wadden, Richard A.; Scheff, Peter A. 1983. Indoor air pollution: characterization, prediction, and control. New York: John Wiley and Sons. 213 p.

Williams, Roy E. 1975. Waste production and disposal in the mining, milling, and metallurgical industries. San Francisco: Miller Freeman Publications, Inc. 489 p.

Alexander, Susan; Greber, Brian. 1991. Environmental ramifications of materials used in construction and manufacture in the United States. Gen. Tech. Rep. PNW-GTR-277. Portland, OR: U.S. Department of Agriculture, Forest Service, Paafic Northwest Research Station. 21 p.

Forest msource supply analysis has increasingly been done in an economic market context Little work has been done to assess the environmental consequences of a change in timber harvests that would result in a shift in competing markets. The purpose of this study was to estimate a relation among construction materials **as** they are used **as** substitutes or complements of each other and to qualitatively assess the environmental consequences of the extraction, manufacture, use, and disposal of wood products, steel, cement, aluminum, and plastics. Lumber cross-price elasticities with competing materials were computed for three major end uses (construction, shipping, and other). The elasticities can be used to estimate the extent to which various commodities are related to each other.

Wood-based products, steel, plastics, aluminum, and cement all have substantial extraction impacts; steel and plastics extraction results in the most voluminous, lasting, and toxic effects of the five industries. Sawn-wood products and cement seem to have the least environmental effects resulting from manufacture, while steel, aluminum, and plastics created major problems. Each industry creates problems in disposal.

Keywords: Environmental impacts, wood substitutes, pollution.

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