



United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

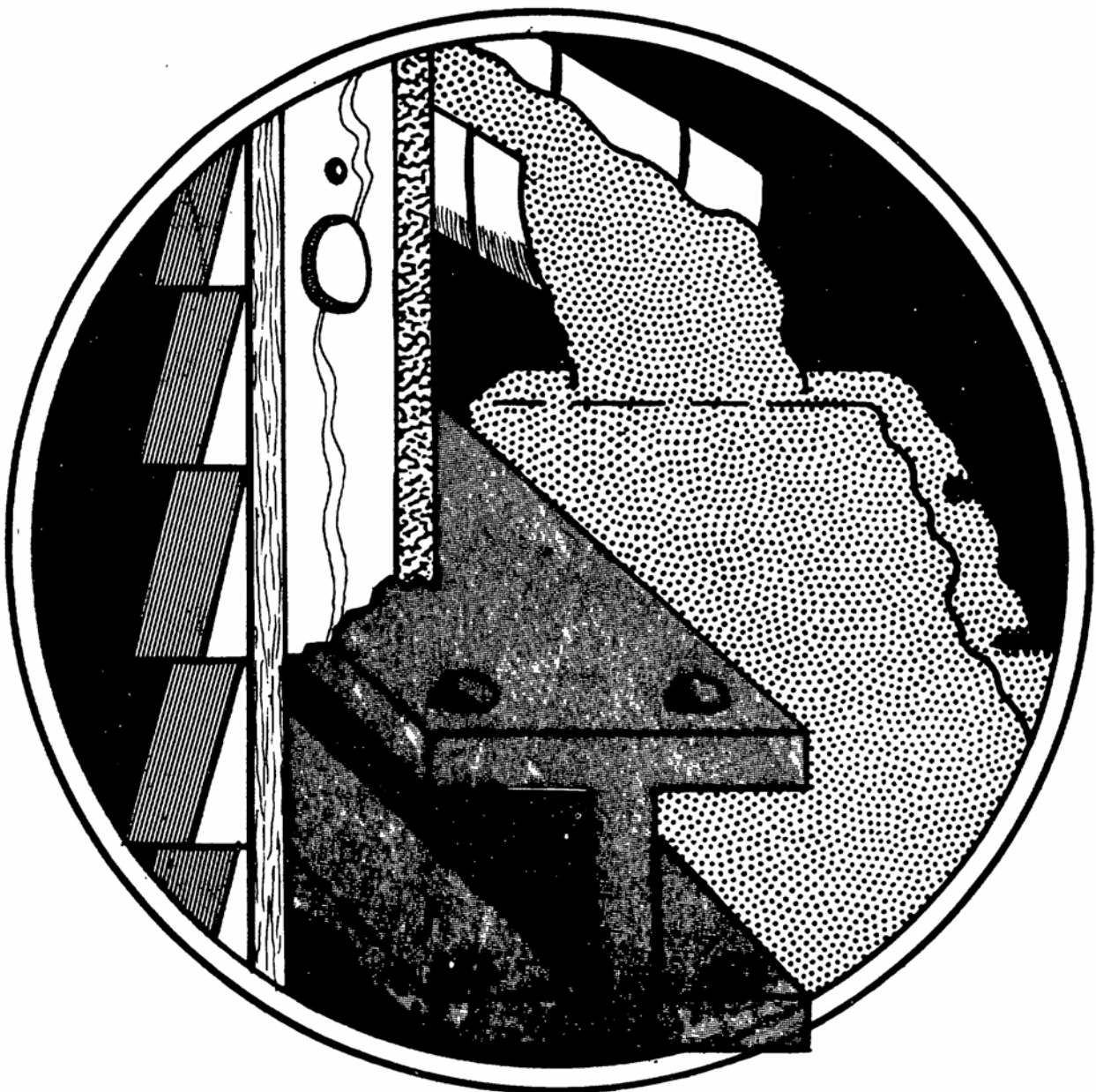
General Technical
Report

PNW-GTR-277
October 1991



Environmental Ramifications of Various Materials Used in Construction and Manufacture in the United States

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Abstract

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, Pacific Northwest Research Station. 21 p.

Forest resource 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.

Summary

Environmental policy decisions and analyses typically have been based on knowledge of environmental impacts stemming from single industries. There have been few guidelines to assess the environmental consequences of changes in resource markets, and the consequent effects of changes in the demand for and supply of complements and substitutes for various resources. This paper demonstrates the cross-market interactions from changes in the forest products industry and qualitatively analyzes some of the known environmental and health effects of extraction, manufacture, use, and disposal of wood and its market substitutes and complements: plastics, steel, aluminum, and cement.

Empirical evidence supports the general view that wood and other materials (steel, concrete, aluminum, and plastics) are substitutes in many end uses. In construction, for example, steel, aluminum, and concrete all substitute for softwood lumber; however, the use of plastics complements the use of softwood lumber. The advantages and disadvantages of this substitution depend, in part, on the different sets of environmental effects associated with each commodity. Thus, one should be careful when doing a partial analysis. A change in one market may be brought about through attempts to control environmental problems, but such a change may bring about other unforeseen environmental problems in another industry or region.

Differentiation should be made between industrial wastes and municipal wastes. Industrial wastes from steel, pulp, paper, and plastic manufacture include waste-waters which often contain toxic contaminants and solid waste in great quantities. Wastes from aluminum manufacture present landfill space problems as do industrial wastes from panel product manufacture. Municipal waste contains much ferrous material and plastics in addition to aluminum products. Wood products, other than panel products, and concrete products pose the least disposal problems in both categories of wastes.

Obtaining reliable data from industry has been generally reported to be difficult. Industries feel that increased interest in their wastes cannot be beneficial and consequently alternately have either exaggerated or minimized the quantity as the inclination directed. Other industries have paid so little attention to what they have declared unusable as to be honestly ignorant of quantity and in some cases composition of the wastes (Eldredge 1977). Problems arising from disposal once the waste has left the factory gate are often disregarded, and hence economic considerations such as loss of resources, environmental damage, and inherent value are neglected (Bridgewater and Mumford 1979).

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Introduction

Nationwide forest resource assessments have focused on market and environmental concerns of the timber resource (for example, USDA Forest Service 1958, 1965, 1974, 1982, 1990). To date, the environmental assessments have insulated the timber economy from the other raw material markets and thus presented only a partial picture of the environmental consequences of changing markets. The purpose of this report is to broaden the environmental frame of reference by demonstrating that changes in the timber markets can have cross-industry impacts on other natural resource markets and these market impacts will involve environmental ramifications that extend beyond the forests.

Following is a discussion of the end-use markets for wood products, and substitutes and complements for wood, and an assessment of the economic interrelations between lumber and aluminum, plastics, steel, and concrete. The environmental effects of the extraction, manufacture, use, and disposal of wood, plastics, cement, steel, and aluminum also are discussed.

End-Use Markets and Potential Substitutes for Wood

Three primary end-use markets are discussed in the following sections: construction, shipping, and other manufacturing. These categories were chosen because they isolate the major sectors within which raw material interrelations may be logically discussed. In the following discussion, the focus is on the substitutability potential of other industrial raw materials for wood products. It should be recognized, however, that there also is apt to be inherent complementarity among wood products and other materials in many applications, such as plywood subflooring used with steel framing in construction. Debate over the long-term must focus on which influences predominate: the substitute influences or the complement influences.

Construction

The construction markets have constituted the single largest market area for wood products and other industrial raw materials. In 1986, residential construction, residential upkeep, and nonresidential construction consumed 61 percent of all lumber consumed, 74 percent of all structural wood panels consumed, and 51 percent of all nonstructural wood panels consumed. Nonstructural panels, in turn, constituted about 5 percent of the United States paper and paperboard output in 1986 (USDA Forest Service 1990).

Nonwood products are used in concert with wood products but are showing increased abilities to substitute for wood products in many construction applications. Concrete slab construction has displaced some of the demand for wooden floor joists and subflooring. Plastics and aluminum have proven substitutable for wood in siding and trim uses. Aluminum and steel have been used as alternatives to wood framing materials in both residential and nonresidential construction applications. In 1983, construction uses accounted for 22 percent of all aluminum consumed (The Aluminum Association 1983), 21 percent of all plastics consumed (Society of Plastics Industry 1985), and 21 percent of all steel consumed (American Iron and Steel Institute 1985). In addition to the direct use of these materials, metal forming systems and concrete precasting substitute for wood products in on-site concrete forming.

Shipping and Packaging

Another major market area for wood products and their substitutes is shipping and packaging. Through the 1970s and 1980s, one of the largest uses of wood was in shipping products (pallets, containers, dunnage, etc.). Pallet technologies principally accounted for the 12 percent of lumber consumption attributed to shipping products in 1986. In the pulp and paper sector in 1986, 47 percent of the paper and paperboard production went to packaging and shipping uses (USDA Forest Service 1990).

Plastics are the primary substitute for wood products in packaging and shipping. In packaging, plastics substitute for paper and paperboard products for several uses: bags, boxes, cartons, and wrapping. In material handling, plastic slipsheets and material transport containers have been substituted for pallets in some uses. Of the 1983 plastics consumption in the United States, 29 percent was in packaging and shipping uses.

In 1983, 30 percent of all aluminum consumption was in packaging and containers. Much of the aluminum use in packaging and containers is in food and drink and can serve as a substitute for paper and paperboard products used in food and drink packaging.

Steel containers and packaging (for example, barrels) represented 9 percent of the steel consumption in 1983. One would expect a relatively minor amount of substitutability between steel shipping containers and wood shipping containers.

Other Manufacturing

Wood products manufacturing is typically broken down into furniture and other manufacturing. In 1986, 4 percent of the lumber consumption, 2 percent of the structural panel consumption, and 24 percent of the nonstructural panel consumption was in the furniture category (USDA Forest Service 1990). Other manufacturing in 1986, represented 5 percent, 3 percent, and 18 percent of the consumption of lumber, structural panels, and nonstructural panels, respectively.

Many substitution possibilities exist for wood in furniture manufacturing as well as in miscellaneous manufacturing. Metals and plastics have made large inroads in the institutional furniture markets and in the home furniture markets.

Interrelations Between Lumber and Other Industrial Raw Materials

To demonstrate potential cross-market impacts of changes in the timber markets, lumber cross-price elasticities were estimated for plastics, aluminum, steel, and concrete used in construction, shipping and packaging, and other manufacturing (table 1). These elasticities show how a 1-percent change in softwood lumber prices would influence consumption of the other commodities used.

Table 1 shows that a 1-percent increase in softwood lumber prices may be associated with an 0.85-percent increase in steel usage in construction. When commodities are substitutes for each other, the cross-price elasticities will be positive; when they are complements, the cross-price elasticities will be negative. In construction uses, aluminum, steel, concrete, and plastics all appear as economic substitutes for softwood lumber. In the shipping and packaging sector, steel and plastics are economic substitutes, while aluminum is an economic complement to softwood lumber. This conclusion is reasonable, in that lumber is apt to be used in material handling of the goods packaged in aluminum. In other manufacturing, steel, aluminum, and plastics are economic substitutes for softwood lumber.

Table 1—Softwood lumber cross-price elasticities by end-use^a

Commodity	Construction	Shipping and packaging	Other
Steel	0.85	0.52	1.02
Aluminum	.51	-.15	.82
Plastic	.05	.47	.58
Concrete	.60	NA	NA

NA= not applicable.

^aPercentage change in commodity consumption for a 1-percent softwood lumber price (total quantity of softwood lumber held constant). Supporting analysis available from authors.

The elasticities reflect the market changes stemming from a softwood lumber price change, given that the quantity of softwood lumber remained constant. When price and quantity are both allowed to vary, the analysis becomes more complex. Table 2 summarized alternative simulations for future forest market conditions in terms of percentage variations from a baseline projection. The baseline projection was the “1983 Assessment Supplement Simulation” by Haynes and Adams (1985); this baseline is compared to the Haynes and Adams (1985) “Reduced Private Commercial Timberland” and “5 Billion Board Foot Departure” simulations. Table 2 reflects the percentage of change in softwood lumber quantity and price relative to the baseline for the 1990 simulation year, and the resulting effects on other commodity markets, if their prices were to remain constant from simulation to simulation.

The results summarized in table 2 demonstrate how changes in the timber products markets can impact the other commodity markets. As prices of the lumber products go up and quantities are curtailed (for example, the reduced timberland situation), then outputs of other industrial commodities generally increase to substitute for the wood products; the converse is true for the scenarios that decrease prices and increase supplies (for example, the departure scenario). The changes in the other commodity markets are apt to bring on environmental ramifications unique to those industrial sectors. The next section will review some of the environmental concerns related to wood products and the substitute commodities.

Environmental Effects

This section will summarize the environmental effects of the extraction, manufacture, use, and disposal of wood products and their substitutes. The extraction, manufacture, and disposal of most materials used by people is regulated. Many of the effects cited here can be and have been mitigated mainly through strict enforcement of regulatory standards. The intent is not to condemn any industry mentioned; rather, it is to highlight environmental concerns raised by the Environmental Protection Agency (EPA) and other reputable sources.

Wood

The source of much of the information in this section is published by the Forest Service (USDA Forest Service 1982). Citations from other authors will indicate when the information source changes.

Table 2-Simulated percentage of change in substitute commodity usage when softwood lumber price and quantity are allowed to vary^a

End use	Commodity	Reduced private commercial timberland simulation	5-billion-board- foot departure simulation
----- <i>Percent change</i> -----			
All	Lumber price	2.56	-8.64
	Lumber quantity	-1.24	2.60
Construction	Steel	3.42	-9.94
	Aluminum	.85	-3.44
	Plastic	-.30	.46
	Concrete	1.70	-5.52
Shipping and packaging	Steel	1.40	-4.63
	Aluminum	-.39	1.30
	Plastic	1.25	-4.14
Other	Steel	3.04	-10.65
	Aluminum	2.12	-7.32
	Plastic	.98	-3.93

^a Price and quantity variations for softwood lumber are based on Haynes and Adam (1985) and are 1990 values relative to the "1983 assessment supplement simulation." Other commodity prices are held constant. Supporting analysis available from authors.

Harvest—The activities associated with timber management start a complex system of changes in the forest environment. Actual impact will differ in extent, depending on actual methods used and care taken. Timber management activities change the vegetation cover. Timber harvesting and slash disposal, such as broadcast burning, usually remove a large amount of all types of vegetation. Even more vegetation may be removed if the area is scarified or herbicides are used. Clearcutting removes the most vegetation, but vegetation removal occurs to some degree with all types of timber harvesting. After the harvest, grasses, shrubs, and noncommercial tree species will predominate if regeneration is not successful. With successful reforestation, and perhaps the use of timber stand improvement, commercial tree species will be favored over noncommercial tree species, shrubs, and grasses. Artificial regeneration can lead to entirely different forest types. This restructuring of the plant community can be beneficial in terms of present and future timber supplies, but has repercussions throughout the forest ecosystem.

Soils are primarily affected by direct disturbance during and after timber management activities that involve slash disposal and vegetation removal. Road construction, skid trails, log dragging, and scarification all involve a great deal of soil disturbance. Soil disturbance can cause erosion and mass movement; the amount and the timing depends on the soil type, slopes, and amount of disturbance. Soil disturbance can continue long after timber management activities end if roads and logging trails are not completely closed and if recreational vehicles use the area. In addition to erosion, the use of heavy machinery in some timber management activities can cause soil compaction and decreased soil infiltration rates, which restrict the ability of plants to obtain needed moisture and nutrients from the soil.

Vegetation removal has major effects on the water resource, both directly and indirectly through the effects on the soil. Water yields increase when an area is harvested. The amount of increase depends on the type of harvest, precipitation, and site characteristics. Vegetation removal also affects the timing of water release, because there is faster runoff during storms, and snow melting patterns are changed. Eroded soils often end up in streams, increasing turbidity and sedimentation. When combined with increased water velocity from higher yields, this can result in increased bottom scour and bank erosion. Ground-water flows can also be affected by the removal of plants.

Nutrients washed from forest soils often end up in streams. Removal of riparian vegetation and poor slash disposal near the edges of streams add to the nutrient problem, through debris pollution and increased bank erosion. Erosion and slash can reduce the dissolved oxygen content in streams, and stream temperatures can be dramatically increased by removal of riparian vegetation. Changes in water habitat are particularly damaging to fish reproduction and the ability of fish eggs to survive.

All these changes in the water resource lead to a habitat that may not support the same animal or plant communities and will not have the same capacity for assimilating wastes, pollutants, and organic matter. In extreme cases, the problems can lead to eutrophication of lakes and reservoirs.

Herbicides involve special pollution and safety concerns. Their economic and increased productivity effects can be great, but the scientific and judicial communities have not agreed on the safety of the herbicides.

About a quarter of the particulates emitted each year into the atmosphere are from the burning of forest fuels, although carbon dioxide problems are generally attributed to the burning of fossil fuels. Air pollution from timber management activities that involve burning consists primarily of particulates such as smoke, dust, carbon monoxide, and dioxide. The concentration and duration of timber management related air pollution in specific locations differs by type of pollutant and by both daily and yearly weather patterns.

Manufacture—The manufacture of wood products can be divided into industries with diverse environmental impacts. The following discussion includes the categories pulp and paper, composite panels, and plywood and lumber.

Waste-water generated by the manufacture of paper pulp ranges from 1,800 to 70,000 gallons per ton of paper product, depending on raw material, end product, plant process, and water conservation and reuse practices. Waste-water from pulp-paper plants contains conventional as well as toxic pollutants. About one-third of the pulp and paper mills in the United States discharge to publicly owned treatment works (POTWs) (Dyer and Nicholas 1983).

Most pulp mills recover and reuse chemicals and waste liquors from each stage of the pulping process. There is potential for sudden discharge of these chemicals and waste liquors when an upset in the process, such as shutdown or startup, causes flows to exceed recovery and available storage capacity. Mills place sewage outlets at all potential overflow points. Waste discharges from stock preparation, in which pulps are blended with additives, are usually minimal and may occur when there are upsets in the normal production process. Upsets also may cause discharges during paper making. Bleaching is often the major contributor to plant effluent, and bleach process dioxins are of increasing concern (Dyer and Nicholas 1983).

Sludges generated from the pulp-paper industry are voluminous but mostly nontoxic. They are composed principally of cellulose fibers, chips, knots, and other small particles; of biological sludges; and from inert clay and mineral pigments, coatings, and filler materials. Organic materials in raw waste-water that are toxic to aquatic organisms are removed by biological waste treatment and end up in the sludge. Heavy metals are found in the waste water of mills that use reclaimed fibers and are mostly from the inks in the recycled materials. The metals end up in the sludge (Dyer and Nicholas 1983).

Sludges are mostly put in landfills, burned as fuel, and incinerated. The amount of ash, an inert and noncombustible material, is one factor used to determine the method of disposal. Sludges with high ash content are more likely to be put in landfills. Disposal in landfills is a problem because of the high volume of material, its poor bearing capacity after placement, and its susceptibility to leaching (Dyer and Nicholas 1983).

Screenings and primary sludges from the insulation board and hardboard segments of the composite panels industry will contain wood, bark chips, fibers, and foreign materials. Toxic contamination of these residues is possible but depends on the production process of the wood source-material. Secondary sludges usually are composed of the biomass resulting from biological treatment. Toxic organic contamination of the biological sludges from insulation board and hardboard manufacturing is usually low. Putting sludges and screening in landfills is the predominant method of disposal of the wastes in these industries. Where toxic content is low and suitable agricultural users are nearby, sludges have been applied to land as a soil conditioner (Dyer and Nicholas 1983).

The manufacture of urea-based resin composite board produces formaldehyde. The industry must pass government formaldehyde emission standards by the use of vents and specialized production techniques. In addition, planer residue must be landfilled. Planer residue is generated when the particle board is sanded. The residue contains dirt and grit and cannot be used or incinerated.¹

¹ Allen, Kelly; Hams, Sandy; Heges, Chuck [and others]. 1987. Particleboard production in Oregon. Unpublished manuscript. On file with: Department of Forest Resources, College of Forestry, Oregon State University, Oregon 97331.

In the plywood and lumber segment of wood manufacture, sawmill and milling wastes can amount to as much as 45 percent of the harvested wood weight. Computerization and refinement of cutting techniques have increased the percentage of wood that becomes lumber or plywood. Wastes are composed of bark, sawdust, planer shavings, chippable coarse residue and slabs, dry trim, and other losses. These wastes were once burned in wigwam burners (Niessen 1977). Now most of these wastes are used as fuel or converted to pulp. Additional recovery stems from bark sold for nursery applications or other industrial uses, and peeler core recovery into usable product.

Use—Formaldehyde is a harmful product of urea-based resin products in use. It is present in particle board and plywood with urea-based resin (Turoski 1985). Particle board and urea-foam insulation have been identified as formaldehyde emitting sources. The extent to which formaldehyde may be emitted from urea-formaldehyde foam, and probably from plywood products containing formaldehyde, is directly related to the composition of the precursor resin, which is a function of the manufacturing conditions, and the extent of breakdown reactions in the foamed product, which depends on the acidity of the foam *in situ* (Wadden and Scheff 1983).

Other factors affecting formaldehyde levels in homes are indoor temperature, the infiltration rate, and the difference between indoor and outdoor temperatures. As the activity level in occupied homes increases, the formaldehyde level decreases. Higher temperatures cause an increase in levels of the gas, but higher differentials in inside-outside temperature increase the air exchange rate and decrease formaldehyde levels. Formaldehyde levels in mobile homes are generally believed to be higher than those in conventional homes (Groah and others 1985).

In recent years, the residual formaldehyde content of urea-formaldehyde bonded products has been reduced by a factor of more than 10 (Meyer and Hermanns 1985).

During the early 1980s, formaldehyde was brought to the attention of the general public, largely because of the heated debate about its carcinogenic properties. The irritant characteristics causing toxic contact dermatitis and irritation of the eye and upper respiratory tract have been well documented. There is experimental evidence of irritation of mucous membranes and conjunctiva of individuals at concentrations frequently found in residential indoor air. Formaldehyde is classified as a strong contact allergen (Nordman and others 1985).

The Federal government has established formaldehyde emission standards, and industry must use vents and special production techniques to meet those standards. The amount of formaldehyde emission from panels used in housing is regulated also.

Disposal—Household refuse contains wood, newsprint, magazines, books, cardboard, waxed board, and packaging made from wood fiber (Bridgewater and Mumford 1979). Municipal wood, wood product, and paper refuse is largely biodegradable and easily incinerated. Paper comprises about 37 percent and wood 3.1 percent of municipal refuse by weight. Furniture, pallets, tree trimmings and logs, pilings, and construction and demolition debris are usually collected separately and shredded and burned when feasible (Niessen 1977).

Plastics

The plastics industry presents many problems in air pollution, water pollution, and solid waste disposal. The air pollution problems result from manufacturing processes, and more importantly, from possible products of incineration of plastics wastes. The water pollution problems are primarily a product of manufacturing operations. The solid waste disposal problems are perhaps the greatest of the three.

Oil extraction- Wastes in oil and gas extraction result from the discharge of produced water, drilling muds, drill cuttings, well treatment, and produced sands. For offshore and coastal extraction, there is also deck drainage and sanitary and domestic wastes. The significant or potentially significant waste-water constituents are oil, grease, fecal coliform, oxygen-demanding parameters, heavy metals, total dissolved solids, and toxic materials (U.S. EPA 1976c).

Major sources of pollution in the drilling system are the drilling fluid or "mud" and the cuttings from the bit. The composition of modern drilling muds is complex and can vary widely, not only from one geographical area to another but also in different portions of the same well. Basic mud components include bentonite or attapulgite clays, barium sulfate, lime, and caustic soda. Muds may have an oil or water base. Material cut and loosened by the bit and fluids that may enter the hole from the formation (water, oil, or gas) are brought to the surface by the mud. Cuttings, silt, and sand are removed and discharged overboard on offshore drills if they do not contain oil. Some drilling mud clings to the discharged material. Onshore, discharges are disposed of in a pit, which is backfilled at the end of drilling operations. Many constituents of the mud are salvaged when the drilling is completed (U.S. EPA 1976c).

A more recent production technique that may become a significant source of waste in the future is called tertiary recovery. The process usually involves injecting some substance into the oil reservoir to release or carry out additional oil not recovered by primary recovery (flowing wells by natural reservoir pressure, pumping, or gas lift), or by secondary recovery. Presently, little is known about the wastes that will be produced by these production processes. They obviously will depend on the type of tertiary recovery used (U.S. EPA 1976a).

When a new well is being completed, or when it is necessary to work on a well, the well is normally "killed;" that is, a column of drilling mud, oil, water, or other liquid of sufficient weight is introduced into the well to control the down hole pressures. When the work is completed, the liquid used to kill the well must be removed so the well will flow again. If mud is used, the initial flow of oil will be contaminated with mud and must be disposed of. Offshore, mud may be disposed of into the sea if it is not oil contaminated, or it may be salvaged. Onshore, the mud may be disposed of in pits or may be salvaged. Contaminated mud is usually disposed of by burning at the site (U.S. EPA 1976c).

In acidizing and fracturing, the two most common methods to increase well flow, the spent fluids are wastes. They are moved through the production process and treatment systems after the well begins to flow again. Initial production from the well will contain some of these fluids. Offshore, contaminated oil and other fluids are barged ashore for treatment and disposal; contaminated solids are burned (U.S. EPA 1976c).

The EPA considers oils, oxygen-demanding pollutants, heavy metals, toxicants, and dissolved solids contained in drilling muds or produced water as the primary waste constituents. Waste water is taken care of by various processes including chemical treatment, distillation, and deep well injection. The EPA concluded that oil and gas extraction have no significant impact on air quality, but do have some impact for solid waste disposal (U.S. EPA 1976c).

Manufacture -The plastics products industry can be divided into four segments. The first is the manufacture of raw material or monomer. The second is the conversion of monomer into resin or plastic material. The third is conversion of the plastic resin into a plastic item such as a toy, synthetic fiber, packaging film adhesive, paint, and so on (US. EPA 1974a). The fourth segment, reprocessing, is the conversion of scrap plastic to a useful material (Sittig 1975).

The major sources of possible air contamination in resin manufacture are the emissions of raw materials or monomer into the atmosphere; solvent or other volatile liquids during the reaction; sublimed solids such as phthalic anhydride in alkyd production; and solvents during storage and handling of thinned resins (Sittig 1975).

Waste-water problems arise directly from resin manufacture and its byproducts. Waste-water problems are particularly evident with batch operations (such as in the synthetic polymers industry) and from area housekeeping, utilities blowdown, and laboratories. Flow rates and compositions of process waste-water streams at points of origin were not available according to EPA because the companies surveyed have rarely monitored these streams, except where excessive losses of a particular component have been of concern, such as in the waste waters from a distillation unit. Much of the data on waste-water flows and raw waste loads has been derived from limited numbers of samples over short periods. Because the synthetic polymers industry is based to a large extent on batch production methods and often the commercial need to produce many product types of a basic polymeric material, the reported waste-water flows and raw waste loads per unit of production varied considerably (Sittig 1975).

Air pollution in the plastics products industry consists primarily of removing processed chemicals such as solvents, softeners, and plasticizers from plant exhaust streams. Air and water pollution problems are relatively small in magnitude, compared to the solid-waste problem. Nonrecyclable plastic is produced by all aspects of manufacture in addition to scrap plastic, which is reused by the industry (Sittig 1975). Nonrecyclable plastics present a continuous solid-waste disposal problem.

Use—Wastes or pollutants from resin and plastics products are an issue that is receiving more attention. Polychlorinated biphenyls (PCBs) are not manufactured in the United States any longer, but they are present in many plastics and oils still in use, such as lubricating oils in large machinery. The PCBs are heavy oils that are chemically inert, heat resistant, nonflammable, and electrically nonconducting. Once scientists began to look for these substances in the environment, they found them everywhere, particularly in industrialized areas. Some PCBs have been found in fish, birds, whales, seals, polar bears, European hares and foxes, and North American

mink. Residues are found in the body tissues of Europeans, Israelis, Japanese, and Americans. Symptoms of PCB exposure include abnormalities of the skin, headaches, discharge from the eyes, and swelling of the eyelids, musculoskeletal symptoms, and gastrointestinal symptoms. Even if no further pollution were to occur, enough PCBs are already dispersed to cause concern for the indefinite future. In North America, an estimated 300,000 tons have been put into dumps and landfills and may or may not be leaking into air and water. About 30,000 tons have been released into the atmosphere and were probably carried back to earth by rain or snow. About 60,000 tons were released into fresh and coastal waters (Schneider 1979).

In many lakes and rivers in the United States, PCBs have been found. Most of these waters have been polluted by discharge of industrial wastes, either directly or indirectly through municipal sewer systems. Although PCBs are now the most prevalent of the halogenated hydrocarbons in the environment, the most serious biological effects may be due to other related chemicals, common contaminants of PCBs. Dioxins and dibenzofurans are formed from other halogenated hydrocarbons in the presence of oxygen from the air, especially at high temperatures. Workers are likely to be exposed to the toxic contaminants when working with PCBs at elevated temperatures; for example, in steel mills where casting waxes contain PCBs. Incineration of PCB-containing trash, such as plastics or copy paper, is likely to produce dioxins and dibenzofurans and, in fact, these chemicals have been found in fly ash from municipal incinerators (Schneider 1979).

Plastics products in use may pose a hazard to plants. In one study, aqueous leachates obtained from soaking polyvinyl chloride (PVC) sheets for different amounts of time and applied to crops severely inhibited the growth of all crop species tested. The inhibition was greater with leachates from PVC sheets soaked for longer periods, and the effect lasted for two subsequent plantings (Sharma 1985).

Disposal—The disposal of plastics products is an important and often controversial issue. About a third of industrial waste is PVC. Large quantities of PVC wastes are generated because PVC is more difficult to process than the other major thermoplastics, and it is used in numerous formulations. The second major industrial waste is low-density polyethylene. The estimated concentration of "nuisance" plastic in urban and industrial solid waste was 2.2 percent by weight in 1980. A major source of nuisance plastic is packaging. Nuisance plastic from manufacturing constitutes 15 percent and housewares 6 percent of urban and solid waste by weight. Most consumer plastic is hard to recycle because it is often part of a composite product (Sittig 1975).

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

calcined to alumina. The residue from this process is red or brown mud. A mud lake is a receiver and reservoir of process water, a sink for evaporation and seepage, and a collector of precipitation. Not all water in the production of the muds returns to the plant, because the terminal density of the settled solids may range from 35 to 75 percent. This entrapment is one of the means used to remove water from the recycle circuit (U.S. EPA 1974b, 1976b; Williams 1975).

Red mud is generated at aluminum plants along the lower Mississippi River, the gulf coast, and in central Arkansas. At most plants, the red mud is impounded in large mud lakes adjacent to the plants, although some is discharged into the Mississippi, and some is used in industrial applications such as cement making (Talley and Ongerth 1974).

Other major waste waters in aluminum refining include spent liquor, condensates, and barometric condenser cooling water. Spent liquor is reused, and occasionally waste is removed. Half of the alumina is removed, and the rest is left in solution to prevent contamination with coprecipitates. A portion of the spent liquor periodically is reduced to low volume through evaporation to eliminate contaminants. The resultant sulfate slurry is discarded in an abandoned mud lake or a landfill. Many operations in a bauxite refinery produce steam, which is condensed and used for boiler-feed water, product washing, and washing of red muds. The entrainment of barometric condenser cooling water should be minimal from a well-designed and well-operated evaporator, with unsatisfactory levels being reached only during breakdown (Williams 1975).

Pollution control is a serious problem in aluminum smelting. The severity of the pollution prevention requirements is illustrated in that the cost of pollution control can be about 75 percent of the cost of a basic smelting plant (Bridgewater and Mumford 1979).

Use—Aluminum in cookware is believed to pose a health problem, but there is no evidence to back the assertion. Aluminum in use has not been proven to present a health or environmental problem.

Disposal— By weight, aluminum represents a very small fraction of collected municipal refuse. Estimates are in the range of about 0.5 to 1.0 percent, or 600,000 to 900,000 tons annually. Much of this aluminum is in container and packaging items. The major solid-waste problem associated with aluminum is the littering of such items. Aluminum is one of the most valuable component materials of municipal refuse in terms of scrap price, typically selling for 15 to 20 times the price of scrap steel, glass, or paper (Talley and Ongerth 1974).

Steel

The steel industry is among the most complex industries in the number and types of processes employed. Operations extend from the mining of coal and the mining and milling of iron ore at one extreme to the processing and shaping of steel products at the other.

Extraction—In the steel industry, extraction includes the mining of coal and iron. Iron is the second most abundant material in the crust of the Earth and the fourth most common element. Although iron is abundant, the supply of direct shipping ores (high-grade ores requiring no beneficiation except coarse crushing; for example, hematite averaging 58- to 60- percent iron) is now limited. The energy requirements for mining and beneficiation depend strongly on the type of ore used, whereas the energy for chemical reduction is the same for all ores (Bravard and others 1972).

Solid waste in the form of overburden and gangue is a major problem in the mining industry. As the depth of ore bodies mined increases and the grade decreases, the rate of solid waste produced increases. Runoff from solid-waste piles can result in stream sedimentation. The major and most significant liquid waste, particularly in coal mining, is acid mine drainage and acid runoff from relocated overburden. Drainage control ranges from changing the flow of ground water by impeding movement of water into mined areas, to collection and treatment of drainage from abandoned mines by liming and sedimentation. The major gaseous waste problem in mining is methane in underground mines, primarily coal mines (Williams 1975).

The amount of area disturbed by coal mining is influenced by the type of mine and the thickness of the coal bed. Half the underground coal *in situ* can be extracted, and 80 to 85 percent of surface coal can be mined. Major problems in rehabilitation are likely wherever the overburden is high in acidity or salinity, the soil cover is thin and its elements, including micro-organisms, are delicately balanced, and most importantly, the rainfall is sparse. Acid mine drainage is associated with both underground and surface mining and causes erosion, sedimentation, and subsidence. The problem is stubbornly resistant to solution, and there is likely to be a continuing need to control drainage at the mining site, to treat effluents, and to control water sources. A large amount of acid mine drainage originates in inactive mining sources that are difficult and costly to treat (National Academy of Sciences 1975).

Manufacture—Coke plants are ordinarily operated in conjunction with steel mills to produce coke and its byproducts, including coke-oven gas, coal tar, crude and refined light oils, ammonium sulfate, anhydrous ammonia, ammonium liquor, and naphthalene. Heat is supplied to the ovens by burning about 40 percent of the gas produced. The rest of the gas is used for fuel elsewhere. The residue from the oven is cooled by water sprays. Most of the water is reused, but the settling basin may overflow and become a source of waste water. All coke plant ammonia is recovered (Williams 1975).

In a closed system, there is no waste water. In an open system, the final cooler water can be the major source of contaminated waste water. Contaminated water is the primary pollutant along with gasses. The principal liquid wastes in coke making originate from the ammonia liquor, coke quenching effluents, benzol plant decant waters, and final cooler waters. They contain phenols, cyanide, biological oxygen demand (BOD, one of the aspects of pollution measured by the EPA), ammonia, sulfide, suspended solids, and oil. The amount of pollutants produced depends on the plant and its recycling standards (Williams 1975).

Molten iron is normally produced by a blast furnace. The furnace is charged with iron ore, limestone, and coke via its top, and heated air is blown into the bottom. Blast furnaces produce fumes, smoke, and gases as airborne wastes. Other impurities combine with the slag, which floats on the surface of the molten metal. Waste water is produced by the wet scrubbers when used on the furnaces and also by slag operations. The principal waste water produced by blast furnace operations is wash waters for the exit gases (for removal of suspended matter) and noncontact cleaning water. The coke may also produce pollutants that were prevalent in the coke-making waste waters. Waste waters from iron-making blast furnaces therefore may contain ammonia, cyanide, phenol, suspended solids, and sulfide. The ferromanganese furnace will contain manganese in addition to the normal parameters inherent in the typical iron-making furnace (Williams 1975).

Waterborne wastes from steel making result from scrubbing of the gas stream to prevent air pollution and from noncontact cooling. Basic oxygen and electric furnace waste waters may contain suspended solids and fluorides from feldspar, one of the basic raw materials in steel making. The open hearth, due to the nature of its scrap mix, also will contain zinc. Nitrates may be present because of the huge volumes of air required with the open-hearth method to provide better combustion (Williams 1975).

In the vacuum degassing process, steel is subjected to a high vacuum in an enclosed refractory-lined chamber. Steam jet ejectors with barometric condensers produce the vacuum. In the refining process, certain alloys are added that may be drawn into the gas stream. In addition, the system is purged with nitrogen so as to have no residual carbon monoxide (CO). The waste-water products from this operation therefore are condensed steam and waste water containing suspended solids, zinc, manganese, lead, and nitrates (Williams 1975).

Waste waters from continuous casting operations result from spraying scale from the surface of the steel. As a result, continuous casting waste waters may contain suspended matter and oil. The mold-cooling and machine-cooling systems usually are closed systems and the water picks up only heat (Williams 1975).

Improvements in pollution control performance at the Nation's steel mills are coming about in response to strong government and citizen pressure for cleanup. Many companies emit large loads of suspended solids, iron, chemical oxygen demand (COD, one of the aspects of pollution measured by the EPA), thermal pollution, phenol, fluoride, chloride, and three toxic heavy metals (cadmium, lead, and zinc) into the water used in the plant. The pollutants produced by steel mills are of particular concern not only because of the quantities emitted but also because pollution from the steel industry is concentrated in densely populated regions (Cannon 1974).

Use—No health or environmental effects of steel in use were discovered in the literature search.

Disposal- A large portion of municipal waste is ferrous; that is, of iron origin. Municipal waste averages 7 percent in ferrous material before incineration, and 30 percent afterwards (American Iron and Steel Institute 1971, 1972). Every year, millions of automobiles and appliances are disposed of as well. Half of all steel is manufactured from scrap, three-quarters of which comes from steel wastes generated at the mill by internal processes. One-quarter comes from junkyards, recycling centers, and municipal dumps. Railroad rates discriminate against scrap in favor of iron ore. Contamination of scrap is difficult to overcome, though several techniques have been developed (Cannon 1974).

Slag, the byproduct of iron and steelmaking, presents a special solid-waste disposal problem for the steel industry. In the past, slag has been dumped in huge piles near the steel mills where it creates severe hydrogen sulfide and dust-related air pollution problems. The current production of blast furnace slag is almost totally utilized, primarily as filler material in airport and highway construction, in Portland cement, as aggregate in bituminous pavement, and as a base for mineral wool, a fireproofing material that can substitute for asbestos insulation. About two-thirds of the slag produced in steelmaking is recycled into the blast furnace. The rest is used for the same purposes as blast furnace slag. Demand is not sufficient to deplete the accumulated slag from past production (Cannon 1974).

Concrete

Cement is a powdery complex calcined mixture of different inorganic calcium, aluminum, and silicon compounds that can be made into a paste with water and that will cure or set into a solid mass when allowed to stand. Concrete is $1/7$ cement, $2/7$ sand, and $4/7$ stone by volume. The ratios can be modified to alter the properties (Franklin 1976).

Extraction -The most commonly used cement is Portland cement. The raw materials of Portland cement consist primarily of limestone or some other lime-containing material such as marl, chalk, or shells, and clay, shale, or some other argillaceous (clayey) material such as ashes or slag (Popovics 1979).

The location of a cement works is usually determined by the availability of adequate supplies of the raw materials within reasonable distance of each other. The quality, uniformity, and quantity of raw materials, and the likely problems of extraction, which determine the amount of overburden to be removed and the form of bedding, are established by a geological survey involving drilling and the analysis of the cores obtained. All types of limestone and marble are used (Bye 1983).

The method of extraction of limestone depends on its hardness. Soft chalks and marls are scraped from the quarry face and crushed in the quarry before transport to the blending plant. Hard material requires blasting and one or more stages of crushing before it is ground. The method of extraction in clays depends on the degree of compaction in the deposit. Soft, high moisture-content clays are mechanically excavated by scraping and are transported from the quarry by conveyor systems. Hard shales are blasted and crushed before being stockpiled (Bye 1983).

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, grease, 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 health 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.

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Forest resource 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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