

NEW MARKETS FOR OLD MATERIALS

FROM
REFUSE
TO
REUSE

CHRIS T. HENDRICKSON,
ARPAD HORVATH, LESTER B. LAVE,
AND FRANCIS C. MCMICHAEL

Transportation boasts notable recycling success stories. The reuse of asphalt pavement, for example, is both economical and technically feasible. Concrete is reused in fills and road base, and recycled reinforcing steel bars (rebars) are sold as scrap. In the 1960s abandoned automobiles were a problem. Now 75 percent by weight of the typical automobile is reused through recovery of parts and materials, steel in particular. Steel bridge decks also are recycled frequently, although lead-based paint on older structures can pose a problem.

Not all recycling is economical, environmentally beneficial, or a direct reuse of materials. For example, the expense of collection and sorting render postconsumer glass recycling uneconomical. The environmental benefit of glass recycling may be marginal because the raw materials for glass are in ample supply. Using postconsumer rubber in new tires is difficult. Other high-volume uses are being investigated, but the only current options, such as additives to asphalt pavement, have not proven sufficiently valuable.

Recycling should be a strategy instead of a goal in itself. The underlying goals are better use of resources (including natural ecological systems) and reduction of the spread of toxic materials.

In pursuing recycling opportunities, the "iron law of recycling" applies: for recycling to be economical, the sum of the costs of collection, sorting, and transporting material, minus its sale value, should be less than the cost of collection and disposal. Social costs and environmental externalities such as pollution should be included in this equation.

Recycling can occur in several ways (1). Materials may be rebuilt or directly reused, as when roadway barriers are moved to a new location. Equivalent new uses may be found, as when reinforcing steel or asphalt pavement are melted down and recast. Materials may be put to a lower-value use, as when plastic from consumer products is reused in roadside appurtenances.

Other methods of disposal that are not generally considered recycling include incineration to produce electricity or heat, as when cement kilns are fueled with used tires; placement of waste in a permitted landfill, the ultimate disposal for much construction debris; and direct release into the environment (for example, roadside littering).

Incineration recovers resources and value from discarded products in the form of energy and could be considered a reuse, but it also contributes to air pollution, and incinerator ash may be a hazardous waste that requires special handling.

A variety of factors influence the extent of material recycling (2), among them the price of recycled materials compared with that of new materials. The engineering properties of recycled materials are also a concern. Decisions made during product design may influence the cost and properties of discarded materials, so designing with the environment in mind, known as "green design," can make recycling cost-effective. Regulatory and customer requirements for recycling content can impose constraints on materials selection.

EXISTING AND EMERGING MARKETS

A variety of markets exist for roadway materials, including a mature market for steel scrap. New steel can be made from iron ore or recycled steel scrap. Electric-arc furnaces can use 100 percent scrap as feed materials, whereas basic oxygen furnaces may use 20 percent scrap. Steel scrap has widely accepted specifications and specialized brokers; as a result, transaction prices are well reported.

The markets for some recycled materials are internal. For example, asphalt pavement companies may recycle in their own operations, making decisions about the amount of new or recycled material to use from day to day. They may stockpile recycled asphalt or concrete pavement for reuse at a later date or in a location different from its source. Paving schedules, the price of new

Chris T. Hendrickson is Duquesne Light Company Professor of Engineering, Carnegie Mellon University, Pittsburgh. Arpad Horvath is research assistant, Engineering Design Research Center, Carnegie Mellon University. Lester B. Lave is Higgins Professor of Economics, and Francis C. McMichael is Blenko Professor and AT&T Foundation Industrial Ecology Faculty Fellow, Carnegie Mellon University.

asphalt supplies, and design specifications govern these decisions. State departments of transportation may recommend 50 percent or more recycled content in new pavements, or none at all. At the local level, sales may be negotiated by direct transaction or through brokers. Stockpiled recycled materials may be sold by the producer to another local company.

Markets for recycled materials have grown over the years. Recycling rates have been increasing in the United States, although slowly compared to the rates achieved by world recycling leaders such as Germany. Widespread collection efforts in the United States have increased supplies of postconsumer materials, but prices have largely remained low because the industrial infrastructure has not been in place to take advantage of recycled feedstock. Instead, the United States has been exporting postconsumer waste because secondary-materials prices have traditionally been higher in other countries, especially in Europe. As demand for recycled-content products has increased at home, the U.S. industrial sector has taken major steps to incorporate new technologies.

Electronic exchanges for recycled materials are growing. With the help of government, public, and private organizations, the Chicago Board of Trade—the largest commodity trading market in the world—has begun to list postconsumer recycled materials such as glass and plastics for trade. High-density polyethylene and polyethylene terephthalate, the two plastics most easily and commonly recycled with current technology, are among the materials listed. Several paper grades may later be introduced.

Trading of these commodities will be entirely electronic. Buyers and sellers can pay a fee to gain access via modem to the Board of Trade's computer bulletin board for recyclables, obtain market information, and trade off the floor. The information on the bulletin board will include the type, composition, and form of materials; prices; quantities; locations of delivery; contact names; and telephone numbers. Anonymous posts and listings are accepted. No futures contracts have yet been introduced. The initial volume of transactions may be lower than that for traditional commodities such as agricultural products.

In addition to the Chicago Board of Trade bulletin board, an electronic information system linking the stakeholders in the recycling business exists on the Internet, created by the Recyclers Exchange from Canada. The service offers access to the recycling market without training or expensive software. The California Department of Conservation offers a computer data base called

Market Watch, listing hundreds of companies that sell or buy secondary materials. Others are appearing.

Several factors are necessary to create efficient transaction markets for materials. Widely available price information and market access reduce transaction costs and extend the number of market participants. Detailed material specifications are essential for buyers, as is a steady supply. Third-party quality-assurance procedures may also be necessary, and a mechanism for dispute resolution is helpful.

Specifications exist for the use of some recycled materials in construction, but not for others. The specifications for scrap steel are widely accepted, including limits on the allowable levels of trace contaminants. Recycled plastics may be routinely incorporated into transportation construction materials in the future. Recycled asphalt has traditionally been reused in pavements, but there is hesitation in its widespread use and specification (3).

Many states have found it necessary to revise specifications to permit the use of recycled materials in road construction. There are several ways to include recycled materials in specifications (4): document previous use, location, and loading on the elements; document the demolition, removal, transportation, and storage of materials; provide certification from a registered testing laboratory regarding the material's characteristics (size, manufactured quality, condition); or develop joint procedures with local building officials for the use of recycled materials.

Specifications become especially important in the consideration of long-term recycling, in which materials undergo many reuses. In some cases, trace contaminants that build up over time make direct reuse difficult or impossible. For example, iron contamination in aluminum castings is difficult to remove and affects the quality of recycled aluminum alloys. Similar effects exist for trace elements in plastics. A batch of clear polyethylene terephthalate bottles is more difficult to recycle if colored plastic bottles are mixed into it. As a consequence, mixed plastics are more commonly recycled into lower-value products such as park benches.

MATERIALS AVAILABLE FOR RECYCLING

Precise figures for the reuse of asphalt and concrete in the construction industry are unavailable, but estimates indicate that these materials account for the largest portion of the tens of millions of tons of construction and demolition waste generated each year in the United States (5). In some states, debris from roads and bridges makes up the



majority of such waste. An increase in recycling would divert much construction and demolition waste from landfills and reduce disposal costs. The Federal Highway Administration and Environmental Protection Agency estimate that the 91 million metric tons (100 million tons) of reclaimed asphalt pavement are produced annually, of which 73 million tons (80 million tons) are recycled to highway applications (6). The construction industry could also use less expensive recycled aggregate material, satisfying part of the annual demand for more than 2 billion metric tons (2.2 million tons) of construction aggregates with secondary materials.

The equipment and technology for cold and hot asphalt recycling have been in place for many years (3). The quality of pavements made with recycled asphalt is high. Asphalt can be reused on the spot, eliminating transportation and sorting costs. The reuse of asphalt saves energy and is usually economically feasible.

Concrete, which represents approximately 15 to 20 percent of the typical construction and demolition waste stream, can be reprocessed into reusable materials. Figure 1 shows a process flow diagram for a typical concrete recycling system (7). Concrete has been reused in fills and road base as drainage stone and aggregates of various grades. Potential uses of recycled concrete are listed in Table 1 (8). Its integration into the production of new concrete is being tested in decorative applications and those in which load bearing is not a requirement.

Metal structures, concrete, and asphalt present opportunities for direct or closed-loop recycling. Transportation construction also incorporates material recycled from other sources. For example, iron and steel slags from production fur-

naces are routinely used in construction for road bases, asphalt-concrete aggregate, and fill.

Plastics are recycled in low quantities relative to their production. A minimal percentage of plastic in municipal solid waste is collected, mainly because the technology to use recycled plastics in high-value applications such as food packaging has not yet been fully developed. The low weight and high volume of postconsumer plastics make collection expensive. Separation of different types of plastics at the materials recovery facilities has traditionally been labor-intensive because of inadequate labeling and the wide variety of plastic products. Of the seven major types of plastics, only two are commonly recycled, high-density polyethylene and polyethylene terephthalate.

Recycled plastic resins may be used more extensively in transportation construction applications in the future. Pellets from recycled nylon carpets may be used to make traffic sign posts, highway barriers, or other roadside appurtenances. In the last few years the plastics industry has spent billions of dollars to develop technologies that use recycled feedstock on a large scale.

PRICE CONSIDERATIONS

The price of steel scrap has varied considerably over the years. From 1980 to 1994 the raw price of steel scrap and the equivalent price in current year dollars varied by more than 50 percent. However, the overall trend without inflation is toward lower prices for steel scrap. These prices reflect changes in supply and demand. From 1950 to 1991, the amount of recycled steel almost doubled. As a fraction of total steel production, scrap increased from 40 percent in 1960 to 55 percent in 1991. These statistics are national averages. Prices varied by location, with prices approximately \$20 per

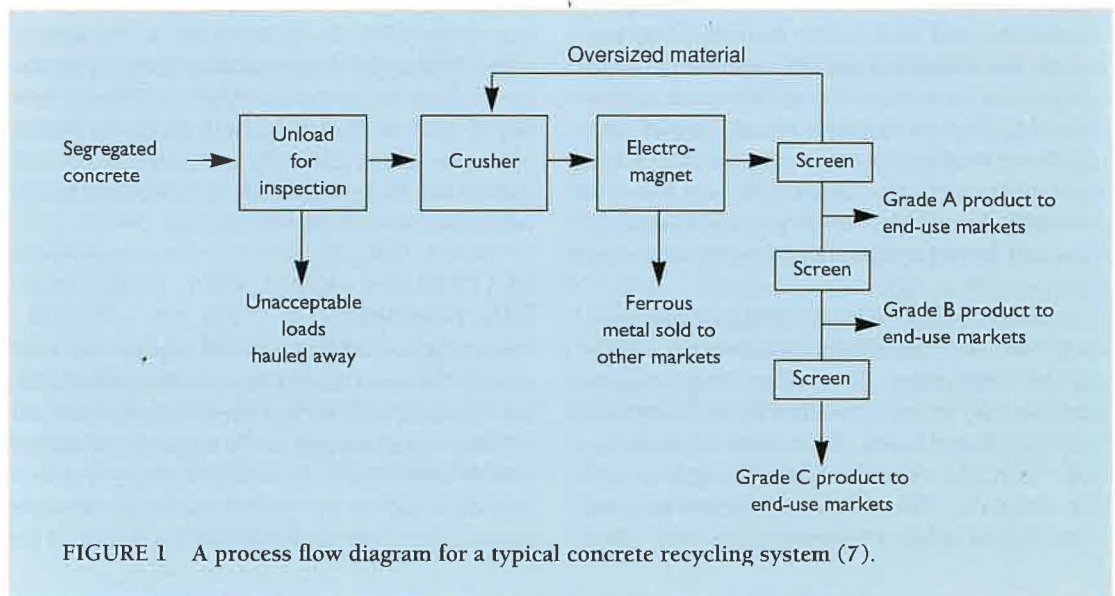


FIGURE 1 A process flow diagram for a typical concrete recycling system (7).

TABLE 1 Potential Uses for Recycled Concrete (8)	
Potential Uses	Grade Requirements
Cover and bedding materials for landfill liners	fine, clean sand particles < 0.1 inch
Landfill daily and final cover	fine material < 3/8 inch
Subbase for building slabs	nominal diameter of 3/8 inch
General construction drainage control	nominal diameter of 1 1/2 to 2 1/2 inches
Landfill temporary access roads Construction site entrance roads	nominal diameter of 2 1/2 to 6 inches
Land reclamation	nominal diameter ≤ 9 inches
Subbase and roadbase for roads, parking lots, driveways, and airports Aggregate for filter layers in landfills, french drains, soil and erosion control, and bridge abutments	as specified in ASTM D 1241-68

metric ton (\$22 per ton) lower in Detroit than in Pittsburgh. Prices also varied by type of steel scrap.

Recent prices for recycled plastics have been particularly volatile. The price of pellets made of postconsumer, unpigmented, recycled plastic from high-density polyethylene bottles increased more than 30 percent during the last half of 1994 (9). The price of pellets made from postconsumer, clear, recycled polyethylene terephthalate bottles has increased slightly during the last several years. Different plastic resins have different prices, which have fluctuated over the years.

In the complex picture of supply and demand economics, it is hard to predict how secondary-materials prices will change in the years ahead. If consumer demand for recycled-content products grows, demand for recycled materials will also grow. If recycling rates increase, there will be a sufficient supply of secondary materials on the market, which may result in falling prices. There is some indication that collection and sorting costs are decreasing (10), opening a way for expanded municipal collection programs. However, if the price is not right for recycling operators, they will drop the collection of low-priced recycled materials.

CONCLUSION

At some cost, everything can be recycled and sent back into production as a feedstock. However, it may not be economically or environmentally viable. Current recycling is an economics issue, but it is also an engineering and environmental issue.

A diverse marketplace is one key element in the economic success of secondary-materials use. The trading of postconsumer materials on the Chicago Board of Trade may facilitate the transfer of recycled materials back into industry, and tie prices more closely to supply and demand.

The U.S. demand for recycled construction materials is expected to increase in the years ahead. Increased investment in the nation's infrastructure is likely to increase the demand for secondary materials in transportation construction.

ACKNOWLEDGMENT

The authors thank Adam Trojanowski and Eric King for research assistance. This work was supported by funds from the International Business Machines Corporation and the National Science Foundation.

REFERENCES

- Lave, L., C. Hendrickson, and F.C. McMichael. Recycling Decisions and Green Design. *Environmental Science & Technology*, Jan. 1994.
- Henstock, M.E. *Design for Recyclability*. The Institute of Metals, London, U.K., 1988.
- Emery, J.J. Asphalt Concrete Recycling in Canada. In Transportation Research Record 1427, *Pavement Surface Courses, Stone Mastic Asphalt Pavements, and Asphalt Concrete Recycling*. TRB, National Research Council, Washington, D.C., 1993, pp. 38-46.
- Johnston, H., and W.R. Mincks. Waste Management for the Construction Manager. 1992 *American Association of Cost Engineers Transactions*. AACE. pp. J.5.1-J.5.13.
- Bossink, B.A.G., and H.J.H. Brouwers. Construction Waste: Quantification and Source Evaluation. *Journal of Construction Engineering and Management*, Mar. 1996, pp. 55-60.
- A Study of the Use of Recycled Paving Material: Report to Congress*. FHWA, U.S. Department of Transportation; and Environmental Protection Agency. FHWA-RD-93-147 and EPA/600/R93/095, June 1993.
- Donovan, C.T. Construction and Demolition Waste Processing: New Solutions to an Old Problem. *Resource Recycling*, Aug. 1991, pp. 146-155.
- Trojanowski, A. Recycling Practices for Reinforced Concrete Debris in the United States. Unpublished master's thesis. Department of Civil and Environmental Engineering, Carnegie Mellon University, Nov. 1994.
- Price History: Virgin vs. Recycled. *Plastics News*, Dec. 26, 1994, p. 102.
- Jaffe, M. Recycling Goals Alluring, But Tricky. *The Philadelphia Inquirer*, Aug. 6, 1995, pp. E1-E2.

