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Special Feature on the Environmentally Sustainable City

Material Flows for a Sustainable City

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Materials flow through cities on a daily basis, entering as needed products and leaving as wastes. Management of municipal solid waste provides both sanitation and recovery of valuable materials. At low income levels, market forces lead to recycling with no need for planning. In developing countries today, as in developed countries in the past, the relationship between urban wages and material prices promotes recovery of many materials. However, as wages rise, people become less willing to engage in labor-intensive recycling. At the same time, the waste stream expands and changes in composition; in particular, paper represents a greater fraction of urban waste at higher income levels. Although the market no longer compels recycling, people in high-income countries are willing to pay for municipal recycling programs, and often protest when recycling is cut back or eliminated. There is a need to plan for recycling in a high-income context, particularly for recovery and recycling of paper products, without reliance on the low wages that led to widespread recycling in the past. As Asian cities and countries develop in the twenty-first century, they will need to manage a changing and growing waste stream and plan for new approaches to recycling in order to make their development sustainable.

Keywords: Material flows, Municipal solid waste, Recycling, Waste management, Economic development.

1. Introduction

People everywhere use material goods and discard solid waste on a daily basis. In a city, the material flows in both directions, coming in and going out, greatly exceed the natural capacity of the local ecosystem. Food, fuel, and consumer goods must flow into the city to meet the needs of the urban population. Discarded wastes must flow out to disposal or processing sites, in most cases outside, or on the fringes of, the metropolitan area. The "ecological footprint" of a city is inevitably many times the size of the city itself.

Waste management can be viewed from two distinct perspectives: either in terms of sanitation or of material recovery. In the most obvious sense, prompt collection and disposal of solid waste is required for urban sanitation; wastes must flow outward every day. A subtler role can also be played by the waste management system: it can recover valuable used materials and reduce the need for new materials to flow inward, thereby contributing to the creation of a sustainable city.

The problems of waste management, and the opportunities to promote sustainable material flows, depend on the level of development. A low-income city has a characteristic pattern of waste, and a corresponding waste management system, bearing a partial resemblance to the preindustrial cities of the past. Recovery of valuable materials from urban waste occurs as a result of market forces, with no need

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for planning. As incomes rise, the municipal waste stream not only expands, but also changes in composition—and the informal, market-driven system of recovery and recycling of valuable materials is weakened. At higher incomes, the requirements of sanitation and material recovery diverge; each must be addressed separately.

Recycling in today's developed countries is a new process, requiring formal organization and relying on nonmarket as well as market forces. As incomes rise in developing countries, it will be necessary to move quickly from traditional to modern styles of material recovery. This transition, although it involves new planning efforts and new expenditure, is a sign of success: it represents progress both in economic development and in the creation of more sustainable cities.

2. Waste in the preindustrial city

In the centuries before industrialization, most urban wastes were organic rather than manufactured in origin. In the cities of Europe and North America, animal wastes were common due to the widespread use of horses for transportation as well as the practice of raising pigs and other animals for food in low-income neighborhoods. Ashes from burning coal and other fuels made up another important component of the waste stream (Melosi 1981). As Benjamin Miller explains in his detailed history of New York City's waste management, many attempts were made to recover parts of this waste stream for use as fertilizer or other valuable products (Miller 2000). Yet none of these attempts were successful enough to solve the urban waste problem. Growing awareness of the health hazards of uncollected waste eventually led to the introduction of organized municipal waste collection and disposal around 1900.

In preindustrial Japan, the cities also produced a largely organic waste stream, but a different waste management system evolved to handle it. Animal wastes were not important, due to the very limited use of horses and the absence of food animals. Human night soil and ashes, some of the major urban wastes, were collected by farmers who used them to fertilizenearby fields. Rather than being unwanted wastes, these materials were actually commodities with positive prices. Night soil collection simultaneously addressed the sanitation and material recovery goals of waste management, a historically unique coincidence of these two objectives. In the closed economy of the Tokugawa period, the extremely labor-intensive process of manual collection of urban waste not only kept the cities clean, but was also one of the few opportunities for improving agricultural productivity. The practice survived for three centuries, until cheaper and higher-quality imported fertilizers became available in the early twentieth century (Tajima 2005).

Market-driven recovery of materials was not limited to organic waste. Recycling of durable materials and manufactured goods has always occurred, and probably represented a larger share of the supply of materials in the past. Historically, the motivation for recycling everywhere was the same as for night soil recovery in Japan: materials were expensive and labor was cheap. The economic history of medieval England, it has been argued, is a story of continual recycling (Woodward 1985). Winter coats, for example, were repaired and passed on from one generation to the next. Even when textiles became more widely available, in the initial period of industrialization, it was still common to economize on clothing,

with changing fashions reflected in the new decorations and accessories sewn onto old dresses (Fine and Leopold 1990; McKendrick et al. 1982).

The nineteenth-century American housewife, as described by historian Susan Strasser, was engaged in an unending and exhausting process of recovering, repairing, and reusing the household's material goods (Strasser 1999). Even though industrialization had begun to transform the leading sectors of the US economy, earlier modes of material use lived on. Packaging of consumer goods was essentially unknown until the twentieth century. Paper was an expensive product, made from cloth rags, until the development of much cheaper, wood-based papermaking in the second half of the nineteenth century. A textbook for American children written in 1882 still felt the need to provide a definition for "wastepaper basket" and explain its use (Strasser 1999, 67).

This extensive recycling and reuse of materials was not motivated by a commitment to sustainability or a belief in frugality, but rather by economic necessity. Some belief systems made a virtue out of necessity and advocated simplicity in material possessions. But few people of any religion could resist the temptation to consume more, and reuse and recycle less, as their incomes rose.

3. Wages and materials

Throughout the late nineteenth and early twentieth centuries, incomes rose rapidly in the countries that are now described as “developed”. In particular, incomes rose faster than material prices, so that it became possible for the average person to buy more goods. Indeed, this change is fundamental to the meaning of economic development: people become less the slaves, and more the masters, of their material environment. As a consequence, people consume more and discard more. Two examples from the United States illustrate this point.

First, the available historical data confirm that in the long run, the cost of material goods has been dropping when compared to wages. Figure 1 shows the price of cotton fabric and of nails expressed in terms of minutes of work time, at the average worker's wage, required to buy the goods.[1] In the 1830s, when price data are first available, the average unskilled worker had to work for more than an hour to earn enough to buy either a yard (about 91 cm) of cloth or a pound (454 g) of nails. By the 1960s, neither purchase required more than about five minutes' worth of wages (Ackerman 1997, 181).

The decline is almost continuous in both series, with the exception of the surge in prices caused by the Civil War (1861–1865); the extremely high cotton prices of those years are not shown because they would be far above the top of the graph. Both before and after the Civil War, the time required to buy both of these goods was clearly declining.

For the second example, consider the history of the disposable beverage container, one of the most visible and widely discussed forms of urban waste.[2] It is, in historical terms, a surprisingly recent form of trash. Before World War II, beer and soft drinks were sold only in heavy, refillable glass bottles—or more often, sold without any packaging because they were consumed on the premises of a bar or

1. The prices shown in this graph are wholesale prices; retail prices would have been higher.
2. This account is based on chapter 7 of *Why Do We Recycle?* (Ackerman 1997).

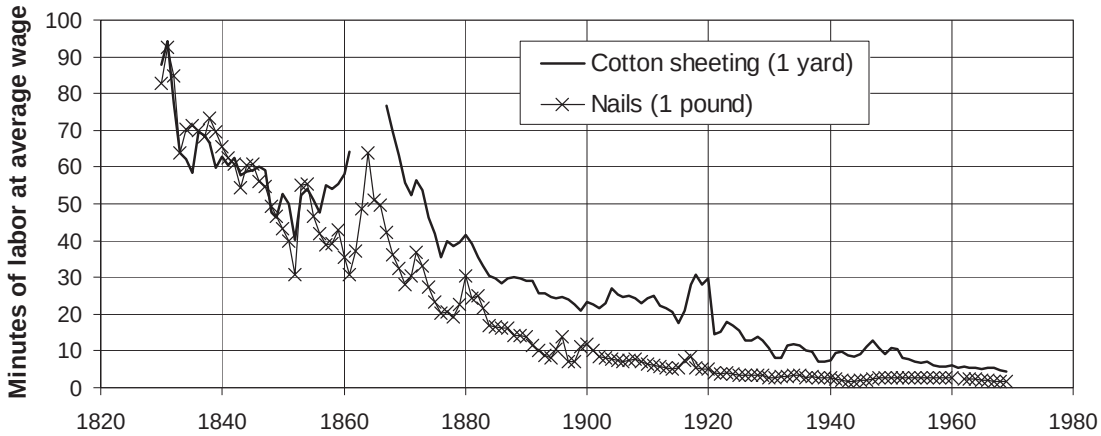

Figure 1. Labor time required to buy materials, 1830–1969

Note: The average wages used are for US urban unskilled labor (1830–1889) and US manufacturing labour (1890–1969).
Source: Ackerman 1997, p. 181.

restaurant. When refillable bottles were used, they were expensive enough so that bottlers charged substantial deposits in order to get the empty bottles returned.

The US beer industry, largely founded by German immigrants, had been accused of pro-German sympathies during World War I. In order to improve its public image during World War II, Anheuser Busch, the leading producer, shipped large quantities of beer in cans to US troops overseas. Even larger quantities of Coca-Cola were shipped to American soldiers during the war; General Eisenhower, the US commander in Europe, believed that Coke was healthier than beer, and persuaded the US government to build new Coca-Cola bottling plants close to the front lines.

Wartime consumption of beer and soft drinks, of course, occurred under circumstances that made it all but impossible to return the empty containers. Thus a generation of young Americans had the first large-scale experience of single-use, nonreturnable beverage containers. This remarkable feat was newly possible in the 1940s; a generation earlier, during World War I, the industry and its technology were far less developed, and shipment of canned or bottled beverages to American soldiers was not an option.

After World War II, traditional refillable glass bottles were initially cheaper than the new cans, but the returning veterans provided a crucial group of consumers who were familiar with, and continued to buy, beverages in cans. By the 1960s, technology had advanced to the point where single-use, nonreturnable bottles and cans became competitive with refillable bottles, and beverage container litter suddenly began to appear on roadsides and in public places. Economic growth created not just more waste, but qualitatively new forms of waste as well.

Beverage container waste, which by now has spread around the world, provides an indirect measure of economic development. Aluminum beverage cans are the most valuable common materials found in

urban waste; their scrap value can be as high as US $0.01 per can. Based on this fact, are aluminum cans unwanted wastes or valuable commodities?

My personal observation—which is only anecdotal information based on a very small sample—is that in Mexico, aluminum cans are never left on the street. Even when other, less valuable, containers are visible as roadside litter, there are no discarded aluminum cans to be seen. Instead, there are occasional storefront businesses that buy aluminum cans from collectors. At Mexican wages, $0.01 appears to be a big enough incentive for market-driven collection of cans.

In the United States, 11 of the 50 states have beverage container deposit/redemption systems, in most cases placing a $0.05 deposit on cans and bottles. Again based on personal observation, there are virtually no aluminum cans left on the street in states with deposits, where collectors receive $0.05 per can. In non-deposit states, however, where collectors would receive only $0.01, discarded aluminum cans do show up in public places. At US wages, therefore, it appears that $0.05 is a big enough incentive to pick up virtually all cans, but $0.01 is not. Note that the relevant wage is that of the urban poor, who engage in can collection, not the average wage. Countries with higher minimum wages and income supports will require bigger incentives to achieve the same level of material recovery through market mechanisms alone.

4. Urban waste in developing countries today

The cities of developing countries today are not repeating the experience of preindustrial Europe or Japan. Human wastes are treated as a sanitary problem, not as a source of fertilizer. Animal wastes are of small and declining importance. Modern manufactured goods are available and enter the waste stream, although in much smaller quantities per capita than in developed countries. Still, there are two great similarities to the waste management system of the preindustrial city: the large organic component of the municipal waste stream, and the availability of low-wage labor for market-driven recycling.

At low income levels, food waste is one of the largest components of urban waste today. As incomes rise, food waste declines in importance while manufactured goods, particularly paper and paperboard products, expand rapidly. This pattern can be observed in the World Bank estimates for solid waste composition by income level, as shown in table 1.

Table 1. Waste composition of low-, middle-, and high-income countries, 1995

	Country income level (%)		
Percentage of waste stream consisting of:	Low-income	Middle-income	High-income
Organics (e.g., food waste) and other (e.g., ash)	88	69	40
Paper and paperboard	5	15	36
Metals, glass, and plastics	7	16	24
Total	100	100	100

Source: Hoornweg with Thomas 1999.

If the low income pattern was expected to persist, then the top priority would be to develop composting programs for food waste (and plans for ash disposal in countries such as China where ash is an important part of the waste stream). Recycling of valuable materials might be expected to take care of itself, in the manner of aluminum can recycling in Mexico. However, this would be an incomplete waste management policy for two reasons: first, some forms of market-driven recycling need to be controlled or eliminated; and second, economic growth leads quickly into new patterns of waste and new challenges for material recovery.

Poverty is a blunt instrument when it comes to promoting recycling. Some of the activities it inspires, such as collecting discarded aluminum cans, may appear environmentally benign, although poorly paid. However, the same economic forces lead to much less desirable occupations, such as landfill scavenging, or manual recycling of electronic waste and other products containing hazardous materials. If labor is cheap and materials are expensive, a purely market-driven recycling process will be designed to capture and conserve valuable materials, not to protect the less valuable human inputs. At the extreme end of the scale, scavengers working—and in many cases, living—on a landfill site can recover many valuable discarded items, but at enormous cost to the scavengers' health.

Surely a sustainable city cannot be based on occupations that are harmful to human health. Thus one priority must be to regulate market-driven recycling, to eliminate the worst practices such as landfill scavenging, and to ensure that hazardous materials are only handled in facilities that provide appropriate protection for workers and the surrounding community.

Despite these concerns, much of the market-driven recycling process is environmentally benign. But it is also unstable. In a country that is rapidly developing, the economic incentives for recycling are rapidly diminishing. As incomes rise from Mexican to American levels, aluminum cans are suddenly left in the streets uncollected, as the can collectors find better paying jobs. The same fate, at varying income thresholds, awaits many other informal recycling processes that a low-income city relies on. A new, planned approach to recycling is needed, at the same time as the composition of the waste stream is changing, as shown in table 1, toward more paper and other manufactured goods.

5. The technical challenge: Paper recycling

In a high-income country, by far the most important material that can be recovered from the waste stream is paper. This conclusion is based above all on the large and growing quantity of paper waste; other materials, particularly metals, may have a higher price per ton.

Metals remain important, but in high-income countries they no longer represent growth industries. Increasingly, technological change is replacing metal (for example, in automobiles) with plastics and composites, which are often less valuable and always less recyclable than metals. Market-driven recycling processes still recover many metal objects; for instance, scrapyards extract metal from discarded automobiles, major appliances, and building materials. (These wastes are often excluded from the waste stream composition figures discussed above.) The cans, small appliances, and other metal

household objects found in the waste stream are worth recycling, but they are not the top priority for material recovery from urban waste.

Paper, in contrast, continues to be a growth industry. The widely discussed technological promise of the paperless computerized office has dramatically failed to come true. At one third or more of the waste stream in high-income countries, paper products represent a majority of the readily recyclable materials. In US recycling programs, more than half of the material collected is paper, whether measured by weight or by market value.[3]

Is paper recycling worthwhile? An academic debate has raged over this question for years, although as we will see in the next section, public opinion has been much less divided. Numerous studies have been done of the relative environmental impacts of recycling versus incineration of paper, with varying results.[4] In terms of energy use, producing paper from wood uses more *total* energy than recycling used paper, but much of the energy used in virgin paper production comes from burning wood waste (parts of the tree that are not made into pulp, and process byproducts); paper recycling uses as much or more *purchased* energy, and hence may entail more fossil fuel consumption. In terms of climate change impacts, studies that ignore forestry impacts often find roughly equal lifecycle greenhouse gas emissions from paper recycling versus incineration. However, if carbon sequestration in forests due to recycling is included in the analysis, recycling is a clear winner.[5] The studies are virtually unanimous in finding that landfilling is the worst option for paper; the only debate from an environmental perspective is between recycling and incineration.

Decisions about paper waste are crucial to the design of the entire waste management system. Since paper represents most of the recyclable material in the high-income urban waste stream, the amount of paper being recycled determines the size of a community's recycling program. Likewise, paper represents more than half of the energy content of the waste stream, so the amount of paper being burned determines the appropriate size, if any, of an incinerator. Profitable operation of an incinerator normally requires that it run continuously at close to full capacity, so it should be no larger than the waste stream that will remain after recycling.

There is a trap lurking here, which some American communities have fallen into: in order to build an incinerator, communities often have to sign long-term contracts to deliver fixed quantities of waste to it, at fixed disposal fees. Frequently the communities are responsible for the fees whether or not they deliver the waste. Once the contracts are signed, it is very expensive for those communities to start recycling more and incinerating less—in effect, they then have to pay both for incineration and for recycling of their paper waste. It is therefore wiser to build a little less incinerator capacity than is needed, rather than a little more. In some cases, the "loss" of paper waste to a recycling program may

3. See the annual reports (through 2001) on “Municipal Solid Waste in the United States” published by the US Environmental Protection Agency, available at http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm.
4. For a review of this literature and summaries of some of the leading studies, see the *Journal of Industrial Ecology*, vol. 1 no. 3 (Summer 1997), a special issue on the industrial ecology of paper and wood.
5. When recycling increases and demand for virgin pulp decreases, forest owners cannot adjust their standing stocks of timber immediately, due to the long lags involved in growing trees; thus there is more sequestration in forests. The climate change implications of recycling are explored by the author in an article for *Local Environment* (Ackerman 2000).

make incineration as a whole unprofitable, in which case other disposal options should be explored for the remaining waste.

6. The political challenge: planning for high-income recycling

Parallel to the technical challenges of recycling paper and other valuable materials, there is a political challenge of planning and organizing a recycling program in a high-income community. As incomes rise and the waste stream expands and changes, the traditional market-driven form of recycling becomes less attractive and less reliable. Larger incentives are required to motivate more affluent people if market incentives are still to be the motive force behind recycling.

In fact, it is impossible to rely entirely or primarily on market incentives for material recovery in a high-income context. While it is possible to use deposits to raise the value of aluminum cans from $0.01 to $0.05, it would be impossibly expensive to do this for all wastes. Deposits are normally used only for wastes that would otherwise be a public nuisance, such as beverage containers, or that pose health or environmental hazards if discarded improperly, such as lead-acid automobile batteries.

Even if it were somehow affordable, it might not be desirable to have deposits high enough to bring back market-driven recycling of most recoverable wastes. To do so would once again make materials more valuable relative to average wages; it would bring back the feeling of poverty, of materials being expensive and labor being cheap. The real challenge of high-income recycling is to find cost-effective, sustainable ways of recovering valuable materials without making everyone feel poor.

In the United States, the modern era of recycling began with advocacy and volunteer efforts in the 1970s, followed by the first municipal programs in the 1980s. In the 1990s recycling swept the nation, with more than half of the population served by curbside recycling programs by the end of the decade. Recycling emerged in many other developed countries on similar schedules. In this context, recycling was not a response to market incentives, for materials were cheap and the purely economic incentives for recycling were weak. Rather, it was part of the environmental movement, the upsurge in environmental consciousness and advocacy that began in the 1970s. People wanted to recycle because they wanted to save the earth—and they wanted to find tangible ways to participate in that effort.

Does recycling actually help save the earth? The environmental benefits of recycling include reduced air and water pollution and reduced impacts of extractive industries on surrounding communities and ecosystems due to the reduced demand for virgin raw materials. Other benefits include movement toward sustainable resource use, allowing a richer bequest of natural resources to future generations, and a sense of visible public participation in environmental improvement. Early advocates of recycling, at least in the United States, often confused the public debate by overemphasizing the “need” to reduce waste disposal and solve the so-called landfill crisis. In retrospect it is clear that there was no landfill crisis, and not even a shortage of landfill capacity in most of the country. But that was never really the point; despite the availability of landfill space, recycling remains widespread and popular.[6]

6. These issues are discussed at greater length by Ackerman in *Why Do We Recycle?* (Ackerman 1997).

It is equally mistaken to suggest, as some critics of recycling have done, that existing recycling programs are prohibitively expensive and should be abandoned in order to save money. Some increase in expense should be expected: public support for recycling implies a desire to do more than the market is doing on its own, to push beyond the bounds of what is currently profitable. A well-run municipal recycling program adds a little to total waste management costs—but only a little. In the mid-1990s, under typical American conditions, a curbside recycling program increased the overall cost of waste management by an estimated $21 per household per year (Ackerman 1997, ch. 4).

A conventional cost-benefit analysis would then ask whether the environmental benefits of recycling were worth as much as $21 per household.[7] It is hard to answer this question, since so many of the benefits are difficult or impossible to monetize (Ackerman and Heinzerling 2004). Nonetheless, an ambitious and detailed national study of recycling in Australia found that monetized environmental benefits exceeded net economic costs for every recycling scenario in the study (National Packaging Covenant Council 2001).

As an alternative to the hopeless task of pricing all the environmental benefits of recycling, it is possible to ask people what they are willing to pay—and then see if a recycling program can be run for that amount or less. When researchers have asked Americans how much they are willing to pay for the existence of municipal recycling programs, the answers have generally been above $21 per household per year. Studies in Utah and Tennessee, far from the most environmentally oriented states in the country, find a mean willingness to pay for municipal recycling of $2–7 *per month* (Aadland and Caplan 1999, 2003; Caplan et al. 2002; Tiller et al. 1997). This suggests that communities with recycling programs are getting something they are willing to pay for, consistent with the observed popularity of recycling. Cutbacks in recycling, motivated by municipal budget crises, have provoked grassroots opposition: both New York City and Washington, DC have attempted such cuts, and both cities have ended up restoring recycling in response to popular demand.[8]

A European study cites four estimates of the willingness to pay for participation in recycling programs, ranging from €20 to €290 per household per year (van Beukering 2001). The lower of these figures is comparable to the estimated costs of a typical American recycling program. Although some European recycling programs are reportedly quite expensive, the survey data suggest that Europeans would be willing to cover the costs of American-style recycling.

Enthusiasm for recycling has led to thousands of municipal recycling programs in the United States and Canada. While these programs have emerged within affluent societies, they are still under continual pressure to economize, to minimize the cost of recycling. Yet in contrast to the market-driven recycling of low-income countries, high-income recycling operates in an environment of comparatively expensive labor and cheap materials. Now there is pressure to increase labor productivity through mechanization and program design that maximizes the quantity of material handled per person-hour. In high-income recycling, materials are at times mistreated to save labor; in low-income recycling, the reverse is true.

7. For a thoughtful presentation of this perspective on waste management, see Porter's study (2002).

8. The suspension of recycling in Washington, DC occurred during a crisis of municipal mismanagement that led to severe budget cuts in 1997. In New York, the recycling program was cut back in 2002, and restored in early 2004—in part because the cutbacks saved much less money than the city had anticipated. See Natural Resources Defense Council 2004.

Decentralized experimentation throughout the United States and Canada has led to a range of local innovations that have increased efficiency and lowered costs of recycling; these efforts are far too diverse and numerous to describe here.[9] Those who are interested in lowering the costs of recycling should also study the example of Australia, which appears to have more mechanized and less expensive recycling programs than most of North America.[10]

7. Conclusions

As countries develop and incomes rise, the requirements of sanitation and material recovery diverge. New, valuable materials enter the waste stream—and the materials most worth recovering are among the least likely to pose health or sanitary hazards. Waste management systems need to develop to meet both objectives; this is likely to include the replacement of old, seemingly effortless patterns of material recovery. As a country develops, it should expect to lose much of its informal, market-driven recycling system. Indeed, it should celebrate this loss, for the old style of recycling rested entirely on poverty and sometimes endangered the health of the poor.

Based on the experience of today's developed countries, rising incomes will be accompanied by advocacy and support for new forms of recycling. While market incentives may play a supporting part in encouraging recycling, environmental values and beliefs play the leading role. From the perspective of sustainability, it is encouraging that affluent people, who can afford to discard materials, still want to participate in material recovery. It is a practical step that people are willing to take in response to values rather than prices, a first hint of a social order beyond market necessity.

Yet affluence does not arrive overnight; as a country grows, it remains essential to make recycling as efficient as possible, to keep its costs down and ensure that it remains affordable. The wide range of international experience with recycling provides a good starting point for designing new programs for rapidly developing countries. North American and Australian recycling programs have shown that it is possible to recover significant quantities of materials at very low cost. However, their collection systems have been designed for relatively low-density urban areas. Further innovations may be needed to create appropriate recycling programs for the Asian cities of the twenty-first century.

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9. Information on US and Canadian recycling is available through the National Recycling Coalition (http://www.nrc-recycle.org) and in the magazines *BioCycle* (JG Press, Emmaus PA, USA, http://www.jgpress.com/biocycle.htm) and *Resource Recycling*, (Portland OR, USA, http://www.resource-recycling.com/rr.html) among other sources.

10. Based on the data in the National Packaging Covenant Council's study (2001) and on personal observation.

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