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HOW GOVERNMENT BUILDING CODES AND CONSTRUCTION STANDARDS DISCOURAGE RECYCLING

by

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EXECUTIVE SUMMARY

Why doesn't everyone use recycled materials? In many areas, recycling is a relatively new technology, and the companies that use the technology tend to be fairly small. Many people don't know about the full range of products made with recycled material, and education is costly. This is especially the case with plastics. The basic problem is one that is common to many new technologiesthe world as we know it came to be in an earlier time, before current recycling opportunities became commonplace. Where recycling technology is relatively new, it has to overcome many institutionalized barriers to change.

Part of the problem is that potential end-users rely on industry standard-setting organizations, like the American Society for Testing and Materials (ASTM) or the American Association of State Highway and Transportation Officials (AASHTO), which write standards that sometimes shut out recycled materials.

- Plastic lumber, a promising construction material, isn't generally being purchasedin part because the ASTM has been slow in drawing up testing standards;

- The ASTM and AASHTO haven't advanced standards for drainage pipes made of recycled PVC or HDPE, because of infighting between different industry groups.

The problem isn't that such organizations exist; these organizations serve a useful purpose in developing standards and performance tests. Rather, the problem is that when governments rely on them, the standards often become mandatory, not voluntary. Another part of the problem is that governments themselves sometimes enforce restrictive regulations that shut out recycled materials:

- Building codes, which are generally enforced on the local level, are very conservative and make it difficult for innovative building materials to be used in construction;

- Highway construction standards are wedded to specific materials, methods, and industrial processessometimes mandating materials (as with a recent recycled rubber mandate) and sometimes prohibiting them. This makes innovation difficult in highway technology, even when such innovation would improve the performance of roadways.

Yet another part of the problem is that government procurement agencies can inadvertently or subtly discriminate against recycled materials, through such methods as:

- The arcane rules of government bidding processes;

- The somewhat arbitrary distinction between pre-consumer and post-consumer recycled materials;

- Color and thickness requirements, and other conditions that are unrelated to performance;

- Materials requirements, for instance in the purchasing of carpets or composts.

One theme runs through this array of government practices. *Governments often don't rely on measures of performance*. In the past, specifying materials or methods may have been the best proxy for performance one could find; when performance is difficult to measure, "doing it the way we've always done it" may have had some justification. Whatever the explanation, it's time for governments to move toward performance standards and away from specifying particular materials.

The question "Why doesn't everyone use recycled materials" is, in a sense, as ridiculous a question as "Why doesn't everyone make things out of steel" The physics and chemistry of recycling are complicated; there are lots of different processes which have lots of different effects, and it would be dangerous to draw blanket conclusions like "We should always use recycled materials" or "We should never use recycled materials." The honest answer is to admit that optimal levels of recycled material usage will vary by situation. Unless we adopt performance standards wherever possible, we can never know what those levels are, much less reach them. Many promising products are being discriminated against today because a performance standard isn't in place.

- Governments shouldn't always rely on industry standards. In areas like plastic lumber or drainage pipe, when the ASTM or AASHTO don't have standards for a possibly good product, it may make sense for governments to draw up their own performance standards, allowing companies to submit performance data from approved testing labs.

- Local building code offices, highway departments, and such agencies should establish clearer and more predictable approval procedures that are more open to innovative technologies. They should rely less on materials and methods specifications, and use performance standards whenever possible.

- Government procurement agencies should scrutinize their procurement specifications to see whether they're using irrational or non-performance-related criteria to buy the products they need. President Clinton's 1993 Executive Order on recycled procurement has reformed and will continue to reform government procurement, though it treats recycling too much as an end in itself. More should be done to require performance standards whenever possible instead of dictating what a product must be made of.

PREFACE

Spurred on in the late 1980s by fears of an impending "landfill crisis," state legislators found a ready remedy in recycling laws. Prompted by these new state laws, local governments put in place over 7,000 curbside recycling programs that began collecting tons of bottles, cans, jars, newspapers, and whatnot. In short order, the legislative refrain moved from "Recycle now" to "We need markets." Legislators moved to calibrate recycling supply and demand with a host of proposed regulations recycled content mandates, manufacturer "take-back" requirements, government procurement preferences, and various subsidies. Whatever the reason, deregulation as a way to expand recycling markets was virtually ignored.

This is unfortunate. Shorn of all its ideological trappings, recycling is essentially a process of innovation. Like electricity, cars, and computers, new recycling technologies must overcome a lot of institutionalized barriers to change. Many obvious regulatory barriers have been removed, but many still remain. Sometimes, these barriers are subtly hidden, disguised as unnecessary procurement standards or superfluous safety regulations. Sometimes, they're unintended side effects of unrelated legislation. But regulatory barriers do exist, and their elimination or modification ought to be the starting place for trying to enhance recycling markets.

It's time for a change of paradigm. For years, environmental policy has been run on a philosophy of "environment good, industry bad." But this philosophy can't adequately deal with the reality of recyclingwhich blends environment with industry.

This policy series, "Recycling and Deregulation: Opportunities for Market Development," will cover the following areas:

- The use of recycled materials in food packaging, and why FDA regulations and other laws, originally enacted to protect the public health, can inhibit recycling;
- The recycling of hazardous wastes, and why some hazardous waste regulations, instead of protecting the environment, discourage the safe reuse of hazardous products, like lead batteries and used oil;
- The transport of solid waste, and developments to watch out for that could limit the supply of recyclables by discouraging their transportation;
- The scrap tire management problem, and how some state efforts to prevent tires piling up in garbage dumps are counterproductive;
- Recycled building materials, and how building codes unnecessarily prohibit their use;
- How industry standards groups, which governments rely on in their procurement practices, can discourage the use of recycled materials in products like plastic lumber and drainage pipes; and,
- How government procurement agencies and miscellaneous other government bureaus, through superfluous regulation, stifle the development of innovative recycling technologies.

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"Barbarism is the absence of standards to which appeal can be made."

José Ortega y Gasset, *The Revolt of the Masses*

"Half our standards come from our first masters, and the other half from our first loves."

George Santayana, *The Life of Reason: Reason in Art*

I. INTRODUCTION

Why doesn't everyone use recycled materials In many areas, recycling is a relatively new technology, and the companies that use the technology tend to be fairly small. Many people don't know about the full range of products made with recycled material, and education is costly. This is especially the case with plastics. The basic problem is one that is common to many new technologiesthe world as we know it came to be in an earlier time, before current recycling opportunities became commonplace. Where recycling technology is relatively new, it has to overcome many institutionalized barriers to change.

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The problem isn't that such organizations exist; these organizations serve a useful purpose in developing standards and product performance tests. Rather, the problem is that when governments rely on them, the standards often become mandatory, not voluntary. Another part of the problem is that governments themselves sometimes enforce restrictive regulations that shut out recycled materials:

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The question "Why doesn't everyone use recycled materials" is, in a sense, as ridiculous a question as "Why doesn't everyone make things out of steel" The physics and chemistry of recycling are complicated; there are lots of different processes which have lots of different effects, and it would be dangerous to draw blanket conclusions like "We should always use recycled materials" or "We should never use recycled materials." The honest answer is to admit that optimal levels of recycled material usage will vary by situation. Unless we adopt performance standards wherever possible, we can never know what those levels are, much less reach them. Many promising products are being discriminated against today because a performance standard isn't in place. This is their story.

II. INDUSTRY STANDARDS GROUPS

Many product standards are written by industry groups. Some of the largest such groups are the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), the American National Standards Institute (ANSI), and the Society of Automotive Engineers (SAE). In 1980, there were about 400 such private groups. Fourteen of them, including ANSI, ASTM, and SAE, accounted for about 85 percent of the 20,000 published standards. Other groups include the International Telegraph and Telephone Consultative Committee (CCITT) and the Institute of Electrical and Electronic Engineers (IEEE). These associations are voluntary, though in the United States, many of their standards aren't. Governments frequently write standards themselves or rely on the standards of some industry group. For instance, building codes don't accept certain construction materials, and governments won't buy certain products, unless the products conform to a certain standard.

Voluntary standards organizations can benefit the consumer by improving communication and helping solve coordination problems among different firms in an industry. Because they're not bound by antitrust regulations, they allow firms to work together to lower manufacturing costs through standardized parts and other conventions. For example, the ASTM is currently developing standards for quality assurances in recycled plastics, which will make end users more confident in the quality of products made with recycled plastics, and which will eliminate the problem of different manufacturers talking about their plastics using different terminology, units, and concepts.

But many small manufacturers complain that such groups are controlled by large, established companies in the industry, who have written the standards to allow use of their own products and who are loath to rewrite the standards that may benefit new firms. For example, Chris Kleronomos of the Ecos Electronics Group had trouble selling his safety analyzer, which tests electrical equipment and systems, because he couldn't get the approval of the National Fire Protection Association. Kleronomos charged that this was because the committee that wrote the standard was headed by his competitor. Such claims may not always applythey may be the excuse of a failed entrepreneurbut they recur often, and there is probably something to them. Some firms are more sophisticated about the standards process; firms that spend time and money preparing for and mastering the process can guide it in directions they like. Firms that have already entered an industry have an incentive to write rules that stop other firms from entering. In cases where standards require large up-front investments, amortizing these investments is a significant barrier to entry.

Standards do, of course, sometimes change; in fact, sometimes firms change their standards to prevent other firms from gaining a foothold. Standards may be more stable in industries where the established players aren't innovating anymore; the QWERTY keyboard layout or NTSC television haven't changed for decades. In other industries, like in the development of local area computer networks (LANs), standards are constantly evolving. The balloting and publication of LAN standards hasn't stopped new LAN technologies from being invented or standards committees from considering additions, variations and new options.

But in many industries, if new standards are ever written at all, it may be only after many years of negotiation. Ten years is not unusual for certain ASTM standards; whether this is appropriate or not depends on whether the concerns that drag the process out are valid and justified on technical grounds, or whether they're intended to restrict competition. If governments require standards that aren't performance-basedfor example, standards that either require or exclude the use of specific materialsthe consumer and taxpayer may end up losing. Many standards simply require characteristics that products have had historically. Once such standards are in place, enshrining old technologies, they can be hard to displace, even if a competing product is better.

The appropriate role of standard-setting organizations has long been a subject of debate. In 1978, the Federal Trade Commission abortively proposed a set of far-reaching regulations to limit standard-setting groups. More recently, the ASTM has been under investigation by the Justice Department for having allegedly rewritten its standards for ABS pipe to specifically exclude a new sort of pipe. As of early 1996, the investigation was still pending, and it's hard to say whether the allegations have any basis in fact. But these examples show that such concerns do exist within industry. These criticisms *do not* imply that the voluntary standard-setting process should be replaced with a government process; a government-run standard-setting process would be subject to similar problems, plus new ones of its own.

These standard-setting procedures can pose a problem for makers of products with recycled content because recycled-content manufacturing is a new field. This means that the companies involved are, on average, smaller than in comparable industries that use well-established technologies and virgin feedstocks. Innovation in recycling technology is also faster than in many other industries; this means that companies may not even participate in standard-setting activities at first, because the process, which is a cooperative endeavor, is so slow.

A. Plastic Lumber

1.He's a Plastic Lumberjack and He's O.K.

"Plastic lumber" is a construction material made out of recycled plastic. It isn't being used for "structural applications"that is, when it plays a vital role in the structural integrity of an objectlargely because of unresolved performance questions. Exterior, non-structural uses are, at the moment, more promising applications for plastic lumber, largely because structural uses are prohibited by municipal building codes. Some of these non-structural uses are:

- *Civil engineering applications*marine piling and decking, sound barriers, wheel stops, fence posts, guard rails, telephone poles, utility posts, railroad ties, and bulkheads;

- *Industrial applications*pallets (the wood crates one finds in supermarkets), fencing, dock fenders, truck bedding, sign posts, and industrial cushioning;
- *Consumer applications*decking, picnic furniture, playground equipment, landscaping ties, and privacy fences.

Plastic lumber can be made out of a variety of different materials:

- out of completely commingled plastics;
- mainly out of HDPE (high density polyethylene), with some contaminants;
- with a mixture of polyethylene and wood flour; or
- reinforced with fiberglass.

Fiberglass-reinforced plastic lumber is the stiffest kind. There are also different ways of making the lumbersingle-screw extrusion, molding, and the like.

In some uses, plastic lumber performs better than wood. Take, for instance, bin boards and bin shelving, which are used to contain and support ice-stowed fish and shellfish in fishing vessels. These boards are usually made of wood, which gets soaked when the ice melts and which are fertile breeding grounds for water-borne bacteria. Since fish placed on contaminated shelves can become contaminated themselves, plastic lumber, which is smooth, non-corrodible, and non-absorbent, is a good alternative to wood in this case. In general, plastic lumber has excellent ultraviolet resistance (with the proper stabilizers), abrasion resistance, chemical resistance, ozone resistance, stress crack performance, and resistance to marine borers. And it doesn't have to be painted, since much plastic lumber is made of white milk jugs, and so the desired color can be pigmented into the material.

Plastic lumber usually costs more than wood. For instance, the village of Brightwaters, N.Y., built a sea wall out of plastic lumber from TriMax, a manufacturer in Ronkonkoma, N.Y. The plastic lumber cost about 50 percent more than treated wood. Other sources give figures of 100 percent, 170 percent, or even 300 percent. Many cash-strapped agencies may not be able to afford that much eco-conscience. However, these numbers overestimate the total relative cost differences, because the total cost includes the cost of the materials, the cost of installation, and maintenance costs over the life of the structure. In Brightwaters, installation costs were about the same for plastic lumber and wood. In the end, the total cost of the sea wall was only about 10 to 15 percent higher than if it had been made with wood. Moreover, some traditional construction materials degrade faster than they used to. This is one ironic side-effect of cleaner waterways; since many wood-treating chemicals have been banned for environmental reasons, and since water pollution has decreased in recent years, waterways are now able to support more wood-eating life. Since there is now more dissolved oxygen in New York Harbor than there used to be, corrosion rates have quadrupled. Due to pH changes and dissolved CO_2, some concrete is now unstable. Marine borers have taken to eating wood piers in waters that for over a century were too polluted to support such life.

So plastic lumber lasts longer than wood and needs less maintenance; it doesn't rot and isn't affected by termites or marine borers. Tri-Max has guaranteed its product for 50 years. A study of recycled plastic bin boards on fishing vessels found that, though the boards themselves cost $640.00 versus $237.20 for wood boards, the total four-year cost was only $720.00 versus $1921.60 for wood boardsa 63 percent savings because of lower maintenance costs. Engineers who worked on the Tiffany Street pier, a 410×49-ft. recreational quay in the South Bronx, estimate that they'll save up to 300 percent by not having to replace the piles for 20 to 25 years, instead of 6 to 10 years with wood. On balance, plastic lumber is often worth the investment. In some government agencies, the use of plastic lumber has forced the issue of lifecycle cost considerations in purchasing. Not everywhere, though; many governments and corporate buyers still keep purchasing and maintenance decisions separate. Most government procurement agencies are still required to buy the lowest-costmeaning lowest purchase priceitem. Some agencies have one budget for lumber and another for paint and labor; plastic lumber requires no paint, but those two budget items don't talk to each other. (This also occurs in the private sector.)

Plastic lumber also has various environmental advantages. If wood is treated with chromate copper arsenate (CCA), the CCA can leach into the water as marine organisms gnaw on the wood and digest (and are killed by) the chemicals. Plastic lumber doesn't leach toxic chemicals. Plastic lumber in marine applications is less harmful to certain marine organisms than chemical-treated wood. Sea urchin studies have shown that while CCA-treated wood reduces sea urchin fertilization, plastic lumber doesn't. There were no indications in the study that the plastic lumber was toxic, even though it was produced from unwashed post-consumer plastic. Environments with plastic lumber had more biodiversity than those with even untreated wood.

On the other hand, plastic lumber has its problems. Plastic lumber is ten times as flexible as wood. Also, thermoplastics are sensitive to creep (or progressive deformation over time under a constant stress), with greater creep at higher temperatures. Plastic lumber has shown a tendency to creep significantly under sustained loads and even under its own weight; plastic lumber posts have been known to warp under no external stress during accelerated aging tests.

There are about 30 different manufacturers of plastic lumber, all of which make their lumber using slightly different technologies and slightly different plastic waste feedstocks. One commentator has disparagingly said, "If you look up in the American Heritage Dictionary the definition of ‘technology,' you will get: ‘The scientific method and material used to achieve a commercial or industrial objective.' The plastic lumber industry doesn't have any technology that has been created along the years of its existence." This is a bit harshbut it is true that many manufacturers are entrepreneurs, not engineers, and use a research and development method described as "poke-and-hope," essentially applying known technology and playing around with conventional additives until they get a plastic that they like.

2. Why Don't People Use Plastic Lumber

Since plastic lumber is a new material, people are reluctant to use it. With wood, there are handbooks that builders can consult and well-known guidelines to rely on. For instance, for a given size and grade of wood, one can find out the mechanical properties and adjust them downward by an appropriate amount if the plank in question has knots or if the humidity in the area is different than average. No such handbooks exist with plastic lumber, though some studies have been done on its structural properties. Two identical-looking pieces of plastic lumber, even if they were made using the same method but by different manufacturers, could differ in their mechanical properties by a factor of four. Even though most of the plastics being used are polyethylenes, there are two very different kinds of polyethylene: HDPE (high-density), with a modulus of elasticity of 160,000 lbs./sq.in., and LDPE (low-density), with a modulus of 20,000 to 30,000 lbs./sq.in. The modulus of elasticity measures how much a material will be deformed under the action of a certain force; the higher the modulus of elasticity, the harder it is for the material to deform under stress.

Given such variability, it's natural that everyone isn't rushing to buy plastic lumber. Without fully developed design criteria, plastic lumber isn't appropriate for long-term structural applications.

Since there are no established standards, test methods, or grading systems, there is no way to reliably use plastic lumber in structural applications (for example, building construction). Building code officials are reluctant to approve plastic lumber products, and the products fail badly in the wrong application. The ASTM is the organization that people rely on to establish these standards, but negotiations have been going on for over two years, and there is still no standard. Some have blamed the ASTM's slowness in establishing a standard on the youth, unprofitability, and disorganized nature of the plastic lumber industry, and on the presence on the relevant committee of members of the "wood lobby." Some have claimed that the wood representatives slow the process down with counterproductive suggestionsa common allegation with industry standard-setting groups, though such allegations are generally unprovable. Says one manufacturer, "It's hard to have a rational conversation with wood people at public forums."

3. Why Are Existing Tests Misleading for Plastic Lumber

Since there are no tests specific to plastic lumber, plastic lumber is usually tested according to wood or solid plastic standards. Both of these types of tests are misleading.

- Typically, when plastic is tested for its tensile strength, it's molded into the shape of a "dogbone" (more or less the shape of a capital letter I). But unlike most plastics, plastic lumber isn't homogeneous. The inside is foamy, and the outside is a hard skin. The "specific gravity," or density, of wood is between 0.4 and 0.7. (Water, by definition, has a specific gravity of 1.) Foamed plastic lumber has a density of 0.8. If plastic lumber is mashed up into a homogeneous lump and molded into a dogbone shape, the results will represent the performance of a homogeneous lump of plastic with a density of 0.9 to 0.95. But since plastic lumber is foamed on the inside and has a hard skin, the results one gets with the dogbone are quite different than the real-life results of plastic lumber.

  Also, when the plastic lumber is molded into a dogbone, it loses the extraneous material that it used to containbottle labels, stray nails, and so on, all of which could affect its structural properties for better or for worse.

  In addition, dogbones can't actually be made out of plastic lumber, with a foamed center, because dogbones are about one-eighth of an inch thick, while plastic lumber is typically at least three-eighths of an inch thick because it's made to traditional lumber thicknesses. If one were to make it too thin, one would lose some of the skin or some of the core, which would also affect its structural properties.

- The problems are similar with wood testing protocols. One way of testing wood is to apply a force to the wood to find out its "rate of strain." But with wood, the results of the tests are not very sensitive to such things as the temperature at which the test is done. With plastic lumber, these variables matter. Plastic is inherently temperature dependentstrong and brittle when cold, weaker and more ductile when warm. And different structures which could use plastic lumber will be subject to different temperature ranges. Warmer thermoplastics generally have lower moduli of elasticity and higher creep, and compressive strength and bending strength decrease with increasing temperature at a greater rate than wood. Even though warmer plastic lumber can be stronger, it can also be more brittle, and therefore have lower impact strength.

  So the wood tests, while specific enough for wood, aren't specific enough for plastic lumber. (On the other hand, wood is sensitive to humidity, and the wood tests go into detail about moisture. These are not important considerations for plastic lumbers.) This means that the results of the plastic lumber tests aren't guaranteed to be consistent from one test to another. Nor are they guaranteed to give an accurate picture of how the plastic lumber will perform in real life.

  Also, for some of the wood tests, the sample of wood doesn't have to be in a real-life size. For instance, some wood tests allow you to test popsicle-stick-sized pieces. The modulus of elasticity of wood, for instance, is the same for a two-by-four as for a two-by-six, but this is not the case for plastic lumber because it isn't homogeneous.

For clarity and comparability between different plastic lumber products, ASTM tests for plastic lumber have to be specifically designed for plastic lumber. Some agencies, like the Ontario Ministry of Transportation, have already developed, or are developing, specifications directly tailored to plastic lumber.

Between 11 and 16 million board-feet of plastic lumber are being made today. This represents 40 million pounds of waste plastics. The growth rate has been almost 50 percent per year for the last few years. How much plastic lumber could be used if there were a standard As a thought experiment, assume that 50 percent of all the potentially recyclable thermoplastics used in 1991 were instead made into plastic lumber (for a hypothetical projection of how much recyclable plastic could be diverted to plastic lumber manufacture). This would give us 25 billion board-feet of plastic lumberequivalent to almost half of annual U.S. lumber production. The lumber industry produces 34 billion board-feet of softwood (for instance, pine) and 12 billion board-feet of hardwood (for instance, oak and maple). This means that shortage of material isn't the problem for the plastic lumber industry. If plastic lumber were physically able to replace half of all wood lumber, there would be enough material to support the industry for a long time. Of course, plastic lumber hasn't been shown to be interchangeable with wood lumber, so this thought experiment, for the moment, is nothing more than that. But in non-structural applications, one estimate pegs potential demand at about 6 billion board-feet, or approximately 19.013 billion pounds.

To take just one application, consider backyard decks. If one assumes that there are 30 million decks in the country, which last on average 20 years and take up an average of 500 sq.ft., then if 1/20th of them are replaced each year, that already makes 750 million sq.ft. of plastic lumber each year, which translates into 5.07 billion pounds of decking material. (Of course, many people may still prefer wood decks.) Or, to take another application, consider marine pilings. There are 500,000 piles used annually in the U.S. (including new piles and replacement piles); each of them takes up about 45 cu.ft., and if they're made of plastic lumber, they weigh 1,900 lbs. a piece. This means that if all marine pilings were made of plastic lumber, we would use 22.5 million cu.ft., or 950 million lbs., of waste plastic.

Bear in mind that these are just hypothetical, best-case scenarios. The collection, processing and handling costs of plastics present special problems for cost-effective recycling, so it may be difficult to achieve hypothetical goals. But the numbers are worth keeping in mind, as a reminder that whatever the problems of the recycled plastic industry, lack of potential demand ought not to be one of them.

B. Plastic Pipes

1. Pipe Dreams; Or, Ceci N'est Pas Une Pipe

Standard-setting groups and government procurement agencies often have method specifications, which dictate the method by which an item has to be made for it to be approved or purchased. Method specifications can limit the use of recycled-content products by disqualifying recycled feedstocks or recycling-based technologies and processes. Even in cases where recycled-content products can meet or surpass performance specifications, they may not be considered because of method specifications.

PVC (polyvinyl chloride) and HDPE are the most widely used plastics for the construction of plastic pipe. PVC pipe is about 75 percent of all thermoplastic pipe (which is itself about 95 percent of the 4,200 million pounds of plastics that go into pipe, conduit, and fittings). HDPE pipe represents about 15 percent of thermoplastic pipe. We can distinguish between "pressure pipes," which are used to transport things like gas which move through the pipes under pressure, and "non-pressure" or "gravity pipes," like storm drains in which water flows under gravity. Non-pressure applications account for 57 percent of all PVC pipe. (No such number was available for HDPE pipe.) Until recently, the ASTM, the recognized standard-setter in this field, didn't allow recycled plastic in drainage pipes. AASHTO still doesn't. In most cases, the ASTM continues to forbid or discourage recycled plastic, and governments that rely on ASTM standards won't buy pipes with recycled content until the ASTM draws up a standard. The EPA, in establishing comprehensive recycled procurement guidelines for the federal government, remarked that next to the availability of post-consumer recycled PVC, "ASTM specifications that either implicitly or explicitly disallow the use of recovered content" were the biggest roadblocks to establishing a procurement guideline for recycled-content drainage pipe.

The EPA has estimated that drain and sewer pipes could be made with 25 percent recycled PVC and that pipe fittings could be made with 10 percent recovered content. European testing shows that "3-layer" PVC pipe, which has a layer of recycled PVC between two virgin PVC layers, performs similarly to virgin PVC pipe. But it wasn't until 1994 that ASTM issued its first provisional standard for the use of recycled PVC in sewer pipes. It took about two years for the ASTM to issue standards on recycled PVC in pipes, which is a short time for the ASTM.

Today, there are two provisional recycled PVC standards, one called "PS 1," for smaller diameter pipes, and another called "PS 8," for larger diameter pipes. These standards allow for the use of recycled materials and go into great detail regarding how to make PVC pipes with recycled content. PS 1 requires a *minimum* of 5 percent recycled content. The 5 percent minimum isn't for technical considerations, but simply because some entities, like governments, have special policies on buying recycled materials. If a supplier says that his pipe complies with ASTM standard PS 1, the buyer wants to be sure that the supplier didn't just put 0.01 percent recycled material into the pipe and say it was "made with recycled material." So the 5 percent minimum is there to ensure that pipes containing recycled material really do contain it. Such a requirement may not in fact be necessary; if a purchaser really wants to know recycled content, he'll get the exact percentage from the supplier, whether or not there's a 5 percent requirement. Conversely, if the supplier isn't going to divulge percentages, then if the buyer wants, say, 40 percent recycled content, a 5 percent minimum won't guarantee that the 40 percent is there. This is a minor point; at present, ASTM standards don't cover any PVC pipe with more than 0 percent but less than 5 percent recycled content, but that's not a lot of pipe.

ASTM specifications for corrugated HDPE pipesF 405 and F 667don't specifically exclude recycled materials, but whether they allow them is uncertain. The materials allowed in standard F 405 have to "conform with the requirements of Grade P14 Class C, Grade P23 Class C, Grade P33 Class C, or Grade P34 Class C, as defined and described in Specification D 1248." F 667 requires that the compounds used conform with certain requirements of D 3350. So what about D 1248 and D 3350 D 1248 and D 3350 set forth a whole set of standard specifications related to polyethylene. These standards don't actually *prohibit* recycled material, but they may as well. When buying virgin HDPE, one has it made to certain specifications. When obtaining recycled HDPE, it may or may not be up to spec, but one would have to test it to find out. So certifying that recycled HDPE complies with D 1248 or D 3350 requires a series of tests that pipe manufacturers need not pay for if they use virgin materials.

The relevant AASHTO standardsM 252 and M 294are more explicit. Both M 252 and M 294 *explicitly mandate* virgin polyethylene. ASTM F 405 and F 667, and AASHTO M 252 and M 294, also allow "reworked material," but limit it to material "generated from the manufacturer's own production."

The pipe specifications predate the push for using recycled materials, and the relevant ASTM committee has been in a seven-year deadlock over HDPE pipe standards. Decisions in the ASTM typically require a supermajority to passmany require a two-thirds majorityso delaying is easy. The committee contains representatives from the concrete, steel, and PVC pipe industries, all of whom would lose money if recycled HDPE pipe gained a foothold in the drainage pipe market. It has been charged that the concrete, steel, and PVC pipe industries are being deliberately obstructionist, not only toward recycled HDPE pipe, but toward HDPE pipe of any kindeven F 667, one of the standards for virgin HDPE pipe, was almost voted down by the committee when it came up for renewal (some suspect for economic reasons). According to one participant in the recycled HDPE drainage pipe standard-making process, the concrete and steel factions have sat on the sidelines so far; the debate has been mainly between the different plastics factions:

- PVC pipe makers who want to keep their edge over HDPE;
    - Companies making high-pressure (and higher-price) HDPE pipe grades, who want to see these grades required;
    - Independent corrugated-pipe makers, who already use blends of virgin and post-consumer recycled material in agricultural and highway drainage pipe, who want to keep using these cheaper raw materials.

2. Put That in Your Pipe and Extrude it

In certain cases, the quality of post-consumer HDPE can be better than that of some types of virgin HDPE. Virgin HDPE is sold in "prime" and "wide-spec" (or "off-spec") varieties. Prime resins are more expensive than off-spec resins, and pipe makers usually use off-spec resins to save money. There's less variability in prime resin, but for gravity pipes, a little variability isn't much of a problem. Recycled HDPE is less expensive than even off-spec virgin HDPE; some manufacturers can save about 10–15¢/lb. by using recycled HDPE (at about 31¢/lb.) instead of off-spec virgin HDPE (at about 45¢/lb.). And recycled HDPE is sometimes of higher quality because it's made of products which were high-quality to begin with. The recycled HDPE that pipe makers use can come from recycled milk bottles, which are FDA-approved, or from detergent bottles; these products are consistent in quality, though they may require additives to lengthen their lives. Other scrap sources that pipe makers use, including smooth wall polyester pipe leftovers, are superior to most post-consumer scrap and require less "refurbishment." Manufacturers can be fairly confident of the characteristics of those sources.

Upcoming AASHTO standards are expected to require that pipes be made out of plastics that are both HDB (hydrostatic design basis) ratedthat is, pressure-gradeand ESCRenvironmental stress-crack rated. AASHTO standards M 252 and M 294 already require some environmental stress crack resistance, and this requirement is expected to be tightened in the future. HDB and ESC ratings are nebulous terms in the pipe industry; it's not well-known how cracks in pipes develop. Do pipes crack because of outside pressure ("environmental stress cracks") Or do they crack because of stresses resulting from the bending of the plastic when it was first formed Or do they crack because the composition of the pipe changed over timebecause, say, some chemicals leached out of the plastic over time as the pipe was exposed to some detergent This isn't known for sure. Some research indicates that there's no inherent different between environmental stress cracks and any other kinds of cracks, so it's not always clear what "environmental stress crack rating" actually is. In any case, what is clear is that the definitions of pressure-rated resins and ESCR resins are politically charged. Different industries are interested in having the type of pipe that *they* make written into the standard.

Some manufacturers and researchers say that there are elements in ASTM trying to require that corrugated HDPE pipe be made out of pressure-rated resins. The resin companies dispute this. Says Stanley Mruk of the Plastics Pipe Institute: "Neither PPI nor any resin interest known to me has ever pushed for the use of stress-rated materials for non-pressure drain pipe.... A little localized crack usually isn't a problem. It is for this reason that most of us agree that [polyethylene] drain pipe need not be made of the same highly crack-resistant materials as are used for gas pipe. However, to ensure that the crack, if it develops, stays localized (continuing crack growth could result in structural failure of the pipe), most of us also agree that the materials used for drain piping must have a minimum measure of long-term crack resistance. How much crack resistance, and how to define it, are the crux of the issue regarding the new ASTM standard."

If pressure-rated resins ever do become required, then the pipes will cost more (twice as much, by one estimate) and use more plastic. Also, it will be a lot harder to make the pipes out of recycled plastic, since recycled plastic isn't widely available in pressure-rated grades. Pipe users, in this case, will be more likely to use, say, virgin PVC pipe, smooth-walled heavy duty (virgin) polyethylene, or steel. This requirement may be necessary for pressure pipes, like gas pipes, where internal pressures are high and small cracks will spread and make the pipe fail. Pressure pipes are under "hoop tension," and like an inflated balloon, will develop a crack at their weakest point and fail completely. But gravity pipes, like drainage pipeswhere the water is driven not by internal pressure but by gravityare different. They're under "hoop compression"; nothing's trying to make them bigger, but the soil around the pipe is trying to make them smaller. It would be inappropriate to build dams, which are under compression, from the same material as suspension bridges, which are under tension. Since pressure-rated resins are designed to withstand tension and not compression, they would actually perform worse than non-pressure-rated resins that are used in gravity pipes.

All of this political squabbling doesn't mean that the ASTM and AASHTO aren't going anywhere. On the contrary, the existence of ASTM PVC provisional standards demonstrates that progress can be made. Recently, a provisional HDPE standard has been drawn up as well. Ultimately, there will probably be two permanent standardsone for small pipes (up to 6 inches in diameter), and another for large pipes in *temporary* applications. Large recycled HDPE pipes may not get a standard for permanent applications for a whilenot for technical reasons, but because this would encroach a bit too much on their competitors' territory. Temporary applications seem to be acceptable for recycled HDPE (both technically and politically); other standard pipe materials are more expensive anyway. And even temporary applications, like the slope drainage pipes that highway departments use while building overpasseshave the potential to use millions of feet of pipe.

3. Piping Down the Valleys Wild

Not all corrugated HDPE pipe production is bound by the ASTM standards. Some corrugated HDPE pipe makers use recycled materials even when ASTM standards apply, because it saves money. Some of the time, the buyers of corrugated pipestate governments, for exampleknow that the pipe has recycled content and doesn't meet ASTM standards, but they're satisfied that it performs well. By some accounts, this rule-bending is common, though it would be easier for small companies, since large pipe manufacturers are under more rigorous scrutiny. Most of the use of recycled material, though, is legitimate and occurs when ASTM standards don't apply. One company, for instance, has to follow ASTM standards in over 50 percent of its pipes, but in the non-ASTM pipes, uses about 25 percent recycled HDPE, with the level of recycled HDPE varying according to HDPE prices. Another manufacturer makes 20 percent of his pipes out of 40 to 50 percent recycled content. Yet another manufacturer makes 4-inch diameter pipes either out of 100 percent virgin material or out of 100 percent recycled HDPE, depending on whether or not he has to abide by ASTM standards. Half of his pipe150,000 feet, or 50,000 pounds of HDPE, is virgin, and another 150,000 feet or 50,000 pounds is recycled. The amount of recycled material one can use depends on one's manufacturing methods. Manufacturers who make pipes out of 100 percent recycled content use different machines and take their recycled material in different forms than those who can only use 25 percent or 40 to 50 percent. About 25 to 50 percent seems to be a realistic estimate for how much recycled content could be used in corrugated HDPE pipe if it were allowed, though the EPA has endorsed the 100 percent figure.

As a whole, the corrugated HDPE pipe industry makes about 500 million poundsof pipe every year. How much of that is recycled content Estimates vary. Some say the number is at least 50 million pounds, and can be as high as 100 million pounds if we take "under-the-table" recycled content use into account. Others suggest lower estimates, on the order of 25 million pounds. These are all unofficial, eyeballing estimates. According to another estimate, only about 5 percent, or 25 million pounds, has any recycled HDPE at all, and very little of that has more than 50 percent recycled content. So less than 12.5 million pounds of recycled HDPE are now being used in pipe. If the other 95 percent of pipe production could be made with 25 to 50 percent recycled content, then recycled HDPE use could increase by 95 percent of 25-50 percent of 500 million pounds, or 119 to 237 million pounds per year. (Estimates of the possible increase would be lower if we use the other, higher estimates of current usage. These numbers, of course, would be two to four times greater if pipes were made of 100 percent recycled content.) Pipe manufacturers, who now have to maintain two separate inventories, one for ASTM pipe and another for non-ASTM pipe, would be happy to only keep one inventory and would start using recycled content across the board, where appropriate. By one estimate, if ASTM adopted a standard, recycled HDPE use would go up by 75 to 100 million pounds in the first year. Also, if HDPE pipe becomes less expensive because it's being made with recycled content, it may even replace concrete or steel pipes in certain applications. So the use of recycled HDPE could go up even more. And this is not even considering trends in the HDPE pipe industry, which is expected to produce 750 million pounds of pipe by the turn of the century. Since 1990, the use of polyethylene pipe by transportation departments has increased by 40 percent per year. This means that 5.3 times more polyethylene pipe is being used in the transportation industry today than five years ago. Transportation uses are now about 20 to 25 percent of total HDPE pipe production.

As for PVC, the domestic market for PVC sewer pipes is 300 million pounds a year. The inner layer of the pipes, which is the only part that contains recycled material, accounts for about 80 to 85 percent of the cross-sectional volume of the pipes. And the amount of recycled material in the inner layer can vary from about 10 percent (when using blister pack) to 100 percent (when using house siding). This is a big range, and it's difficult to say what the average recycled PVC usage will be, nationwide. But as a very rough estimate, this means that as much as 25 to 255 million pounds of recycled PVC could conceivably be used in sewer pipes. And only 14 million pounds of post-consumer PVC were recovered in 1994. So this market alone could potentially absorb a large chunk of post-consumer PVC.

To get around the ASTM standard problem, the EPA has suggested "that procuring agencies evaluate the applicable ASTM standards and specifications which pertain to pipe applications to determine whether those standards and specifications prohibit the use of recovered resins. If so, EPA encourages procuring agencies to purchase pipe that is certified to meet the applicable ASTM performance requirements, in lieu of pipe that is ‘ASTM approved.' EPA recommends that procuring agencies review their own construction specifications and revise them as appropriate to reference only the technical provisions of the applicable ASTM standards so as not to preclude pipe containing recovered materials."

Some governments have already set up their own specifications. For instance, before the provisional recycled PVC standard was established, the County of San Diego had already made up procurement guidelines (with performance standards) for recycled PVC pipe. Moreover, the San Diego guidelines relied heavily on different ASTM standards:

> *"The County prefers that the PVC piping material contain recycled PVC material. Exception is allowed for piping and fittings sizes not available in the specified size with recycled content or unavailable supplies to meet the project schedule. PVC pipe having recycle[d] content shall meet the following requirements: (PVC pipe having recycled content is available from PWPipe, Riverside County)*

- *PVC Pipe shall be coextruded per the terminology ‘coextruded pipe,' ASTM F-891, Coextruded PVC Plastic Pipe.*
- *PVC Pipe shall meet Dimensions and Tolerances (IPS Schedule 40 Series), Pipe Flattening, and Impact Strength requirements of ASTM F-891.*
- *The inner layer shall have recycled PVC content and shall have a D-4396 Cell Classification of 11432."*

Naturally, there's a difference between, on the one hand, *removing* barriers and using performance specifications, and, on the other hand, *mandating* the use of specific materials, à la San Diego. The former is desirable; the latter may not be. Governmentsor, indeed, anyonethat buy pipes should want pipes that perform in a certain way. Recycled plastic may or may not perform worse than virgin plastic, but that shouldn't be the issue. If the standards are performance standards, that question will take care of itself, as materials that live up to the standard are accepted and materials that don't are rejected. What the San Diego specifications show us, though, is that governments can use existing standards to talk about recycled pipe, even if no special standards have been written.

C. Electrical Boxes

Inside a wall, behind a light switch, is a plastic box into which all of the wires go that are connected to that switch. This box is called an "electrical box" or a "handy box." Before an electrical box can be used in a building, it has to conform to the applicable building code. Building codes have to abide by the requirements in the National Electrical Code, which has been adopted by the National Fire Protection Association. The National Electrical Code requires that electrical boxes be "listed," or approved, by a nationally recognized organization. The leading organization that sets standards for electrical equipment is Underwriters Laboratories (UL). UL doesn't allow recycled material to be used in electrical boxes unless they can make sure that the recycled content is "the same" as whatever virgin material is already being used.

What does "the same" mean UL looks at the "fingerprint," which is a set of test results, including an "infrared spectroscopy," a "thermal gravitational analysis," and a "differential scanning calorimeter." The problem is that recycled polyvinyl chloride (PVC), say, can come from many different manufacturers, each of which makes PVC in slightly different ways. There is no guarantee that the recycled content in an electrical box will have the same fingerprint as the virgin content.

If it were important, from a technical standpoint, to have identical virgin and recycled PVC in an electrical box, then UL's restrictions could be chalked up to prudence. But technically, an electrical box can perform perfectly even if it's made with different sorts of PVC. A performance standard, not a materials standard, should be used to separate the boxes that perform well from those that don't. Electrical boxes are attached to walls with nails, and if the hammer hits the box instead of the nail during installation, the box shouldn't break. This is an impact test, and electrical boxes already have to pass that. They also have to be able to handle low temperatures. UL knows that boxes made of 100 percent virgin PVC already satisfy all the applicable requirements. So when UL sees a box with recycled content, it demands that all the plastic be consistentin other words, that the recycled PVC have the same composition as the virgin PVC. If the plastic is consistent, then obviously, it satisfies every requirement that a virgin PVC box does.

Equally obvious is that an *inconsistent* box might also pass the tests. Just because consistent boxes will pass the tests doesn't mean that they're the only ones that will pass the tests. But because UL's standard is a material standard, and not a performance standard, such boxes are precluded from consideration. In this case, material standards get in the way of innovative uses of recycled materials.

Recently, UL has allowed a wider range of variation between the fingerprints of the virgin material and the recycled material. But they're still using unofficial rules of thumb like a maximum regrind plastic content of 25 percent. "Regrind" is another term for "in-house scrap"a byproduct of the production process that hasn't touched the consumer. Anything with more regrind has to go through a full set of tests. UL also demands complete mandatory testing for anything with any post-consumer recycled plastic content at all. Also, manufacturers of electrical boxes with recycled content have to get UL approval for changes in the composition of their products; such approval can take half a year or more. The testing itself can take over a year and cost tens of thousands of dollars. Geon Company makes an electrical box called the MR200 out of nearly 100 percent recycled PVC; its testing took over a year. The long-term heat aging alone cost between $20,000 and $30,000, and the total cost was over $30,000. Geon is a large company, but small producers can't afford such expensive testing. And even for large firms, this kind of expense can deter innovation with recyclables.

D. What to Do

ASTM, AASHTO, and UL are voluntary organizations. No one should censor them. Indeed, they serve a useful purpose in working out industry standards. The problem isn't that discriminatory standards sometimes exist. Rather, the problem is that *governments sometimes mandate* adherence to these standards, in effect codifying them and making any changes difficult.

The overriding philosophy in the public sector is not to take risks. As Bill Eggers and John O'Leary put it, "Mistakes are embarrassing.... The public-sector environment, where every mistake gets jumped on and excellence is ignored, discourages change." Innovations like using plastic lumber, recycled HDPE drainage pipes, or other products with recycled content, have been perceived to involve risk; when given the choice, many governments choose the path of least risk by falling back on established norms like the ones from the ASTM.

Therefore, getting governments to bypass the ASTM process when it makes sense can involve the very difficult task of getting governments to adopt a more entrepreneurial, risk-taking attitude toward life. Figuring out how to do this is way beyond the scope of this paper. But it's a necessary step.

III. BUILDING CODES, GOVERNMENT CONSTRUCTION STANDARDS, AND OTHER RED TAPE

A. Construction Materials

1.General Regulatory Hassles

Recyclers of construction materials have to deal with restrictive ASTM standards. Some products, like crushed brick, which doesn't meet any ASTM standard, are barred from virtually all public works. Grasselli Point Industries of Linden, N.J., reports that much of the material that comes to its plant won't pass muster for concrete aggregate, or even dry base materialthough it is used in certain private-sector construction jobs, like construction and reconstruction of shopping mall parking lots.

Construction material recyclers also come up against other regulatory barriers. The permitting process for Grasselli's crushed brick business in the early 1990s, for instance, took two years. The company had to get nine permits from federal, state, and local governments, go through many public hearings, and spend $275,000 in fees for lawyers, engineers, soil investigation and permits. Before Grasselli could set up its brick crusher on the site of an old Du Pont chemical plant, New Jersey's Department of Environmental Protection required that a six-inch layer of crushed stone be placed over the eight acres where the crushing plant and stockpiles would be located. The company had to spend $200,000 on this before the plant even opened, even though Du Pont had already spent $7.5 million to remediate the site. These sorts of problems aren't unique to recyclers, but they're added onto other problems like building code restrictions.

2. The Building Code System

Many building codes were written before widespread recycling. Either they prohibit or limit the use of recycled materials, or they require testing that becomes so expensive that potential purchasers are scared off and use conventional materials. The state of California, for instance, flatly prohibits the reuse of construction "debris" in "structural" applications. The problem is that the definition of "structural" is broad. Anything that helps hold a wall up is structuraleven if that wall isn't load-bearing. Most walls in houses aren't exterior walls, nor are they main interior walls; they're just partitions to divide rooms from one another. Even in non-structural applications, the use of recycled materials is limited. Some building codes reportedly limit the amount of recycled plastic that can be used in building materials to 25 or 30 percent.

One challenge for people who build with recycled materials is changing the code book to allow the use of recycled materials. Making new construction materials out of recycled material is difficult because of expensive building code testing requirements. This affects recycled manufacturers disproportionately because the recycled construction material industry is new, and most of its products are innovative. How easy it is to introduce a new product depends on which building codes are being enforced in a particular area. In general, building codes are set up by four national organizationsthe International Congress of Building Officials (ICBO), Building Officials & Code Administrators International (BOCA), the Southern Building Code Congress International (SBCCI), and ASTM. Generally speaking, each of these organizations has jurisdiction over a different geographical area; in New York state, for instance, the building codes are usually set by BOCA. The geographical breakdown is only by custom, though; in reality, the codes vary slightly from state to state and even from locality to locality.

ThermaLock Products of Buffalo, N.Y., makes the ThermaLock Block, a building block made partially of recycled plastic. The ThermaLock Block, which consists of a thick layer of molded plastic sandwiched vertically between two layers of concrete, can take the place of normal concrete blocks in construction projects. The Block is designed to make walls five times more resistant to heat loss than other building blocks. ThermaLock Products has been going through a battery of testing programs for 2½ years. Doing the testing for one of the four building code organizations doesn't ensure that these results will be accepted by the other three. For example, if one organization requires testing of three samples, one could run the tests on the three samples only to find out that another organization requires five samples. Conceivably, one could make sure that the results will be accepted by everyone by using the most stringent testing method. But that's more expensivefive samples cost 40 percent more to test than three. Usually, small firms that are just starting out only try to get their product accepted in their own area. ThermaLock has spent over $250,000, and expects to spend another $200,000, on the approval process. The block still hasn't been accepted by the four code bodies, and won't be for another year. A single block is worth under $2, so they have to sell over 225,000 blocks just to recoup the money they spent on testing. The process is expensive and time-consuming, and the end isn't in sight yet. Five billion concrete blocks are produced in the United States each year, and ThermaLock hopes to one day capture 2 percent of this market.

This is typical of the travails of manufacturers of innovative building products. According to Tom Savoy of the Association of Foam Packaging Recyclers, waste polystyrene isn't being recycled into flame-retardant construction products because of building code restrictions. Or take, for instance, Gridcore International of Los Angeles, Calif., which makes building panels out of 100 percent recycled fibers, primarily cardboard. Gridcore's panels have the approximate bending strength of particle board, but with one-third of the weight. The panels are used in stage sets, furniture, exhibits at trade shows, and similar applications where lightweight panels are needed. But they're not being used in construction because of code certification problems. The company estimates that it will take a year and $500,000 to $1 million to become certified for even the most basic interior construction applications. It knows that its products are strong, non-toxic, and have a Class C fire rating (like particle board and plywood)because the products have been tested by independent labsbut the certifying organizations will only accept testing results from their own labs and according to their own testing procedures. And if one's materials don't conform to the building code, they won't be used by architects and builders, because of liability fears.

How much of a market does this involve In the United States, 34.5 billion sq.ft. of three-quarter-inch-thick wood panel products are produced each year. This includes plywood, particle board, oriented strand board, medium density fiberboard, and masonite. Three-quarters of thator about 26 billion sq.ft.is used in housing and construction. If Gridcore's product were approved for use in construction, it could be used for interior walls, floors, and ceilings25 percent of the entire construction panel market, or about 6.5 billion sq.ft. Later, if they develop moisture-resistant coatings, they'll be able to use their panels in roof sheeting and external walls, which will increase their potential market considerably.

In the meantime, Gridcore is going into the manufactured house market. Manufactured housing takes even longer to be approved; Gridcore estimates that such certification would cost $2 million to $4 million. Lacking such certification, Gridcore expects to build houses in places like South Africa, Vietnam, Malaysia, the Philippines, and South and Central America. These are all poor countries, where people need inexpensive products that are quick to assemble and flexible in design. Because of the costs of certification, though, the United States will be denied such products, except in certain exempted areas, like migrant farmworker housing or nonresidential buildings.

Or consider Rastra, a European firm that makes a building block out of 86 percent recycled polystyrene mixed with cement. Concrete is one of the best materials to build out of, but it's usually too expensive for homes; the Rastra block uses concrete efficiently enough that it can competeboth economically and physicallywith wood. It's also termite-proof and fire-proofin a UL study, a 1,820^{o}-flame was aimed at one side of a 10-inch block for two hours without raising the temperature of the other side. And so far, it's earthquake-proof, though more studies are being done on the subject. There's enough of a building market that this product style could eventually use 100 percent of the U.S. recycled polystyrene market. A small, 1,000 sq.ft. house requires about 100 blocks. Each block is 10"×15"×120", or 10.4 cu.ft. Of that, 3.3 cu.ft. is a cavity, and 14 percent of the rest is cement. That leaves 6.1 cu.ft. of polystyrene, so a small house has 610 cu.ft. of polystyrene. Low-income advocates were early Rastra supporters, and Habitat for Humanity builds some homes out of the material. The County of Ventura Solid Waste Management Department has publicly praised and promoted the material"we can expect to see more recycled-content products being developed which might be very different from what we're used to, but hopefully, as with Rastra, these products can offer benefits which are also beyond what we're used to." Other local government agencies, though, don't agree. The manufacturer has spent over half a million dollars getting the product approved, even though it's been used for 25 years in Europe. Building code organizations don't accept the results of testing done by other labs.

It is possible to get a product on the market without the approval of building codes. But to do that, you have to be lucky enough to find someone who'll specify your product into the building, sell the idea to the owner of the building, and get a structural engineer to work with you to engineer the building so it stands up. On the other hand, brick manufacturers (or makers of other approved products) don't have to get involved in the building process at all, since their products are already approved.

3. Municipal Building Codes

Building codes are enforced on the local level; this means that local officials can tighten the requirements, but they can't loosen them. Most cities stick to the code set up by the organization in their area, but all cities can have more stringent codes, and many do. For instance, in certain small cities, like Amherst, N.Y., and in major metropolitan areas, like New York City, Los Angeles, and Chicago, there are additional building codes at the municipal level that supplement the basic codes. In cases where products are uncertified, the building codes give local building officials the power to approve or not approve a product. Some building officials, for instance in the Midwest, are tolerant of innovative houses; Bob Glassco of Pyramod International, which builds houses out of rice straw panels, notes that when he was building a house for writer Karl Hess in a rural county of West Virginia, the local building official said, "That's interesting; tell me how it turns out."

Larger building departments have more engineering savvy, but are weighed down with more regulations; California building codes (which are statewide) are fairly prohibitive. On the other hand, smaller building departments have more discretion but tend to be more resistant to new products, demand more paperwork before approving something different, and in general set up roadblocks. Many building officials rely on the Uniform Building Code book, which goes into the size, weight, and thickness of everything that goes into a house. One contractor, for instance, had an ICBO certification that was up for renewal after a certain time. When the time arrived to renew the certification, the ICBO was reworking its classification system to accommodate new sorts of building materials. As a result, there was a delay between the expiration of the old certification and the new one. Just because it had expired, though, didn't mean that the old certification was worthless; it was, after all, based on actual testing results that the ICBO had approved. Some building officials look at such a certification and honor it; others don't because the date has expired.

In some of these cities, manufacturers have to pay an annual user fee to be approved by the municipal building code. In New York City, the fee is about $800 per year, and in other cities, the fees are about $500 to $1,000. This may not be a lot, but the municipal authorities also require manufacturers to submit a lot of paperwork every year with their application. The whole process costs thousands of dollars. More than half of the buildings in major metropolitan areas require this special approval by the local building codes, so not having local approval limits one's market dramatically.

Casas Royale, a San Diego firm, makes walls out of "compositecrete," which is composed of lightweight concrete, polymer binding agents and recycled polystyrene, sawdust, cardboard, plastic, paper and porcelain. Even though the compositecrete has passed all the necessary American health and safety testsincluding flame-testing and testing for toxic fumesuse of the material is limited in the United States. Recycled building materials are hard to use in new construction on this side of the border. Local governments are suspicious of the material because it's new. The city of San Diego demands new tests, which can cost from $5,000 to $7,000, each time the composition of the material changeswhich can happen quite often, since the company uses whatever materials are handy. This is a lot of money; in one area of San Diego, Casas Royale was building houses for $22,000 (where a house built out of standard materials would have cost $35,000), and the regulatory fees would already have been $18,000 for either type of house. So the additional cost of testing can be approximately 15 percent of the total cost of the house.

The success of recycled materials depends, in large part, on their price advantage over virgin materials, and the increased cost of regulation can whittle away at such a price advantage. In some cases, the cost of using recycled materials can be prohibitive. Determining the composition of the material to the city government's satisfaction also requires elaborate sorting and becomes, in the words of Hugh Stone of Casas Royale, "an inventory kind of nightmare." The people at Casas Royale are liable for 10 years if their material fails, so they're already reluctant to build houses with inferior products. This kind of regulation, moreover, is unnecessary, since the recycled materials aren't used for structural purposes. The load is borne by a steel perimeter, so knowing whether the compositecrete contains polystyrene or paper is of limited value.

In St. Charles County, Missouri, Union Electric's Sioux power plant has recently built a 50-acre "ash" pond, to store the ash that remains after coal is burned. This plastic-lined pond will fill up in 20 to 25 years, at which point Union Electric will build a new one. The ash can be compressed into bricks, and the Electric Power Research Institute, as an experiment, is building some homes in Pittsburgh with these bricks. Local building codes don't allow the use of such bricks in areas closer to Missouri. Robert Sauber, managing director of North American Cellular Concrete, estimates that with coal-burning power plants generating over 70 million tons of fly ash per year, and with utilities looking for a way to recycle it, U.S. market potential could result in the start-up of 25 manufacturing plants for fly ash-based concrete blocks within the next decade.

By some estimates, the entire process of marketing a new productfrom the day one introduces it to the day it gets accepted and starts making moneycan last 10 years. This is longer than most small businesses can last. The time involved is a serious impediment to the development of new building technologies, particularly building technologies involving recycled materials. If building codes and local governments were reasonable, the process could be shortened by 3 to 4 yearsbecause the regulations and testing requirements would be less onerous, but also because learning the approval process wouldn't take as long. In some cases, learning the process can take longer than the process itself.

4. A Possible Fix

Building officials' attitudes aside, one of the main problems is that building codes mandate *materials*, not *performance*. Pyramod International's rice straw panels are viewed dubiously in California because they're made of rice straw; a recent law allows buildings to be built out of bales of rice straw, but this law doesn't cover rice straw panels. In general, building officials want a material to be approved by the ICBO, which relies on ASTM standards, which are written for particular materials. ASTM standards go into immense detail for known materialsthe plywood standards go into how dense the grain should be and how frequently knots can occurbut obviously, the ASTM has no specifications for a material they haven't heard of before. When one develops a new building material, one has to take it to the ASTM, get it approved, show the results to the ICBO, get them to approve it, and finally show that certification to a building official. This is a tedious and expensive process, and as long as this is the case, building codes will inhibit innovation.

Building codes should be reformed to rely as much as possible on performance standards, and not on materials standards. When building codes simply prohibit the use of recycled materials, they prevent a weighing of trade-offs between different social goods. Recycled materials can be less expensive than virgin materials, so restrictions on the use of recycled materials can hinder the growth of affordable housing. Even though there have been no studies showing that recycled building materials perform worse than new ones, sometimes it makes intuitive sense to be wary of using, say, recycled lumber. Two-by-fours may have split while they were being taken out of their previous use, and those splits may not be noticeable at first glance. If one removes a nail from a board and puts another nail into that board, the new nail may not hold as well.

But these caveats don't mean that one should never use such materials. There is, for instance, the advantage of price. Until the recent fall in the value of the peso, most of Casas Royale's recycled construction was occurring in Mexico. A group called Building Materials Recycling, whose motto was"Anyone in San Diego who has usable building materialswe'll take them off your truck and set them on pallets," is dedicated to keeping used building materials out of local landfills by distributing them in Mexico, where they're easier to use. Many of Building Materials Recycling's materials are donated for low-income housing. However U.S. building codes may treat these materials, they're often better than the current alternatives in low-income areas of Mexico. The situation in Mexico makes the trade-offs involved quite clear. Affordable housing is a scarce commodity, and for many of the poorest people, overregulation could make the difference between having a home and not having a home. If building codes are too restrictive, poor people are limited in their choices. Either they get a home that complies with the restrictive building codes, or they get no home at all. Denying them the opportunity to make the necessary trade-offs and accept a home made of nontraditional materials is neither compassionate nor just. It may make sense to consider recycled materials in the United States as wellfor instance, in buildings that people don't live in, like barns or garages. Moreover, as indicated earlier, often materials made from recycled products perform as well as or even better than traditional materials.

Occasionally, legislation tries to address this problem. In 1991, the Illinois legislature considered a bill to allow use of recycled materials. "Whenever virgin plastic is specified or required under any State or local building code," the bill said, "the code shall be deemed to allow the substitution of a recycled plastic of the same type, provided that the recycled plastic meets the same qualitative standards as the specified virgin plastic. The Department of Energy and Natural Resources may, upon its own motion or upon request, examine any recycled plastic building material available in this State and certify the virgin plastic materials for which it may be substituted." And, because even if there were no building codes, builders might still refuse to use recycled materials for fear of liability: "No person shall be liable in this State for damages arising out of the substitution of a recycled plastic building material for a virgin plastic material, provided that (i) the Department of Energy and Natural Resources has certified the recycled plastic material as a substitute for that virgin plastic material, and (ii) the substitution was not expressly prohibited by the owner, architect or other person responsible for the selection of the building material."

This Illinois bill wasn't perfect. For instance, it was limited to plastics, and only allowed the substitution of plastic for the *same* plastic. So if the bill had been adopted, recycled polystyrene could only replace virgin polystyrene. Such an approach would do nothing, say, for the Rastra block or the ThermaLock Block, which replace concrete or bricks with materials containing polystyrene. It also wouldn't do anything for construction debris recyclers. In fact, it's quite narrow. And it relies on a government agency to certify materials one by one for particular uses. A better approach would be to rewrite the building codes so that they embody clear and objective performance standards, and then accept testing results that follow certain approved protocols. All the same, the Illinois bill would have been better than nothing. It was rejected by the Illinois House Energy and Environment Committee in March 1991.

B. Highway Construction

Method specifications also exist in state transportation departments and on the local level, creating problems for road builders. The following sections discuss hindrances to the uses of different materials in highway construction. Some are restrictions on what process can be used. Others are unintended side effects of legislation that was originally intended to increase the use of recycled materials. And others are the result of drawing up highway specifications tied to individual materials, not performance specifications.

1. ISTEA and Scrap Tires

In December of 1991, Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA, pronounced "iced tea"), which reauthorized the federal highway program. Part of ISTEA mandated that states use rubber-modified asphalt (RMA) in federally funded roads in certain prescribed proportionsin 1994, 5 percent of asphalt pavement financed by federal highway funds has to contain at least 20 lbs. of rubber per ton of asphalt (or 300 lbs. of rubber per ton of binder used as a spray applied membrane); the percentage rises to 10 percent in 1995, 15 percent in 1996, and 20 percent in 1997 and each year after that. If the mandate wasn't met, noncompliant states would lose 5, 10, 15, or 20 percent of their federal highway funding. Each year, 500 million tons of asphaltic concrete are laid, and 40 percent of those are in federally assisted highway projects. This means that 200 million tons are subject to ISTEA, and so the RMA numbers come out to be 100,000 tons of rubber in 1994 (17 million scrap tire equivalents) and 400,000 tons in 1997 (68 million scrap tire equivalents). One scrap tire from a passenger car produces between 10 and 12 pounds of crumb rubber. At present, about 5 million scrap tires are used each year in RMA applications.

Before ISTEA, the FHWA considered RMA to be experimental; this was a significant barrier to the use of scrap tire rubber in roads at the state and federal levels. But ISTEA itself had its perverse effects. Before, state departments of transportation were being discouraged from using RMA; now, they were being forced to use RMA or risk losing their federal highway funds.

- Scrap tire rubber was originally used in asphalt to enhance the asphalt's propertiesnot to alleviate real or perceived waste disposal problems. The rubber mandate, though, was designed with tire disposal in mindand so the percentages in ISTEA were more ambitious than the current state of practical technology. Even California and Arizona, the leading states in the nation in the use of rubber-modified asphalt, would have had trouble meeting the percentages of the mandate, which were picked out of thin air.
- The rubber mandate was inflexible; states had to use their rubber in hot mix asphalt pavement, but couldn't count rubber used in road and shoulder fill, sound and crash barriers, or other civil engineering applications toward the ISTEA requirement. Some critics suggested that a more appropriate way to deal with the scrap tire problem would be under the Resource Conservation and Recovery Act, by which each state would be able to develop its own scrap tire management plan.
- The federal highway funding sanctions were an all-or-nothing deal. In a year where 20 percent of roads had to contain recycled rubber, no credit was given for achieving 19.9 percent.
- The rubber mandate had the unintended effect of making some agencies consider switching from asphalt pavements to portland cement concrete pavements, just to avoid the mandate.
- Scrap tires are not uniformly available in all states.

The rubber mandate was also criticized for being an "unfunded mandate," since it mandated that states make particular costly investments in their highways, without funding these investments. There was the possibility that states would be able to pass much of the higher cost on to the federal governmentwhich normally pays 85 percent of the costs of building, maintaining, and repairing federal roads. But that would have left the states with an increase in the remaining 15 percentand the fear that the federal government wouldn't increase its funding, leading to a sharp reduction in the purchasing power of state DOTs. The average cost of rubberized asphalt is $48.35 per ton, as opposed to $29 to $37 per ton for conventional asphalt. The Pennsylvania DOT has estimated that the use of crumb rubber modifier would increase costs by 15 percent; ISTEA compliance costs would be $2.88 million in 1997. The Kansas DOT has estimated costs of $2 million in 1995 and $2.8 million in 1996. The Virginia DOT has estimated costs of more than $6 million annually. Governor Voinovich of Ohio estimated that with the additional cost of complying with the rubber mandate, Ohio could repave nearly 700 miles of rural highways and rehabilitate 137 aging bridges. And the U.S. DOT has estimated that complying with ISTEA could cost the states as much as $1 billion. (RMA can lengthen the life of a roadway, but whether it does or not, and the extent of the benefit, depends on the circumstances where it's used. The rubber mandate severely limited the discretion of highway departments to figure out whether, and when, to use RMA.)

As a result, most states begged for relief from the rubber mandate, and many state DOTs threatened to refuse to comply with the RMA mandateeven Arizona, which leads the country in use of RMA. Congress refused to give the FHWA the money to implement ISTEA in 1994 and 1995, and will likely do so in 1996. As a result, the FHWA announced that it wouldn't penalize anyone for not complying with the mandate; essentially, the rubber mandate has been on hold since ISTEA went into effect, and it's expected that it will continue to be on hold until its authority runs out. We're now in the third year of the ISTEA implementation prohibition. There is also talk of repealing the section of ISTEA entirely; Rep. Deborah Pryce (R-OH) introduced the Highway Mandates Repeal Act of 1995 in March 1995 for this very purpose, and other pending legislation that's likely to be enacted (including the National Highway System bill) also includes the repeal of the rubber mandate.

While the fire and health hazards of tire piles are real and well-known, the ISTEA rubber mandate may not have been the best way to deal with them. The FHWA is currently doing studies and tests to address the technical issues of recyclability, air emissions, and worker health and safety. The worker safety studies will be done with the National Institute of Occupational Safety and Health, and the FHWA's Strategic Highway

Research Program will also do some testing. The FHWA also has a separate, 60-month study involving several engineering schools and research institutions. And ASTM is developing criteria for testing RMA-related performance characteristics. The FHWA studies won't be done until 1996 at the earliest. If they turn out well, there may be an increase in the use of RMA. But by some estimates, the market for RMA has been pushed back five years because ISTEA has bred resentment toward RMA among state DOTs. Moreover, even if state DOTs went along with the rubber mandate, scrap tire recycling might still be set back; since the goals of the mandate don't coincide with what's feasible in road-building technology, the mandate will end up establishing false markets for scrap tires at the possible expense of other, more efficient uses.

2. Mineral and Industrial Wastes

Fly ash is a waste product from the production of electricity and coal, as well as from other incineration and furnace processes. Ground granulated blast furnace (GGBF) slag is a byproduct of the steel industry. Before the Clinton administration's Executive Order on recycled materials in October 1993, the EPA mandated that the government consider buying cement and concrete containing fly ash. Since the Executive Order, use of fly ash has become mandatory, both for the federal government and for state agencies that use federal money for construction. I use the term "mandatory" loosely, since there are still three reasons that the government can avoid using fly ash:

- if it's not available competitively within a reasonable time frame;
- if it's too expensive;
- if it doesn't meet appropriate performance standards for a particular application.

These exceptions leave a lot of room for the government to maneuver. The federal government doesn't mandate any specific amounts of fly ash, because they're allowing individual procurers to use the applicable standards from the ASTM, AASHTO, and the American Concrete Institute. Still, most states use fly ash.

The same Executive Order tells the EPA to also draw up a comprehensive procurement guideline for a number of other items, including GGBF slag for cement and concrete. Still, there hasn't been much change. As of 1994, only 12 state highway agencies had any experience at all with GGBF slag in cement or concreteDelaware, Florida, Illinois, Maryland, Massachusetts, New Hampshire, New York, Oregon, Pennsylvania, Texas, Virginia, and West Virginia.

Fly ash and GGBF slag are only two examples of mineral or industrial wastes. Appendix I, II, and III provide a more complete picture of mineral and industrial waste usage in roadways. Appendix II shows state highway agency research activities on uses for waste materials and by-products, while Appendix III shows actual usage. Usually, highway agencies do research on a material before using it, so ideally, all uses indicated in Appendix III should have corresponding research in Appendix II. But some of the usage in Appendix III is experimental or is being used for testing or demonstration purposes only. The moral of Appendix II and III is that there are a lot of empty boxeswaste materials which a state isn't using and which it hasn't done any research on. A lot of the time, this might just be because that waste material isn't available in the state; GGBF slag, for instance, doesn't grow on trees. But if the material were suitable for highway uses, it could always be imported from other states.

The problem isn't that highway agencies aren't using a lot of recycled materials; whether a material is suitable depends on site-specific information, the properties of the material in question, and the performance characteristics that the highway agency wants. Rather, the problem is that the specifications are wedded to particular materials and technologies.

The "materials and method specification" approach to highway construction has been standard since the mid-19th century. Under such a process, "the highway agency specifies the exact materials and procedures for the contractor to follow. These... specifications typically include material proportioning and mixing limits, and the proper procedures to follow for a job to be acceptable. Variability in material properties and construction techniques is generally ignored. As long as the contractor adheres to the prescribed methods, full pay can be expected." But this sort of specification has its pitfalls. It assumes that all of the instructions needed to perform the work satisfactorily can be reduced to written or graphic form. But this isn't always the case. In fact, everything depends on the skill and integrity of the contractor, the inspectors, and the engineers; even if method specifications are faithfully followed, they may not produce the right product.

More to the point for our purposes, though, method specifications impede innovation. With the increase in highway construction after World War II, and with the beginning of the Federal-Aid Interstate System in the 1950s, large companies specializing in highway construction began doing more work, and the knowledge required to build modern roads became more equally distributed between highway agencies and their contractors. As a result, innovations in construction methods became commonly initiated by the contractor. But method specifications were typically codified in written documents and often supported by attitudes not easily changed; they often lagged behind and sometimes even retarded advances in construction technology. As Darrell Harp, assistant commissioner of the New York Department of Transportation, put it:

> *What is the most devastating aspect of [materials and methods specifications] The contractor can't use his own initiative because he has little option when he is told precisely what he must do, what type of materials he must incorporate and exactly how it is to be put in place. Innovation is stymied. Another drawback is that the improvement of the product will be very slight and it is doubtful that you will see a reduction in overall cost. If we were to live forever with materials and methods specifications, I suppose we would still be driving around in Model "Ts."*

Materials and technologies change all the time. Desired performance characteristics, on the other handthat is, the desired relationship between vehicle weight and speed and such factors as smoothness, friction, and durabilityhave been more or less the same ever since the time of the Romans. Highway agencies should develop performance characteristics; once that is done, appropriate material usage will work itself out.

This is all well and good, but the trouble is that until recently, we didn't understand the relationship between the factors controlled during production and the performance and worth of the finished product. Without such understanding, a method specificationrelying, essentially, on what has worked in the pastis the only way to go. But there's also the danger that relying on method specifications will slow down the necessary movement toward developing the knowledge that will allow performance-related specifications to develop. The states are moving, more or less, in that direction, but many still have elements of a materials-based approach. For instance, a state could establish performance standards but supplement them with minimum or maximum use requirements for different materials, for instance, a minimum of 15 percent fly ash or a minimum of 25 percent slag. Or, a state could establish performance standards, with the requirement that all materials come from a certain approved list. In fact, though, if performance-related standards can be designed that express everything desirable about a roadway, all other requirements are superfluous.

Surprisingly, few agencies have developed performance-related specifications. According to a recent study by the Transportation Research Board's National Cooperative Highway Research Program, only the New Jersey DOT has actually developed true performance-related standards, which include the following characteristics:

- *End-result*Specifications based on measurable attributes or properties of the finished product, rather than on the processes used to produce the product;
- *Statistically based*Sampling plans and decision criteria that consider the variability inherent in the finished product and in the sampling and testing processes;
- *Performance-modeled*Specifications based on attributes related to the performance of the product through quantitative relationships, or models, that have been validated for the specific materials and climatic conditions anticipated;
- *Cost/performance optimized*Quality levels with sampling and testing procedures and frequencies, the combined costs of which are consistent with the criticality of the performance benefit sought;
- *Adjustable payment*Positive and/or negative pay adjustments (incentives and disincentives) which

reflect changes in the worth of the product resulting from departures in the level of acceptable quality.

And even New Jersey only uses performance-related specifications for portland cement concrete and portland cement concrete pavement. For many components of roadwaysfor instance, soils, subgrades, subbases, bases, and riding surfacesactual performance standards are still hard to come by. But it's still possible to develop performance-based specifications, which rely on fundamental engineering properties that predict performance, or performance-related specifications, which rely on materials and construction quality characteristics that correlate with those fundamental engineering properties. The NCHRP remarks that "while the research community involved in the development of [performance-related specifications] is well versed in both its theory and practice, awareness within the highway construction community at large seems quite low.... With the exception of the New Jersey DOT, [performance-related specification] development to date has been advanced almost exclusively by a small number of university and industry consultants. The risk in not broadening the base of participation in this work to include more of the agencies that will ultimately be responsible for its implementation is that the prototype specifications that are developed may not adequately reflect the needs and constraints of operating agencies."

Performance-related specifications should be adopted wherever possible. The only reason they haven't been developed already is that there hasn't been any pressure to develop them. Once these specifications are developed and adopted, the main barrier to the acceptance of recycled-content highways will be taken care of. If they perform as needed, a performance-related specification will vindicate them; those materials that don't perform as needed will still be rightly weeded out. According to the NCHRP, "There is a need for a national consensus among federal and state highway and environmental agency personnel regarding the beneficial reuse of non-hazardous waste materials or by-products. Such a consensus could eliminate the need to obtain solid waste permits for installations that are no threat to the environment." The NCHRP also notes inflexible procedures at the state level as a barrier to the use of recycled materials and recommends that such materials be considered in "local, county, or municipal construction projects, where traffic volumes are low, budgets are tight, and procedures are more flexible."

3. Miscellaneous Barriers

- In the Boulder, Colo., area, some of the best graveling area in the county has been turned into parks and open space land, importing new material from other areas (which may not be of the same consistency as local rocks) is expensive, and mining is restricted. But the city of Boulder only allows 10 percent recycled asphalt pavement in its roads (though it uses more in alleys, parking lots, and as shouldering material), and its county only allows up to 25 percent.
- Cyclean, an asphalt recycling company from Round Rock, Texas, had difficulty getting its recycled asphalt to be considered for use in state highways, because its "microwave method" didn't conform to long-established Caltrans method specifications. The Cyclean process has been used by the states of Texas, Georgia, Michigan, and Pennsylvania, and by the city of Los Angeles. In Los Angeles, using the Cyclean technology saved the city $1 million30 percent of what it was paying for virgin HMA materialand cut air pollution. Since the recycled asphalt contained 100 percent recycled asphalt contentmuch more than other methodsit kept 200,000 tons of asphalt and concrete out of local landfills and saved the mining of 180,000 tons of rock and 60,000 barrels of oil.
- Many highway agencies allow broken glass, or cullet, to be used as a substitute for aggregate in asphaltic concrete pavements. For example, the New Jersey DOT allows the substitution of up to 10 percent glass (by weight) for aggregate in asphalt base courses. In 1992, the department placed two sections of asphalt surface courses of about 0.3 miles each containing 10 percent glass. But why 10 percent The Clean Washington Center, in Seattle, Wash., conducted laboratory tests on glass cullet for compaction, durability, gradation, permeability, shear strength, specific gravity, thermal conductivity, and workability as a construction aggregate. According to the Clean Washington Center, base courses can have up to 15 percent cullet content, and subbases and embankments can have up to 30 percent without compromising road performance. Recycled glass can also be used in other public works contexts; in Thurston County, Washington, recycled glass has recently been accepted for use in pipe

beddingthe layer of pea gravel-sized rocks beneath pipes. But Thurston County is the only county in Washington state that uses it in major, nonexperimental projects.
- Various zoning barriers at the local level require that asphalt concrete and portland cement concrete recycling be done only at remote quarry sites rather than near road construction and rehabilitation projects.

C. How to Deal with the Red Tape

While many industries are barely recognizable with respect to how they were a century ago, the building and highway construction industries still behave much as they did back then.

The red tape problem is twofold. Part of the problem of local bureaucrats is their unpredictability. Potential innovators are loath to innovate if they don't know what standards their products will be judged under. In the construction industry, this is what keeps buildings built according to time-honored, and sometimes inefficient, methods.

But there's more to the problem. Even if government agencies were always predictableand they frequently are, since this is the principal strength of bureaucracyresource use might still be inefficient. What's important isn't just that government be predictable, but also that it predictably follow *desirable goals*. In this case, what are desirable goals The building construction and highway construction industries only exist for one reasonto provide the service that their customers want. When judging the regulations that control those industries, we should ask: Do these regulations lead to the construction of higher-quality (or lower-cost) buildings or roads

The key to achieving this is adopting *performance standards*. We certainly don't want to use recycled materials for their own sake, especially in areas like highway or building construction, where failure can actually kill people. Conservative building codes are important, but they should be based on performance, not materials. Adopt performance standards, and everything will fall into place. This may be easier said than done, though. Performance standards are often expensive to draw up, especially when we don't know all we would like to know about the relation between methods and performance. Sometimes, methods may be the best we can do. But in important industries where we spend enormous amountslike the construction industrythe benefits are often worth the effort.

IV. GOVERNMENT PROCUREMENT AGENCIES

A. Federal Bidding Requirements

Cities and states often don't deal with individuals; instead, they buy from contractors who submit bids on everything that the agency needs. For instance, if a city needs office supplies, it will buy from the contractor that offers the best price on the whole range of office supplies that it needs. If a recycled paper manufacturer offers a better deal on a certain grade of paper but doesn't make anything else, he is shut out of the purchasing process unless he can convince a contractor to carry his product. Even in those cases when a government agency deals with an individual company, the agency may require that the company be in-state or have an in-state branch, for example, or award price preferences to in-state companies. It may also require large amounts of paperwork from any company that wants to deal with the agency. Such rules are more difficult for small companies to meet, and recycled product manufacturers are disproportionately small firms.

Some manufacturers also have to overcome quirks of the competitive bidding process. When agencies specifically decide to buy a recycled product, they have to identify more than one producer of such products, or else the bidding can't be competitive. What if only one company makes such products The American Plastics Council reports that in 1991, only one company made quality recycled plastic shower and toilet partitionsand was automatically shut out of the competitive bidding process. Obviously, there were several makers of virgin plastic partitions, but because some agencies draw distinctions between recycled and virgin partitions, the recycled plastic partitions couldn't compete at all. Some of the blame can be placed on a process that artificially distinguishes between virgin and recycled plastic shower partitionsessentially, drawing distinctions based on industrial process and not on function. If *all* shower partitions could be bid on together, the problem would disappear.

Many governments only look at the purchase price of an item when buying products. This means that if a product made out of recycled material costs more but lasts longer or has lower maintenance costs than the corresponding virgin product, governments won't buy it, even if the long-term costs are lower. For instance, plastic lumber picnic tables and benches typically cost more than wooden ones, but they can have longer lifespans and lower maintenance costs. The same problem arises with pavements with rubber content; the bias toward low-bid projects (an understandable bias which was designed to curb corruption, inefficiency and mismanagement) dates back to the mid-19th century. Putting crumb rubber modified into a pavement is more expensive than conventional paving methods because of the labor involved to develop the crumb rubber, but the pavement's performance in a life-cycle cost analysis can be cost-effective. In Florida, for instance, pavements with ground tire rubber have been known to cost 10 percent more than conventional asphalt pavement, but last 20 percent longer than similar conventional pavements.

B. Post-consumer vs. Pre-consumer: A Counterproductive Distinction

"Pre-consumer" recycled material is plant scrap or other recycled materials that were not collected from consumer wastes. "Post-consumer" recycled material has been used as a consumer item before having been discarded and then made into something else. Many recycling laws distinguish between pre-consumer and post-consumer recycled material, and encourage post-consumer recycling. This distinction, in fact, is found in RCRA, which doesn't even consider pre-consumer material "recovered." According to RCRA, "recovered material" means "waste material and byproducts which have been recovered or diverted from solid waste, but such term does not include those materials and byproducts generated from, and commonly reused within, an original manufacturing process." In the specific case of paper, RCRA does allow for the use of pre-consumer material, but it emphasizes post-consumer materials.

But this distinction is an artificial one; unless they are recycled, both pre-consumer and post-consumer waste are discarded in landfills or incinerators, and much pre-consumer waste can't be recycled on site by the generator. Several categories of productssuch as newspapers, phone books, magazines, and cataloguescan be classified as pre-consumer or post-consumer, depending on where they were collected, even though the items themselves do not change. For example, magazines thrown away after they were read are post-consumer waste. But the same magazines, if they weren't sold but were returned by the distributor, are pre-consumer waste. These are some of the problems with the distinction:

- Post-consumer wastepaper is complicated and expensive to identify and separate in a mill. For a company like Fort Howard, a recycled tissue paper manufacturer that processes over 1.4 million tons of wastepaper per year, this separation effort can be expensive. This has increased the cost of recycling and raised the prices of products that have to certify their post-consumer content.
- Some pre-consumer wastepaper has inks, waxes, metallic or plastic coatings, or glues which are difficult to remove and which one may not want to have lying around in a landfill. Printers' waste, for instance, has heavy ink content, and bindery trim has adhesives; neither of these can be reused without being recycled. If recyclers do not use these wastepaper sources and instead use post-consumer wastepaper, a lot of pre-consumer wastepaper will be landfilled.
- If mandated post-consumer content is too high relative to available supplies of post-consumer wastepaper, the price of wastepaper will go up so much that producers of recycled content paper could lose out to producers who use virgin fiber. This can be an important issue when the post-consumer mandate is implemented, say, on the state level. Then, California paper manufacturers could be forced to raise their paper prices while Oregon manufacturers aren't. (This is less of an issue if the mandate is a national one.)

James River's deinking plant in Halsey, Oregon, for instance, recycles 450 tons of paper a day. It's designed for office paper, but there's no ready supply of office paper in the area, since the infrastructure for office paper collection isn't well developed. They end up going to Texas, Iowa, or North Dakota to bring in enough office paper to keep the plant going. In the process, they bypass perfectly good pre-consumer wastepaper sources. There are many opportunities for recycling closer to the plant, but they aren't being used because of the emphasis on post-consumer recycling. Of course, even with a complete infrastructure, the area might not be able to supply 450 tons per day. Also, we don't know how much of the 450 tons would be "pre-consumer" if the pre-/post-consumer distinction were eliminated. These details, like all answers to questions of "What might have been", are difficult to know. But what we do know is that by its very nature, the distinction skews paper recyclers' decisions, making them spend more effort to get post-consumer paper when pre-consumer might be cheaperand therefore raises costs. If laws start to mandate exclusively post-consumer content, pre-consumer waste will have less value, and will be less likely to be recycled.

A few numbers, though, are instructive. In mid-1995, the American Forest and Paper Association reported that many grades of recovered paper were in short supply, and recovery rates for two of the largest recovered paper grades were closing in on what were estimated to be "maximum feasible recovery levels." The recovery rate for old corrugated containers reached 63 percent in 1994, compared to an estimated maximum of 66 to 72 percent. The recovery rate for old newsprint was 59 percent, compared to an estimated maximum of 67 to 72 percent. Office papers were in tight supply in many places in mid-1995, and the situation was expected to get tighter as recovered paper exports rise and new deinking facilities opened. With the U.S. paper recovery rate at record levels, many mills were reconsidering their decision to use recovered paper as a feedstock, and some closed or reverted to virgin fiber because recovered paper had become too expensive for them.

Federal purchasing also favors post-consumer content over pre-consumer content. For instance, President Clinton's Executive Order on recycled procurement specifies at least 20 percent post-consumer content after December 31, 1994, and 30 percent after December 31, 1998, for federal procurement of high speed copier paper, offset paper, forms bond, computer printout paper, carbonless paper, file folders and white woven envelopes. The minimum content standard for other uncoated printing and writing paper (like writing and office paper, book paper, cotton fiber paper, and cover stock) is 20 percent post-consumer and 50 percent total recovered content. In this case, post-consumer prices will be higher and pre-consumer prices will be lower than they would otherwise be. There will be over-recycling of post-consumer waste and under-recycling of pre-consumer waste, and resources will be spent on post-consumer waste which could have been more efficiently spent recycling more pre-consumer waste. The end result will be less total recycling of the wastepaper stream.

C. Other Superfluous Restrictions

1.Color and Thickness

- "Poly binders" are solid plastic binders. Virgin poly binders are made out of HDPE; recycled poly binders can be made out of 100 percent post-consumer PET (polyethylene terephthalate) or 100 percent post-consumer HDPE. HDPE binders are typically made out of recycled milk containers, which come in a frosted white color, so it's easy to dye recycled HDPE in any color. But for the recycled binder manufacturerin general, a smaller business than its virgin competitorsoffering binders in many colors can be an expensive proposition. The binder manufacturer has to buy colored plastic in bulk from the HDPE recycler, and so might not be able to afford stocking every color. The result is that recycled HDPE binder makers can be shut out of the government purchasing process if the required color isn't available.
- When different types of plastic are blended together, they usually come out in an ugly shade of olive green. Since all the different sorts of plastic have their own colors, recycled commingled plastic is difficult to color. This has been known to affect recycled plastic shower and toilet partitionssome governments prefer partitions in lighter colors. In New Jersey, traffic cones have to be orangeand they can't be painted. In Lansing, Michigan, trash bags have to be a light mint green. Many trash can specifications require white or yellow cans.

- Some government agencies require that the paper they buy have a certain brightness. Sometimes, there can be good reasons for such requirements; at other times, brightness requirements can lead to ridiculous situations like that of Paper Service Ltd. of Hinsdale, N.H., which couldn't sell its *toilet paper* to the state government of New Hampshire because it wasn't bright enough. President Clinton's Executive Order called for the removal of unnecessary brightness and stock clause provisions and lignin content or chemical pulp requirements. The Executive Order was only binding on the federal government, but the job should be finished up for government agencies at all levels.
- Specifications for trash can liners generally contain thickness requirements. Bags made with recycled content and designed to meet performance requirements often exceed the maximum gauge standard or mill thickness and don't qualify for purchase. Trash bag specifications shouldn't include references to the thickness of the liner, the resins to be used, or preferences for flat or gusseted bags. Thickness, after all, isn't a performance characteristic; bags of equal thickness could be hefty or wimpy. How much a bag can hold without breaking is what we're interested in. Other thickness requirements include New York State's half-inch-thick shower partition requirement; recycled plastic shower partitions are generally at least one inch thick.

2.Temperature Resistance

Standard three-ring binders are made out of cardboard and covered with vinyl. Two sheets of vinyl are welded together at the edges of the binder, and at low enough temperatures, the vinyl cracks at the edges. When government agencies buy vinyl-covered binders, they demand that the binders pass the "cold crack" test, so that they don't crack too easily in cold temperatures. Binders can be made with recycled content; recycled vinyl binders are typically made with about 50 percent reground factory waste and 50 percent virgin material. Factory waste can come from many different vinyl manufacturers, each of which makes vinyl slightly differently. This means that there is too much variability in recycled vinyl to get a reliable result on the cold crack test. Since recycled vinyl binder makers don't have a constant result in the cold crack test, they are shut out of the government procurement processeven though binders don't need to withstand low temperatures unless warehousing and trucking conditions demand that they do. Since binder manufacturing is competitive, the prices of recycled binders are comparable to those of virgin binders. But the rules of government purchasing frequently shut recycled binders out of the market. Do governments in warm areas need to buy binders that can withstand low temperatures Probably not. But, for historical reasons, governments look for products with the same characteristics as the products they've always bought.

D. Carpets

Polyester carpets can be made out of recycled PET. For instance, soft drink bottles can be converted to polyester carpets. Nylon and wool carpets, on the other hand, are difficult to make with recycled content. Nylon recycling methods exist, but they're not economical with carpets. In practice, the only carpets with recycled material are polyester carpets. The problem is that most buyers prefer nylon carpets to polyester carpets, for performance reasons; generally, polyester carpets don't have the resilience or flexibility of nylon. Nylon carpets account for two-thirds of the carpet market, and polyester carpets only account for 7.5 percent. (The rest are mostly olefin carpets, which are made of polypropylene.)

Still, at least in principle, polyester carpets are recyclable while nylon carpets aren't. But many purchasers, both in government and in industry, regularly specify that their carpets be made of nylon. About 90 percent of commercial purchasers, for instance, specifically buy nylon fiber carpets. The Army Corps of Engineers also requires the use of only nylon or wool carpet. There are no good performance tests available for carpets, and so they buy nylon because they know from past experience that nylon works well.

Of course, such practices discriminate against polyester; if purchasers can't compare the performance of different types of carpet, then they'll continue buying what they've always bought and are happy with. Even if polyester carpets improve as time goes on, they'll have trouble breaking into the carpet market. The Carpet and Rug Institute uses performance standards developed by the ASTM and the American Association of

Textile Chemists and Colorists (AATCC) for characteristics like dry breaking strength, tufts per square inch, resistance to insects, colorfastness to light, electrostatic propensity, and flammability. But there are more subjective factors related to the carpet's change in appearance over timewhat do the fibers look like after they're twisted These are difficult to objectively evaluate, and the carpet industry has been researching ways to satisfactorily measure these characteristics for the last 30 years.

E. Landscaping Products

Hydraulic mulch is a landscaping and erosion control product, made of small pieces of cellulose fibers, which can be either wood or paper. Federal and state specifications can be a barrier to the increased use of hydraulic mulch products. A 1990 survey by a mulch manufacturer revealed that 19 states either disallowed paper-based hydraulic mulch or had specifications that didn't include it in the list of approved materials. And according to the EPA, some federal specifications also prohibit the use of paper-based mulch. Some agencies claimed either that they weren't familiar with the product or that they had had bad experiences with it in the past; the EPA counterargues that the agencies' experience was over 10 years old and didn't reflect recent improvements in quality. Both the recalcitrant agencies and the EPA, though, are missing the point. The problem isn't that the agencies aren't using paper-based hydraulic mulch; that all depends on what performance characteristics the product has and what performance characteristics the agencies want. Rather, the problem is that performance characteristics aren't part of the specifications at all; instead, the specifications are based on materials, like bark or hay. As a result, even if paper-based hydraulic mulch is a perfectly good product, the agencies won't find out about it. (A similar problem is present in the case of compost; some agencies require that their compost be made from mushrooms or from horse manurewhich precludes the use of yard debris.)

In fact, the industry is divided on the benefits and drawbacks of paper-based and wood-based mulch. Naturally, manufacturers of each product claim that theirs is superior. The International Erosion Control Association is developing performance standards for hydraulic mulch to resolve the dispute; these standards will be based on how much vegetation is produced, and not on the product's physical characteristics.

Recycling Earth Products, a company based in Vista, Calif., converts scrap drywall from construction sites into new wallboard, paper, and a gypsum soil amendment. Even though the gypsum soil amendment could be used safely, the company couldn't sell it to the state of California because of established Caltrans specifications. Caltrans requires that the fiber in its soil amendments contain no more than 2 to 3 percent ash. When Recycling Earth Products takes fiber out of wallboard, the fiber contains about 3 to 4 percent gypsum. Gypsum isn't ash, but Caltrans considers it ash for the purposes of its specifications, and so it doesn't buy Recycling Earth's Products soil amendment. The irony, though, is that gypsum (unlike ash) is useful to have in soil amendments; it provides calcium and also breaks down the soil to help roots penetrate. When Caltrans buys virgin fiber, its adds about 10 percent gypsum to it *intentionally*. And yet, the gypsum that was in the wallboard to begin with is considered a "contaminant."

F. Reforming the Procurement Process

In my emphasis on the government procurement process, I don't mean to suggest that private industry's procurement processes are flawless. They aren't. Many companies, especially large corporations, are excessively rule-bound or simply don't realize that they're wasting their money by buying products made of virgin materials when better products exist that are made with recycled materials. Private companies ought to also examine their procurement process and find the areas where waste exists.

But there are valid reasons for closely scrutinizing the government procurement process. First, waste in private industry is somewhat less likely than waste in government, because private industry tends to be more fixated on the bottom line. Second, waste in private industry is a matter to be sorted out between those who do the procuring and those who pay the billswhile waste in government is everyone's business, since we all pay the government's bills. Third, the public-sector procurement process is notoriously costly and rule-bound.

As Eggers and O'Leary explain,

> *In the public sector... you are not spending your own money. Because you are using public funds, you have to be fair when awarding contracts. Because of the possibility of kickbacks or other favoritism, new firms need to be allowed to participate in the bidding process. This raises costs.*
>
> *The other big cost factor in public-sector purchasing is political and legislative interferencemost of it well intentioned. "Any purchase, even for a stapler, had to be from a small business," says [Stephen] Kelman [administrator of the Office of Federal Procurement Policy]. "In the government context, how a small business is defined is a term of art. You have to have a big book in front of you to determine if a company is indeed a small business."*
>
> *To sell copying paper to the government, at least before 1994, you had to first certify that none of your employees had ever violated the Clean Air Act, the Clean Water Act, or had committed any defense-related felonies. There are "buy American" regulations, rules that encourage minority- or women-owned enterprises, regulations against buying from companies that use convict labor, and rules that give preference to suppliers that encourage a drug-free workplace. All of this raises costs. Though the federal government has been the worst example, governments at all levels have the same sort of rule-based, formalized purchasing systems.*

How does one reform a system like this One way is by removing some of the rules that govern procurement. This, again, is easier said than done. Many of these changes will have to be done on a case-by-case basis, though some changes can also be done wholesale, like the removal of a number of restrictions on federal purchases below $100,000 and the radical deregulation of purchases under $2,500 in 1994. Some of the more important changesas far as the procurement of recycled products goesare:

- *Adopt reasonable costing techniques*. Don't buy the lowest-priced item when the lifetime cost of that item is higher.
- *Eliminate useless and counterproductive distinctions*, like the distinction between pre-consumer and post-consumer paper.
- Most importantly, *adopt performance standards*instead of requiring that purchased products have irrelevant characteristics, for example color or thickness.

V. CONCLUSION

The moral of the story is that performance standards are the only way to go.

- Governments shouldn't always rely on industry standards. In areas like plastic lumber or drainage pipe, when the ASTM or AASHTO don't have standards for a possibly good product, it may make sense for governments to draw up their own performance standards, allowing companies to submit performance data from approved testing labs.
- Local building code offices, highway departments, and such agencies should establish clearer and more predictable approval procedures that are more open to innovative technologies. They should rely less on materials and methods specifications, and use performance standards whenever possible.
- Government procurement agencies should scrutinize their procurement specifications to see whether they're using irrational or nonperformance-related criteria to buy the products they need. President Clinton's 1993 Executive Order on recycled procurement has reformed and will continue to reform government procurement, though it treats recycling too much as an end in itself. More should be done to require performance standards whenever possible instead of dictating what a product must be made of.

Standards that have no bearing on performance, but which end up precluding recycled material, should be opposed. Governments shouldn't blindly buy recycled, but neither should they specifically eschew recycled.

They shouldn't mandate rubber in roadways, but neither should they prohibit, say, GGBF slag in roadways.

In the past, minimum recycled content requirements have led to increases in the quantity of recycled materials used. Minimum content requirements were one of the factors that led the paper industry to actually come up with performance standards that had previously been lacking. But, in many respects, such standards are like the old "method" and "material" standards of the past. They don't allow for assessment of cost, performance, and the cluster of other variables that determine product quality. In most instances, just how much recycled content makes sense will depend on the "devilish details" involved in producing and consuming specific products. Recycled content mandates don't allow for these variations.

But neither do we want rules that *prohibit* use of recycled content. We should switch from an approach that cares about materials to an approach that cares about performance. Recycled materials aren't appropriate all the time, and neither are virgin materialsand most importantly, we can't even know which is appropriate at what time without adopting performance standards. Governments are in the business of providing certain services, and they should stick to providing those services with as much quality for the buck as possible. Only such an approach can treat both virgin materials and recycled materials fairly.

ABOUT THE AUTHOR

Alexander Volokh is assistant policy analyst at the Reason Foundation. He has authored the previous two studies in the series *Recycling and Deregulation: Opportunities for Market Development*Policy Study No. 196, *The FDA vs. Recycling: Has Food Packaging Law Gone Too Far*, and Policy Study No. 197, *Recycling Hazardous Waste: How RCRA has Recyclers Running Around in CERCLAs*. Volokh's expertise includes environmental risk assessment, solid waste management, environmental law, natural resources, commercial speech, medical drug and device regulation, and race relations.

APPENDIX I

List of Possible Uses for Waste Materials & By-products Evaluated by State Highway Agency Research

Code	Description of Use or Application
ABC	Aggregate base course
ABF	Aggregate backfill
ACM	Asphalt-cement modifier
AGG	Aggregate in asphalt
AR	Asphalt rubber
ATT	Attenuation systems
BAR	Barricades
CEM	Cement replacement
CON	Concrete aggregate
CS	Chip seal
DEL	Delineators or cones
DP	Dust palliative

EMB	Embankment borrow
FF	Flowable fill
FL	Fuel for asphalt plants
FSP	Fence or sign post
GB	Glass beads for traffic paint
GRT	Grout or subsealing
ICE	Ice control or anti-skid materials
JCS	Joint and crack sealant
LCB	Lean concrete base
LWF	Lightweight fill material
MF	Mineral filler inn asphalt
MUL	Mulch or topsoil amendent
OS	Overlay sealant
PB	Pipe bedding
RC	Reinforcing bar chairs
RCC	Roller-compacted concrete
REC	Recycled pavement
RMO	Reclaimed motor oil
RR	Riprap or slope protection
RTA	Rockfall tire attenuator
SAM	Stress-absorbing membrane
SB	Stabilized base course
SHL	Shoulder aggregate
SIG	Sign blanks
SLU	Slurry seal
SM	Soil modifier
SND	Sand substitute
SS	Soil or subgrade stabilization
SUB	Subbase materials
TIM	Plastic timbers, tables or benches
Source: Robert J. Collins and Stanley K. Ciesielski, *Recycling and Use of Waste Materials and By-Products in Highway Construction*, National Cooperative Highway Research Program, Synthesis of Highway Practice 199.	

APPENDIX II

Summary of State Highway Agency Research Activities on Uses for Waste Materials and By-products

	Coal Ash		Other Ash		Slag Materials			Paving & Building Debris				Mining Wastes		
	Fly	Bottom	MSW	Sludge	Blast Furn.	Steel Making	Non-Ferrous	RAP	RCP	Concrete	C&D Debris	Tailings	Quarry Waste	C W
1. Alabama														
2. Alaska								SUB						
3. Arizona	CEM, SS[1]							ABC, AGG	ABC, CON					
4. Arkansas	CEM	AGG, EMB						REC					ABC,EMB	
5. California					ABC, AGG	ABC, AGG	AGG	REC, SB		ABC, CON				
6. Colorado	SB							REC						
7. Connecticut			EMB					ABC, CON		ABC, CON	ABC, CON			
8. Delaware	EMB				CON					EMB	EMB			
9. Florida	CEM, EMB		EMB		AGG, CEM		AGG	REC	AGG					
10. Georgia	CEM, SB							REC						
11. Hawaii*														
12. Idaho*														
13. Illinois										EMB			EMB	
14. Indiana	AR, EMB				AGG, ABC	AGG, ABC		AGG, ABC			AGG, ABC			
15. Iowa	CEM							ABC, REC	ABC, CON					
16. Kansas	MF, SS	ICE			AGG	AGG		REC	CON, SB	EMB, RR		AGG, CON		
17. Kentucky	SS													
18. Louisiana	CEM, MF				AGG, ABC	AGG, CS		ABC, REC	ABC, CON					
19. Maine								REC						
20. Maryland	CEM, GRT				CEM	EMB, SUB		REC	SUB					E
21. Massachusetts			AGG, CON					AGG		ABC				
22. Michigan	CEM, SS				AGG, ABC	AGG		REC, ABC	ABC, CON					
23. Minnesota			AGG, EMB	MF										
24. Mississippi	CEM, SB	ABC, SB						AGG						
25. Missouri	CEM, GRT	EMB, AGG			AGG	AGG		REC	ABC, RR	RR	EMB	AGG	EMB	
26. Montana	CEM													
27. Nebraska	CEM, MF							ABC, AGG	ABC, AGG					
28. Nevada								REC				AGG		
29. New Hampshire	CEM, FF		AGG		CEM			AGG, SB						
30. New Jersey	CEM, MF									ABC, AGG				
31. New Mexico*														
32. New York	CEM, MF	ICE	SUB		CON, CEM	SUB		REC, SB	REC, SUB	RR	EMB	AGG, RR[1]		
33. North Carolina	CEM							REC						
34. North Dakota	CEM													
35. Ohio								REC						
36. Oklahoma	CEM, SS											AGG, CS		
37. Oregon	CEM, SB				CEM			REC						
38. Pennsylvania	CEM, EMB	EMB, ICE			AGG, CON	AGG, SUB	AGG,ICE	REC	CON, SUB	SUB				
39. Rhode Island	CEM							REC, SUB						
40. South Carolina	CEM	EMB			AGG	AGG		AGG		ABC				
41. South Dakota														
42. Tennessee	CEM				AGG		AGG	REC						
43. Texas	CEM, SS	ABC, AGG			AGG, CON		AGG			ABC				

44. Utah	CEM	ABC						REC						
45. Vermont								SB, SHL					ABC, SB	
46. Virginia	CEM, SB				AG, CON			REC						
47. Washington	CEM							AGG						
48. West Virginia	CEM, EMB	ICE			AGG, CON	AGG, ICE		ABC, AGG						S
49. Wisconsin	CEM, EMB							ABC						
50. Wyoming	CEM, SB	ABC, AGG						REC	CON					

Has not performed any recent research on uses for waste materials or by-products

[1] Waste rock

Source: Robert J. Collins and Stanley K. Ciesielski, *Recycling and Use of Waste Materials and By-Products in Highway Construction*, Table 7, pp. 27–30.

Summary of State Highway Agency Research Activities on Uses for Waste Materials and By-products

	Domestic Wastes					Kiln Dusts		Roofing Shingles	Sulfate Waste	Lime Waste	Silca Fume	Foundry Wastes	Wood Chips, Sawdust	Used Motor Oil
	Scrap Tires	Glass	Plastic	Paper	Compost	CKD	LKD							
1. Alabama*														
2. Alaska	AR								DP				LWF	
3. Arizona	AR					MF								
4. Arkansas	AR					SB, EMB								
5. California	AR, CS	AGG, SB												
6. Colorado	EMB, SAM		ACM											
7. Connecticut	AR, ATT	AGG,EMB			MUL									
8. Delaware														
9. Florida	AR	AGG,EMB	FSP, RC					AGG			CEM			FL
10. Georgia	JCS		FSP, SIG	MUL										FL
11. Hawaii*														
12. Idaho*														

13. Illinois			BAR				SS					SND		
14. Indiana												AGG		
15. Iowa	AR	AGG												
16. Kansas	AR		DEL	MUL		EMB, SS								
17. Kentucky							SS		EMB	SS				
18. Louisiana									SHL					
19. Maine	AR, CS	GB	FSP,TIM		MUL[1]									FL
20. Maryland	AR				MUL[1]								MUL	
21. Massachusetts	AR													FL
22. Michigan	AR		FSP, TIM											
23. Minnesota	AR, EMB							AGG						
24. Missisippi	AR													
25. Missouri	AR			MUL		SS	SS			SS				RMO
26. Montana														
27. Nebraska	AR													
28. Nevada	CS		ACM											
29. New Hampshire	AR, SAM	ABC		MUL	MUL						CEM		MUL	

30. New Jersey														
31. New Mexico														
32. New York	AR, JCS	AGG	ACM		MUL[1]	MF, SB	MF, SB		ACM				MUL	
33. North Carolina	AR, EMB		FSP										MUL	
34. North Dakota														
35. Ohio	ACM									MUL				
36. Oklahoma	AR													
37. Oregon	AR, LWF										CEM			
38. Pennsylvania	AR, AGG	AGG,ABC[2]		MUL				AGG[3]				AGG		
39. Rhode Island	AR													
40. South Carolina	AR, CS					SB						AGG		
41. South Dakota														
42. Tennessee	JCS		SIG											
43. Texas	AR								SB					
44. Utah						MF								
45. Vermont	EMB	AGG	FSP											

46. Virginia	AR	AGG				SB			SB					
47. Washington	AR												LWF	
48. West Virginia														
49. Wisconsin	ACM, EMB											AGG,EMB		
50. Wyoming	AR												LWF	

*Has not performed any recent research on uses for waste materials or by-products

[1] Sewage Sludge [2] Also used experimentally in embankments and as backfill [3] Factory Scrap

Source: Robert J. Collins and Stanley K. Ciesielski, *Recycling and Use of Waste Materials and By-Products in Highway Construction*, Table 7, p. 27–30.

APPENDIX III

Summary of State Highway Agency Use of Waste Materials and By-products in Highway Construction

	Coal Ash		Other Ash		Slag Materials			Paving & Building DebrisMining Wastes		
	Fly	Bottom	MSW	Sludge	Blast Furn.	Steel Making	Non-Ferrous	Mine Tailings	Quarry Waste	Coal Waste
1. Alabama	CEM, SB				AGG	AGG		ABC, AGG		ABC, AGG
2. Alaska								ABC, EMB		
3. Arizona	CEM, EMB							ABC		
4. Arkansas	CEM,SS,MF	AGG, EMB						ABC*, SUB[1]*	ABC, EMB	
5. California					AGG, ABC	AGG, EMB		EMB		
6. Colorado	CEM, SB							EMB		
7. Connecticut			EMB							
8. Delaware	EMB, FF				CON					
9. Florida	CEM				AGG, CEM		AGG	SB, SUB**	SUB	
10. Georgia	CEM, SB	SUB			AGG				SUB	
11. Hawaii										
12. Idaho								EMB, ICE*		
13. Illinois	CEM, EMB		SB		CON, ABC	AGG		AGG, SHL	EMB	EMB
14. Indiana	CEM, SB				AGG, ABC	AGG				EMB
15. Iowa	CEM, FF									
16. Kansas	CEM, MF	ICE			AGG			AGG, CON		
17. Kentucky	SB, SS	SS[3]*			AGG	AGG				SUB, SHL
18. Louisiana	CEM, MF				CS	AGG				
19. Maine										
20. Maryland	FF, SB				CON, CEM	EMB				EMB

21. Massachusetts	CEM, EMB		AGG		CEM					
22. Michigan	CEM,SB,MF				ABC, AGG	AGG		EMB		
23. Minnesota	CEM, EMB		AGG	MF	REC			AGG, EMB		
24. Mississippi	CEM, SB	SB								
25. Missouri	CEM, EMB	AGG, ICE			AGG	AGG		AGG, EMB	EMB	
26. Montana	CEM, SS									
27. Nebraska	CEM, MF									
28. Nevada								AGG		
29. New Hampshire	CEM				CEM					
30. New Jersey	CEM, MF	ICE, SND			ABC, SUB			AGG, CON		
31. New Mexico	CEM							AGG		
32. New York	CEM, MF	ICE, SND	SUB	MUL	CON, SUB	SUB		AGG, RR[7]		
33. North Carolina	CEM							EMB**		
34. North Dakota	CEM, SB									
35. Ohio	CEM, SB				AGG					EMB
36. Oklahoma	CEM, SS							AGG, CS		
37. Oregon	CEM, RCC									
38. Pennsylvania	CEM, EMB	EMB, ICE	AGG		AGG, ABC	AGG, ABC		AGG		EMB, ICE*
39. Rhode Island										
40. South Carolina	CEM	EMB			AGG	AGG				
41. South Dakota	CEM							EMB		
42. Tennessee	CEM						AGG[8]	CON		
43. Texas	CEM, SS	AGG, ABC	AGG		AGG, CON		AGG, ABC[9]*	SB**		
44. Utah	CEM	ABC						EMB, MF		
45. Vermont									ABC, SUB	
46. Virginia	CEM, SB							ABC		ABC
47. Washington	CEM	EMB*						EMB		
48. West Virginia	CEM, EMB	AGG, ICE			AGG, CON	AGG, SHL				SUB
49. Wisconsin	CEM, EMB							AGG, SHL		
50. Wyoming	CEM, SB	ABC*						ICE		

*Not considered successful due to poor performance or economics**Used

Phosphogypsum

[1]Red Mud [2]Dredgings [3]Fluidized Bed Residue [4]Ceramic Waste [5]Considered experimental

[6]Sewage Sludge [7]Waste Rock [8]Phosphate Slag [9]Aluminum Slag [10]Wood Lignin

Source: Robert J. Collins and Stanley K. Ciesielski, *Recycling and Use of Waste Materials and By-Products in Highway Construction*, Table 12, pp. 42–47.

Summary of State Highway Agency Use Of Waste Materials & By-products in Highway Construction

	Paving and Building Debris				Domestic Wastes				
	RAP	RCP	Broken Concrete	C&D Debris	Scrap Tires	Glass	Plastic	Paper	Compost
1. Alabama	AGG	AGG							
2. Alaska	SUB				AR				
3. Arizona	AGG, ABC	CON, ABC			AR				
4. Arkansas	AGG				AR				
5. California	AGG, SB		CON, ABC		AR, EMB	AGG[4]			MUL[5]
6. Colorado	AGG		ABC, RR		EMB		ACM[5]		MUL[5]

7. Connecticut	AGG	AGG	CON	ABC, CON	AR[5], ATT[5]	AGG, EMB			MUL
8. Delaware	AGG		EMB	EMB	JCS				
9. Florida	AGG	ABC			AR[5]		FSP, RC		
10. Georgia	REC				AR[5], JCS		FSP, SIG	MUL	
11. Hawaii*	AGG								
12. Idaho*					AR				
13. Illinois	AGG, ABC	CON	EMB		JCS		BAR	MUL	
14. Indiana	AGG, SHL	ABC, SB		AAG,ABC	AR[5], JCS				
15. Iowa	AGG, CON	AGG, ABC			AR[5]	AGG[5]	FSP[5]		
16. Kansas	REC	CON, SB	EMB, RR		AR[5]		DEL	MUL	
17. Kentucky	AGG								
18. Louisiana	AGG, ABC	CON, ABC							
19. Maine	AGG, ABC				JCS, CS[5]		FSP, TIM		MUL
20. Maryland	AGG	SUB			AR[5]				MUL[6]
21. Massachusetts	AGG		SUB		ACM, AGG*				
22. Michigan	REC	REC			AR[5*]		DEL, TIM		
23. Minnesota	REC	ABC			AR[5], LWF				
24. Mississippi	AGG				AR[5]				
25. Missouri	AGG	ABC, RR	RR	EMB	AR[5]			MUL	
26. Montana	REC	REC			AGG[5]				
27. Nebraska	AGG, ABC	AGG, ABC			AR[5]				
28. Nevada	REC	CS			CS		ACM[5]		
29. New Hampshire	AGG, ABC				AR, SAM[5]	ABC		MUL	MUL[6]
30. New Jersey	AGG		ABC		AGG, JCS	AGG, SUB			MUL[6]
31. New Mexico	AGG				AR[5], SAM[5]				
32. New York	REC, SUB	SUB	RR	EMB	AGG[5], JCF	AGG[5]	ACM[5]		
33. North Carolina	REC				AR[5],EMB[5]	GB[5]	DEL[5], FSP[5]		MUL[5]
34. North Dakota	AGG, ABC	AGG, ABC			AR[5]*				
35. Ohio	AGG, SUB	ABC, SUB			AR[5]				
36. Oklahoma	AGG				AR[5], JCS				
37. Oregon	REC, ABC				AR[5]*, EMB		FSP[5]	MUL	MUL
38. Pennsylvania	AGG, REC	CON, SUB			AR[5]**	AGG, ABF		MUL	
39. Rhode Island	AGG, ABC	SUB			AGG*		ACM		
40. South Carolina	AGG		ABC		CS				
41. South Dakota	ABC, REC	REC	EMB						
42. Tennessee	AGG				JCS		SIG		
43. Texas	AGG, ABC		ABC		CS, AR				
44. Utah	REC, SUB								
45. Vermont	SB, SHL				EMB	AGG*	FSP		
46. Virginia	AGG, ABC				AR[5]	AGG[5]			
47. Washington	AGG				AR[5],AGG[5]*				
48. West Virginia	AGG								
49. Wisconsin	ABC				EMB, AR[5]*			MUL, DP	
50. Wyoming	AGG	CON			AR[5]*,JCS				

* Not considered successful due to poor performance or economics **Also used as fuel in cement kilns ***Including Factory Scrap

[1]Red Mud [2]Dredgings [3]Fluidized Bed Residue [4]Ceramic Waste [5]Considered experimental

[6]Sewage Sludge [7]Waste Rock [8]Phosphate Slag [9]Aluminum Slag [10]Wood Lignin

Source: Robert J. Collins and Stanley K. Ciesielski, *Recycling and Use of Waste Materials and By-Products in Highway Construction*, Table 12, pp. 42–47.

Summary of State Highway Agency Use of Waste Materials and By-products in Highway Construction

	Kiln Dusts		Roofing Shingles**	Sulfate Waste	Lime Waste	Silca Fume	Foundry Wastes	Wood Chips, Sawdust	Used Motor Oil
	CKD	LKD							
1. Alabama						CEM			
2. Alaska				DP				EMB	
3. Arizona	MF*								
4. Arkansas									
5. California									
6. Colorado									
7. Connecticut									
8. Delaware									
9. Florida						CEM			FL
10. Georgia									FL
11. Hawaii									
12. Idaho									
13. Illinois		SS	AGG				SND,AGG*	EMB, MUL	
14. Indiana							AGG		
15. Iowa									
16. Kansas	EMB*,SS								
17. Kentucky		SB		EMB					
18. Louisiana	SB*			SHL					
19. Maine								MUL	FL
20. Maryland								MUL	FL
21. Massachusetts									
22. Michigan							AGG		
23. Minnesota			AGG						FL
24. Mississippi									
25. Missouri			AGG***			CEM		MUL	FL****
26. Montana									DP*
27. Nebraska									
28. Nevada									
29. New Hampshire						CEM		MUL	
30. New Jersey								MUL	
31. New Mexico									FL
32. New York	MF, SB							MUL	
33. North Carolina								MUL	
34. North Dakota									FL*
35. Ohio									
36. Oklahoma					SM*				
37. Oregon						CEM		EMB, MUL	
38. Pennsylvania			AGG[5]	EMB			SND, CEM		
39. Rhode Island									
40. South Carolina	SB*						AGG		
41. South Dakota								SS[10]*	
42. Tennessee									FL
43. Texas				SB					
44. Utah	MF*								
45. Vermont									
46. Virginia	SB								
47. Washington								EMB	
48. West Virginia									
49. Wisconsin							EMB		
50. Wyoming								LWF	

*Not considered successful due to poor performance or economics **Including Factory Scrap ***Used as pre-mix maintenance patching material

****Used in state owned vehicles

[1]Red Mud [2]Dredgings [3]Fluidized Bed Residue [4]Ceramic Waste [5]Considered experimental

[6]Sewage Sludge [7]Waste Rock [8]Phosphate Slag [9]Aluminum Slag [10]Wood Lignin

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If the two-by-four were to stretch from 3 ft. to 3.03 ft., then the strain would be 0.03 ft./3 ft. = 0.01. The modulus of elasticity, the ratio of stress to strain, would be (16.98 lbs./sq.in.)/0.01 = 1698 lbs./sq.in. (These numbers are pure fabrications, by the way. They were chosen for ease of mathematical exposition, and dont represent any actual properties of any actual materials.) Personal communication, John OLeary. Personal communication, Malcolm McLaren, president of M.G. McLaren, P.C., Consulting Engineers.

39. Nadav Malin, Recycling: Recycled plastic lumber, Waste Information Digests, November 1993, vol. 4, no. 11.
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    Alan E. Robbins, Technology will prove naysayers wrong, Plastics News, February 27, 1995, p. 10.
40. See R.D. Sachan, T.J. Nosker, R.W. Renfree, and L.C. Chang, Improving quality control: Development of standardized test methods applicable to recycled plastic lumber, Center for Plastics Recycling Research, Rutgers University, presented at SPE Annual Recycling Conference, Schaumburg, Illinois, November 3–4, 1994.
41. Personal communication, Mark Billian, Eaglebrook.
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43. Development of Specifications, p.12. See also Jastrzebski, Nature and Properties of Engineering Materials.
44. Personal communication, Tom Nosker, Rutgers University.
45. Personal communication, Tom Nosker.
46. Personal communication, Malcolm McLaren.
47. Sachan et al., Improving quality control, p. 1.
48. Development of Specifications, p. 14.
49. According to the following speculative, back-of-the-envelope calculation—there are about 16 manufacturers with an average of $500,000 in sales each; the cost of plastic lumber is approximately 75¢ per board-foot, which means that current production is $500,000 per manufacturer 16 manufacturers 75¢ per board-foot 10.67 million board-feet.
50. Personal communication, Malcolm McLaren.
    A board-foot is a foot-long board with a cross-sectional area of 12 sq.in. In reality, the cross-sectional area isnt 12 sq.in., because the dimensions of a two-by-six, say, are in fact 1_ inches by 5_ inches. So if were using two-by-sixes, the volume of a board-foot is 12 inches 1_ inches 5_ inches = 109.6875 cu.in.
51. Personal communication, Pat Smith, Plastic Lumber Trade Association.
52. Personal communication, Prabhat Krishnaswamy.
53. McLaren, Recycled Plastic Lumber, p. 3.
54. McLaren, Recycled Plastic Lumber, figure 2, p. 4.
55. McLaren, Recycled Plastic Lumber, figure 2, p. 4.
56. Personal communication, Malcolm McLaren.
57. Plastic lumber has an approximate average density of 0.8, so a cubic foot of plastic lumber weighs 0.8 as much as a cubic foot of water. A cubic foot of water weighs 62.4 pounds, so a cubic foot of plastic lumber weighs 49.92 pounds. 6 billion board-feet 109.6875 cu.in. per board-foot 49.92 pounds per cu.ft. 1728 cu.in. per cu.ft. 19.013 billion pounds.
58. Back of the envelope calculation by Tom Nosker. A two-by-four or two-by-six has a thickness of 1_ inches, so 750 million sq.ft = 750 million sq.ft. 1_ inches 12 inches per foot = 101.5625 million cu.ft. At 49.92 pounds per cubic foot, 101.5625 million cu.ft. of plastic lumber weigh 5.07 billion pounds.
59. Personal communication, Seaward International.
60. Karen Hurst and Gail Humphreys, Manufacturing with Recyclables: Removing the Barriers, Community Environmental Council, Inc., 1993, p. 38.
61. Mruk, Thermoplastic piping, p. D.3.
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68. Personal communication, Fred Krause.
69. Provisional Standard Specification for Poly(Vinyl Chloride) (PVC) Sewer and Drain Pipe Containing Recycled PVC Material, ASTM Designation PS 1-94. PS 1 covers the types of pipes that conform to ASTM standard D 2729, which include retaining wall drains. PS 8-95, the Provisional Standard Specification for Coextruded Poly(Vinyl Chloride) (PVC) Non-Pressure Plastic Pipe Having Reprocessed-Recycled Content, is for pipes that perform equivalently to ASTM D 3034 sewer pipes and Schedule 40 drain pipes.
70. Standard Specification for Corrugated Polyethylene (PE) Tubing and Fittings, ASTM Designation F 405-93.
    Standard Specification for Large Diameter Corrugated Polyethylene Tubing and Fittings, ASTM Designation F 667-95.
71. F 405, § 5.1.
72. F 667, § 5.1.
73. Standard Specification for Polyethylene Plastics Molding and Extrusion Materials, ASTM Designation D 1248-84.
74. Standard Specification for Polyethylene Plastics Pipe and Fittings Materials, ASTM Designation D 3350-84.
75. Standard Specification for Corrugated Polyethylene Drainage Tubing, AASHTO Designation M 252-93.
76. Standard Specification for Corrugated Polyethylene Pipe, 12 to 36 in. Diameter, AASHTO Designation M 294-93.
77. M 252, § 6.1. M 294, §§ 6.1.1 and 6.1.2.
78. F 405, § 5.2. F 667, § 5.2. M 252, § 6.2. M 294, § 6.2.
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82. Personal communication, Gary Fish, Wisconsin Plastic Tile, and others.
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86. Personal communication, Jim Goddard, Advance Drainage Systems.
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