**SECONDARY MATERIALS:
ENGINEERING PROPERTIES, ENVIRONMENTAL CONSEQUENCES,
AND SOCIAL AND ECONOMIC IMPACTS**

Final Report

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Project Manager
Judy Jarnefeld

Prepared by

**WASTE MANAGEMENT INSTITUTE
STATE UNIVERSITY OF NEW YORK
AT STONY BROOK**
Stony Brook, NY 11794

Project Managers
V. Breslin
S. Reaven
M. Schwartz
L. Swanson
M. Zweig
M. Bortman
J. Schubel

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ABSTRACT

This report investigates two secondary materials, plastic lumber made from mixed plastic waste, and cement blocks and structures made with incinerator ash. The engineering properties, environmental impacts, and energy costs and savings of these secondary materials are compared to standard lumber products and cement blocks. Market capacity and social acceptance of plastic lumber and stabilized ash products are analyzed. These secondary materials apparently have potential markets; however, their economic value is primarily that they won't take up landfill space. For plastic lumber and stabilized incinerator ash products, marine and highway construction seem ideal public works applications. Incinerator ash may be suitable to use in seawalls, jetties, fishing reefs, highway barriers, and roadbed applications. Docks, piers, highway sound barriers, parking stops, and park furniture may all be made from plastic lumber. To encourage public acceptance and improve the market potential of secondary materials, these activities could be beneficial: industry should emphasize developing useful, long-lived products; industry and Federal, State, and local governments should create product performance criteria; government should provide rigorous testing and demonstration programs; and government and industry should cooperate to improve public outreach and educational programs.

Descriptors: secondary materials, plastic lumber, incineration ash products, incinerator, municipal solid waste

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION	1-1
2 COMMINGLED PLASTIC WASTE	2-1
Plastic Recycling	2-1
Separation and Processing Technologies	2-2
Physical, Chemical, and Engineering Properties of Plastic Lumber	2-3
Manufacturing Process for Plastic Lumber	2-4
ENVIRONMENTAL IMPACTS	2-5
Residuals Production	2-6
Waste Water	2-7
Air Emissions	2-7
PLASTIC LUMBER PRODUCTS	2-8
RECYCLED PLASTIC PRODUCTS FOR THE HOUSING MARKET	2-10
COMPARISON OF THE PHYSICAL PROPERTIES OF WOODEN LUMBER AND PLASTIC LUMBER	2-12
Specific Gravity	2-14
Compressive Strength	2-14
Flexural Properties	2-15
Creep	2-15
Biological Degradation	2-16
Chemical Resistance	2-17
Environmental Weathering	2-18
Fire Safety	2-19
EFFECTS OF DEGRADABLE PLASTIC ON THE RECYCLABILITY OF PLASTICS	2-20
ENERGY IMPACTS OF MANUFACTURE AND USE OF PLASTIC LUMBER	2-22
ENERGY SURVEY	2-25
Direct Energy Consumed In-plant	2-28
Transportation Energy	2-31
FACTORS AFFECTING ENERGY TO MAKE PLASTIC LUMBER	2-33
SUBSTITUTION FOR VIRGIN PLASTIC AND WOODEN LUMBER	2-36
Engineered Wooden Lumber	2-36
Product Lifetimes and the Pallet Market	2-37
Park Benches and Picnic Tables	2-40
Highway Maintenance Devices	2-41
Railroad Ties	2-41
ENERGY COMPARISON OF PLASTIC LUMBER AND VIRGIN PLASTIC	2-42
Case 1: Burning Plastic Lumber vs. Burning Virgin Plastic	2-47
Case 2: Landfilling Plastic Lumber vs. Landfilling Virgin Plastic	2-47

TABLE OF CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
Case 3: Recycling vs. Incineration with Replacement Virgin Plastic	2-48
Case 4: Recycling vs. Incineration without Replacement of Virgin Plastic	2-48
ENERGY COMPARISON OF PLASTIC LUMBER AND WOODEN LUMBER	2-49
Differences in Energy Use: Forest or MRF to the Application Site . . .	2-51
Differences in Energy Costs or Savings Incurred by the End-Use . .	2-51
Differences in Product Service Lifetimes and Product Weights. . .	2-52
Cradle-To-Grave Energy Comparisons.	2-53
Case 1: Use wood for the application, and landfill the discarded plastics	2-53
Case 2: Use plastic lumber for the application, and leave the wood in the forest	2-53
Case 3: Use wood for the application, incinerate the plastic discards that would have been made into plastic lumber in Case 2	2-54
Case 4: Use plastic lumber for the application, make the corresponding amount of wooden lumber, but use it for another purpose, and then incinerate the wooden lumber	2-54
Case 5: Use plastic lumber for the application, leave the wood in the forest, and incinerate the plastic lumber	2-54
Case 6: Use plastic lumber for the application, make the corresponding amount of wooden lumber, but use it for another purpose and then incinerate the wooden lumber and the plastic lumber	2-55
NEW YORK STATE IMPLICATIONS	2-55
Renewable Energy and New York State Forest Industry	2-56

TABLE OF CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
Use of Wood Wastes in New York State . . .	2-56
Impact of High Energy Prices in New York State.	2-57
Energy Impacts	2-58
ECONOMIC ASPECTS OF PLASTIC LUMBER	2-61
METHOD	2-61
PLASTIC RECYCLING MARKETS	2-64
PET and HDPE	2-71
Mixed Plastic Products--Plastic Lumber	2-75
LONG ISLAND MARKETS FOR SECONDARY MATERIALS	2-79
Markets for Plastic Lumber	2-80
PUBLIC POLICY RELATED TO COMMINGLED PLASTICS	2-82
Source Separation	2-82
Taxes	2-83
Research and Development	2-83
Standards	2-83
Content Legislation	2-85
Small Business and Entrepreneurial Programs.	2-85
SOCIOLOGICAL ISSUES RELATED TO SECONDARY MATERIALS	2-86
The Absence of Consumer Resistance	2-86
Sources of Resistance in the Profit Making Sector	2-88
THE POLITICS OF GOVERNMENT PURCHASES OF PLASTIC PRODUCTS.	2-91
POTENTIAL FOR SUCCESSFUL GOVERNMENT POLICY-MAKING IN THIS AREA	2-93
Standards	2-93
COMMINGLED PLASTIC WASTE SUMMARY	2-94
 3 COMMINGLED PLASTIC WASTE REFERENCES	 3-1
 4 INCINERATOR ASH	 4-1
PHYSICAL, CHEMICAL, AND ENGINEERING PROPERTIES.	4-1
Incineration Ash Composition	4-2
COMPARISON OF ENGINEERING PROPERTIES OF ASH AND NATURAL AGGREGATES	4-2
Gradation	4-4
Moisture Content	4-4
Organic Content	4-5
Gravimetric Characterization	4-5
Durability	4-7
Applications and Limitations of Ash Aggregates	4-8

TABLE OF CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
LEACHING OF INCINERATION RESIDUES	4-9
STABILIZATION AND LEACHING OF INCINERATION	
ASH BLOCKS	4-13
Leaching of Incineration Ash Blocks	4-16
BLOCK-MAKING TECHNOLOGY	4-17
ENVIRONMENTAL IMPACTS OF ASH-BLOCK	
MANUFACTURING	4-20
PLACEMENT AND MONITORING SECONDARY	
ASH BLOCKS	4-20
Incineration Ash Block Reef	
Placement and Monitoring	
Activities	4-21
INCINERATION ASH CONSTRUCTION BLOCK	
MANUFACTURING	4-24
Unconfined Compressive Strength	4-25
Fire Resistance Testing	4-27
Boathouse made from Cement Blocks	
with Ash	4-27
INCINERATION ASH IN SHORE PROTECTION	
DEVICES	4-28
ENERGY IMPACTS OF MANUFACTURE AND USE OF	
CONSTRUCTION BLOCKS FROM INCINERATOR	
ASH	4-31
DIFFERENCES IN PROCESSING ENERGY	4-34
DIFFERENCES IN TRANSPORTATION AND	
EXTRACTION ENERGY	4-35
Construction Blocks	4-35
Raw Ash	4-37
INDIRECT DIFFERENCES IN ENERGY	
CONSUMPTION	4-39
ECONOMIC ASPECTS OF ASH	4-42
Method	4-43
INCINERATOR ASH RECYCLING	4-43
INCINERATOR ASH BLOCKS	4-45
ARTIFICIAL REEFS MADE WITH INCINERATOR ASH.	4-48
PUBLIC POLICY RELATED TO ASH-BASED PRODUCTS.	4-49
SOURCES OF SOCIAL RESISTANCE TO THE USE	
OF INCINERATOR ASH	4-50
Resistance to Cost of Incinerators	4-51
TRANSFER OF RESISTANCE FROM INCINERATION	
TO ASH PRODUCT	4-53
INSTITUTIONAL RESISTANCE TO ASH AS A	
PRODUCT	4-56
Product Liability	4-56
Government Regulations	4-57
IMPLEMENTATION PROPOSALS	4-59
NIMBY	4-61
INCINERATOR ASH SUMMARY	4-62
5 INCINERATOR ASH REFERENCES	5-1

TABLE OF CONTENTS (cont.)

<u>Section</u>	<u>Page</u>
6 TECHNOLOGY TRANSFER	.6-1
7 CONCLUSIONS	.7-1
APPENDIX A Physical Properties of Plastic Lumber.	.A-1
APPENDIX B Energy Survey.	.B-1
APPENDIX C Marketing Survey.	C-1
APPENDIX D Persons Contacted	D-1

TABLES

<u>Table</u>	<u>Page</u>
2-1 Physical properties of wood and mixed plastic lumber.	2-13
2-2 Total direct energy to make 1 lb of plastic lumber	2-34
2-3 Estimated energy values for virgin plastic matched in composition to typical plastic lumber (Btu/lb).	2-43
2-4 Estimated total direct energy costs for manufacture of virgin plastic lumber and secondary plastic lumber (Btu/lb).	2-46
2-5 Maximum annual New York State net energy costs or savings from manufacture and use of plastic lumber to replace virgin plastic	2-59
2-6 Maximum annual New York State net energy costs or savings from manufacture and use of plastic lumber to replace wood.	2-60
2-7 MSW materials generated and recovered: 1988.	2-65
2-8 Plastic as percent of total MSW generated 1960-1988 projections to 2010.	2-56
2-9 Plastic products in MSW, 1988 (in millions of tons and percent of generation).	2-68
2-10 Use, recycled volume, and potential markets by recycled resin: 1989 (millions of pounds).	2-70
2-11 Use of PET and HDPE in bottles and containers, and recycling rates: 1989 (millions of pounds).	2-74
2-12 Weight and annual market potential for selected items made from plastic lumber.	2-77

TABLES (CONT.)

<u>Table</u>	<u>Page</u>
4-1 Concentrations of substances in MSW bottom and fly ash	4-3
4-2 Summary listing of engineering concerns associated with the physical characteristics of ash.	4-6
4-3 Summary of leaching testing procedures.	4-10
4-4 Range of concentrations in leachate at ash monofills	4-14
4-5 Engineering criteria for residue block secondary products.	4-23
4-6 Compressive strengths of Alpena 88 construction blocks.	4-26
4-7 Compressive strengths of mix designs incorporating chloranan	4-32
4-8 Energy comparison: regular blocks and incinerator ash blocks	4-36
4-9 Overall energy savings as a function of distance to landfill.	4-38
4-10 Incinerator ash material balance summary	4-44
4-11 Potential quantities of ash that could be substituted for natural aggregate use on Long Island.	4-47

FIGURES

<u>Figures</u>	<u>Page</u>
3-1 Plastic as percent of total MSW generated 1960-1988 and projections to 2010.	2-67
4-1 Metal release vs leachate pH	4-12
4-2 Schematic of block-manufacturing process	4-19
4-3 Boathouse made from incineration residue blocks.	4-29
4-5 Potential annual energy savings from use of ash blocks.	4-40

EXECUTIVE SUMMARY

Secondary materials are made from municipal solid waste (MSW) that has been converted into new products with new uses. Secondary materials include plastic lumber made from mixed plastic waste, reinforcing bars made from scrap metals, cement blocks and structures made with ash from burning MSW, and insulation materials made from newspapers.

Secondary materials may have impurities, environmental contaminants, and less desirable and consistent engineering and aesthetic properties. Secondary materials may have less quality, be in less demand, and cause greater environmental concern than virgin materials.

Converting solid waste to secondary materials reduces the amount of waste sent to landfills, incinerators, or that ends up as roadside litter or debris on beaches. Assuming high-quality, useful, cost-competitive, environmentally acceptable products can be produced, significant economic benefits may take the form of avoided disposal costs, growth of new business and industry, and perhaps reduced energy consumption.

Secondary materials also may cause disposal problems. The farther materials move from their initial introduction into the manufacturing process, the greater problems are likely to be. As more source materials are recycled, there is a greater chance for contaminated secondary materials to enter the marketplace.

Two secondary materials, plastic lumber and cement blocks and structures made with MSW ash, are analyzed in this report. They were selected as representative materials that otherwise would make up a large part of the waste stream. They were also chosen because they are somewhat

controversial. If beneficial secondary materials can be produced and marketed from plastics and ash, developing other secondary materials may in fact be easier.

Plastic lumber's engineering properties closely match softwoods such as northern white cedar or eastern white pine, and its compressive strengths are comparable. The specific gravity of plastic lumber, however, is up to three times that of the softwood lumbers. Due to plastic lumber's low modulus of elasticity, additional structural support would be required to prevent excessive bending and a structure made with it would be considerably heavier than a comparable wooden structure.

A major benefit of using plastic lumber may be its resistance to decay and marine borers. Its inherent resistance to biological attack removes the need to treat it with a biocide. Conventional wood piles are treated with copper-chromium-arsenates and/or coal-tar creosote to prevent damage from marine borers. While the treatment produces longer lifetimes for the pilings, the coatings may leach contaminants into the water and affect non-target organisms other than marine borers.

Plastic lumber is currently used for park benches, landscaping ties, fencing, decks, and docks. Manufacturers claim that plastic lumber made from post-consumer waste will last at least 15 times longer than wood, or that the plastic lumber will last more than 100 years. These claims are presumably based on plastic's ability to resist weathering. To date, there is no evidence to support claims for using recycled plastic lumber as an engineering material.

Limited studies discuss the change in engineering properties of plastic lumber after prolonged weathering. According to anecdotal evidence, plastic lumber has failed following

prolonged weathering. More research is necessary before developing end-use specifications for plastic lumber.

Additional testing to determine the initial engineering properties of plastic lumber made from post-consumer plastic is necessary. The melting-extrusion-cooling process to manufacture the lumber produces voids. The specific gravity of plastic lumber varies along the length of a lumber sample. Large or numerous voids in the lumber produce premature failure of the secondary material. Lumber samples should be periodically tested to establish the mechanical properties of plastic lumber.

Energy losses or savings from manufacturing and using plastic lumber are difficult to measure and depend on factors that include product lifetime, the amount of energy used in transportation, whether the product would be recycled, landfilled, or incinerated after use, and whether the plastic lumber replaces a virgin plastic or a wooden product.

Manufacturing plastic lumber from current discards uses less energy than making a comparable virgin plastic product from raw materials, but uses more energy than making a comparable wooden product from raw materials. Determining the life-cycle energy costs of plastic lumber is more complex. For example, assuming plastic lumber lasts as long as virgin plastic lumber and up to twice as long as wooden lumber, then:

- o Energy would be lost, if instead of burning the discarded virgin plastics (with energy recovery) and making a new virgin plastic product, the discards are recycled into plastic lumber. Energy is gained, however, if the discards are recycled into plastic lumber, instead of burning the

discards and without replacing the original virgin plastic product.

- o Energy would be lost, if instead of the traditional practice of using wooden lumber and landfilling plastic discards, plastic lumber is made from the discards and the wood is left in the forest. However, energy is saved, if the plastic lumber ultimately is burned with energy recovery. Energy is also saved, compared to the traditional practice, if wooden lumber is used but the plastic discards are incinerated, again, with energy recovery.
- o Energy would be saved compared to the traditional practice, if the plastic lumber is made from discards and ultimately burned with energy recovery, and at the same time the wooden lumber is also manufactured, used in some other application, and is ultimately burned with energy recovery.

Energy costs or savings in these scenarios may be incurred at times or in regions far removed from the time and place of the actual recycling.

Using the most optimistic set of assumptions for New York State, replacing wooden lumber with plastic lumber could save the State one quarter of one percent of the total annual State energy consumption, an amount equal to 1.63 million barrels of oil. Using the least optimistic set of assumptions, replacing virgin plastic or wooden lumber with plastic lumber could use an additional 910,000 and 390,000 barrels of oil, respectively.

Many economic issues must be resolved to market plastic lumber. Plastic waste recycling is small compared to the amount generated. Recycled plastics make up only four percent of the potential and 0.6 percent of the actual market. To date, markets for recycled single resin plastic are better than for mixed plastic products. This may be due to bottle bill laws that lead to better collection of single resin PET beverage containers and to the plastics industry focusing recycling technologies on single resin plastics.

Marketing problems associated with products made from commingled plastics include inconsistency in feedstock, unpredictable performance, and a lack of suitable engineering specifications and government regulations. Another important issue is whether market outlets are available. Demand for plastic lumber would have to penetrate only five percent of the market for car stops, four percent of the landscape tie market, or one percent of the railroad tie market to absorb the entire calculated potential annual amount of plastic lumber that could be produced at current recycling rates. The potential market is enormous compared to projected supplies.

Marketing problems associated with plastic lumber include that it is expensive compared to wooden lumber, concrete, or other materials. However, product lifetime must also be considered with the initial cost of a material; the average lifetime of plastic lumber and other products made from commingled plastics is undetermined. Other factors such as plastic lumber's low maintenance cost are also important.

There may be marketing problems due to a limited aesthetic appeal; only black or very dark colors are available, and impurities such as bits of paper or metal, are visible in the material. A marketing advantage for plastic lumber compared to items made from virgin plastics or other

material is that it appeals to consumers from an environmental perspective. Some in the industry argue, however, that this is a limited advantage; consumers may not buy recycled products that cost more than nonrecycled products.

Changes in public policy, including expanded source separation programs at the municipal level, tax incentives, research and development programs, establishment of Federal, State, and local government standards and engineering specifications, governmental use of plastic lumber, content criteria that requires certain products to contain a minimum amount of recycled resins, and development of small business and entrepreneurial programs would improve the marketability of plastic lumber.

Effectively using secondary materials made with incineration ash requires that they meet or exceed current engineering and environmental standards before use. Engineering criteria for materials used for artificial reef development, shore protection devices, and construction blocks are well established and provide a minimum performance standard for each application.

The environmental criteria that apply to using incinerator ash in secondary materials are not well established. Several regulatory leaching protocols including the Extraction Procedure Toxicity Test and the Toxicity Characteristic Leaching Procedure were not designed to evaluate the leachability of metals from a marine product. Sea water or fresh water tank leaching studies or modified American Society of Testing and Materials leaching techniques using sea water or synthetic acid rain are more useful techniques to determine the leachability of metals from stabilized products for marine or terrestrial use.

Since one test may be insufficient, several leaching protocols should be used.

Processing energy requirements of ash blocks are similar to those of regular construction blocks. The energy impacts of substituting ash blocks for regular blocks depend on the distance from the incinerator to the landfill or ashfill where the ash would be sent otherwise; the distance from the incinerator to the ash block fabrication plant; the distance from the fabrication plant to the job site; and, the distance from the sand or gravel pit to the fabrication plant. From the fabrication plant to the job site 20 miles for the two kinds of blocks are usually estimated, and, for the sand or gravel pit to the fabrication plant 25 miles for Long Island and 40 miles elsewhere in the State are estimated.

The energy advantage of making ash blocks at or near the incinerator is negligible, and the energy advantage of having a source of aggregate close by (as on Long Island) is also negligible. Energy savings from avoided extraction of natural aggregate are exceeded by energy savings from avoided transportation to landfills when the landfill is 570 or more miles away. If the distance to the landfill is 50 miles or less, 80 percent or more energy savings derives from avoided extraction of natural aggregate. For a landfill 200 miles away, recycling one ton of ash into construction blocks saves the energy equivalent of seven gallons of #2 diesel fuel. Potential energy savings for the State from using incinerator ash in construction blocks are small. Energy savings are generally maximized when incinerators are a great distance from landfills. Air pollution from transport of ash could also be reduced if the ash was beneficially used.

Stabilized ash products may have potential markets in marine construction and highway applications. Seawalls, jetties, fishing reefs, highway barriers, and roadbeds may be ideal for incinerator ash aggregate products; however, these are limited markets for most of the ash currently generated on Long Island. This problem will intensify with new incinerator capacity in the 1990s.

The market for secondary products made of incinerator ash is too limited to make a difference in solving the landfill problem posed by incinerator ash. There may be some economic advantage in avoided costs of taking up landfill space. In addition, incinerator ash may be an important resource to protect Long Island's coastline from the rising sea level and intense storms.

Social acceptance of construction materials made with incinerator ash depends on how ash block proposals are developed and introduced. The distribution of information and using public forums may help reduce opposition. Long-term research along with monitoring ash stabilization and use is recommended. It is also important to dispel the notion held by many people and some environmental groups that ash reuse programs are an important element in encouraging incineration as a MSW management tool.

INTRODUCTION

The term secondary materials refers to products made from municipal solid waste (MSW). The waste has been converted to a new physical form to serve new uses. Examples of secondary materials include plastic lumber made from mixed plastic residues; reinforcing bars made from mixed scrap metals, and insulation made from newspapers. Secondary implies some degree of contamination because waste-products cannot be entirely recycled as virgin materials in the manufacturing process nor reused, as in the refilling of a bottle. Secondary materials have the potential to play an important role in New York State's waste management strategy. Using refuse that might otherwise be sent to landfills, incinerators, or end up as roadside litter or floatable wastes in our coastal waters helps reduce the size of the waste stream. If high quality, useful, cost-competitive, and environmentally acceptable products can be produced, there may be significant economic benefits in avoided disposal costs, growth of new business and industry, and reduced energy consumption.

Secondary materials differ in several ways from products made from virgin or raw materials. Impurities, the potential for less desirable and consistent engineering properties, the possible presence of environmental contaminants, and less appealing aesthetic properties mean that secondary materials may be of lower quality, in less demand, and of greater environmental concern than those made from raw materials. Secondary materials also can present disposal problems. The farther the materials are moved from their initial introduction into the manufacturing process, the greater such problems are likely to be. And, the more the waste has been previously recycled, the greater is the chance for contaminated secondary materials with undesirable

engineering and aesthetic properties to enter the marketplace.

In this report two secondary materials are analyzed: plastic lumber made from mixed plastic waste diverted from the waste stream; and cement blocks and structures made with ash generated from the incineration of MSW. These two products are made from refuse, which may have otherwise become a sizeable fraction of the permanent waste stream. Plastics are estimated to comprise 8 percent by weight of MSW in 1988 and up to 18 percent of the volume of waste disposed of in landfills (US EPA, 1990). Current projections indicate that approximately eight million tons of ash per year could be produced nationally by the year 2000 (Korzun et al., 1990).

These two types of secondary materials were also chosen because they are somewhat controversial. If secondary materials deemed beneficial can be produced and marketed from plastic refuse and ash, hurdles associated with developing other secondary materials may be much less.

The physical and chemical properties of plastic lumber and stabilized incineration ash are compared with standard lumber products and cement blocks. Engineering properties and environmental impacts associated with the manufacture and use of plastic lumber and ash blocks are considered. The energy used to generate secondary materials and the energy potentially saved by not disposing of the materials are compared to the energy required to develop the traditional materials. Environmental impacts of processing, generating, and using secondary products are considered. Market capacity and costs of making these secondary materials are analyzed. Social acceptance is evaluated based on interviews and questionnaires targeted on potential user groups.

COMMINGLED PLASTIC WASTE

PLASTIC RECYCLING

Plastics were estimated to comprise 8 percent by weight of MSW in 1988 (US EPA, 1990), and up to 18 percent of the volume of waste disposed in landfills. Plastics are typically long-lived, and resistant to deterioration, and have physical and chemical properties that make them ideal for a wide variety of applications. Plastics are also lightweight and chemically inert. With the use of additives, plastics can be manufactured to be rigid, flexible, insulating, breathable, impermeable, transparent, or opaque. As a result, plastics have replaced glass and metal in many applications.

Many plastic products are single-use convenience products that rapidly become solid waste. When plastics are disposed, the attractive physical/chemical properties become a detriment. Their resistance to degradation has resulted in plastics being a widespread contaminant. About 39 percent of the plastics discarded in the US in 1988 were containers and other packaging, the principal target of most municipal plastic recycling efforts.

The lack of plastics collection is the major impediment to their recycling. Less than 200,000 tons of post-consumer plastic waste, about 1.1 percent of the plastic in MSW, were recycled in the US in 1988 (US EPA, 1990). The recovery rate for post-consumer plastic waste, as a percent of material generated, trails ferrous metals (5.8 percent), glass (12 percent), paper (25.6 percent), and aluminum (31.7 percent) (US EPA, 1990).

Seven resins account for about two-thirds of all plastic sales: low-density polyethylene (LDPE); high-density polyethylene (HDPE); polyvinyl chloride (PVC); polypropylene (PP); polystyrene (PS); polyethylene terephthalate (PET); and acrylonitrile butadiene styrene (ABS) (US OTA, 1989). Typical post-consumer plastic waste contains from 50 percent to 65 percent polyethylene and PP with varying percentages of PVC, PET, ABS, and PS (Maczko, 1988). These thermoplastics are ideal for recycling since they soften when heated and can be remolded. PET and HDPE are the two resins that are most commonly recycled. PET is currently recycled into a variety of products including scouring pads, insulating fiberfill, and paint brushes. HDPE is recycled into base cups for soft drinks, flower pots, toys, and lumber.

Separation and Processing Technologies

Plastic for recycling programs may be collected in recycling bins in a curbside recycling program or at designated drop-off centers. The plastics may be segregated or mixed with other recyclables. The high volume and low weight of plastic containers make the collection of plastic difficult and limit the cost-effectiveness of curbside collection programs. In addition, the variety of plastics in MSW is of concern as PET and HDPE resins have a much higher market value than mixed resins. To help the public to identify different plastics, the Society of the Plastics Industry is sponsoring a voluntary coding system, that has a triangular arrow stamp with a number in the center and letters underneath that identify the seven major resins used in containers. The codes are: 1, PET; 2, HDPE; 3, Vinyl (V); 4, LDPE; 5, PP; 6, PS; and 7, other (includes multi-layer).

Separation of plastics from MSW can also occur at a materials recovery facility (MRF). As a result of the collection methods, plastic waste often occurs as a mixture of various groups of plastics. Separation of mixed plastic waste usually occurs manually. A number of separation techniques are available and designed to separate plastics based on their unique physical or chemical properties. The Center for Plastic Recycling Research (CPRR) at Rutgers University, New Jersey, is developing automated processes to separate plastic containers made from different resins. The separation technology uses photoelectric beams and infrared technology to identify resins. Rensselaer Polytechnic Institute in Troy, New York, is developing a chemical separation technique using selective solvent dissolution and flash devolatilization to recover individual resins (Plastics World, 1989).

PHYSICAL, CHEMICAL, AND ENGINEERING PROPERTIES OF PLASTIC LUMBER

Plastic lumber is one of the major products currently being manufactured as a secondary material using post-consumer waste plastic. Fifty percent or more of the feedstock used for plastic lumber manufacturing is generally composed of polyolefins, plastics based on polymers made with a specific olefin as the principal monomer (ASTM, 1988a). The polyolefins act as adhesives and encapsulate high-melt plastics and contaminants within a rigid structure. Plastic lumber is being used for fence posts, poles, marine pilings, dock surfaces, park benches, and parking space bumpers. Many of the beneficial properties of plastic including its resistance to rot, chemicals, water, and insects may make plastic lumber an acceptable alternative to conventional wood products.

Manufacturing Process for Plastic Lumber

The technologies used to manufacture plastic products from virgin resins are also used to recycle post-consumer waste plastic. The process involves melting and extruding the plastic into products or pellets. Mixed waste plastic, usually preprocessed before extrusion, involves separating the plastic to collect specific resins, grinding and/or shredding, cleaning, and drying.

One recycling technology used to manufacture plastic lumber using commingled waste plastic has been recently developed by Advanced Recycling Technologies, Ltd., Brakel, Belgium. Advanced Recycling Technologies, Ltd. developed the Extruder Technology 1 (ET-1) process, which is specifically designed to recycle 100 percent post-consumer waste plastic into lumber. National Waste Technologies in Islip Township, New York, and CPRR use the ET-1 process to manufacture plastic lumber.

Both thermoplastic materials from post-consumer waste and industrial scrap may serve as raw materials for the ET-1 manufacturing process. Preprocessing equipment including grinders, shredders, densifiers, blenders, and conveyors are available from the manufacturer.

After preprocessing, the mixed plastic is fed into a vertical auger hopper, which functions as both a mixer and storage silo. After the plastic is dried and homogenized, additives including pigments are added. The mix is then discharged from the mixer into an intermediate hopper, passed over a magnetic metal separator, and carried by conveyor to the extruder.

The ET-1 extruder system is composed of three main components: an extruder, a molding unit, and an extraction unit (Maczko, 1990). The extruder is a short, rapidly rotating adiabatic screw used for melting the plastic. Melt temperatures range from 360 °F to 399 °F and are regulated by cooling fans, circulating water, rotation speed adjustment, or by adjusting the tolerance between the extruder screw and the barrel. Plastics and contaminants with higher melt temperatures, such as PET, become encapsulated within the melted plastic.

The molding unit consists of linear molds mounted on a turret that rotates through a water-cooling tank. The molds are interchangeable to allow for the manufacture of a variety of lumber products with dimensions up to 6 in. x 6 in. x 12 ft. The product shrinks within the mold during cooling, which allows its ejection using compressed air. Following ejection, the product is delivered into a covered receiver and discharged on to a shelf for manual removal. The part must then be completely cooled on a slotted rack to prevent warping.

ENVIRONMENTAL IMPACTS

Impacts associated with recycling waste plastic are difficult to assess due to the differences in preprocessing and manufacturing technologies. There is a potential for the production of residuals, contaminated waste water, and contaminated air emissions from reprocessing and extruding waste plastic into lumber.

A wide variety of additives are commonly used to enhance the processing, performance, and durability of manufactured plastic products. Environmental groups have been concerned about the potential toxicity of these additives and their

fate in the environment (Sadun et al., 1990). Reprocessing waste plastic may result in a product containing a mixture of various additives in unknown quantities. These additives may also be present in the resultant process waste streams.

Additives commonly used to process and manufacture plastics include antioxidants, colorants, plasticizers, flame retardants, lubricants, and UV stabilizers. Many of these additives are toxic. For example, many of the colorants currently used in the plastics industry are metal-based pigments, which include lead, cadmium, and chromium, and are considered metals of environmental concern. Some phthalate plasticizers have also been identified as mutagens and carcinogens (Radian Corporation, 1985).

Residuals Production

Solid waste can be produced from plastic recycling mainly in the form of spillage, routine cleaning, particulate collection from feeding, handling, grinding, and trimming processes. Additional solid waste can be produced from production errors and production process by-products. The waste may be primarily composed of polymers with less plasticizers; fillers; compatibilizers, which are chemicals added to plastic to make resins interact more efficiently; and other additives.

Preprocessing mixed plastic wastes can also produce solid waste. Solvent separation of mixed plastics developed at Rensselaer Polytechnic Institute recovers only the thermoplastics, leaving fillers, reinforcements, colorants, paper, and metals as a residue requiring disposal (Plastics World, 1989).

Waste Water

Water is used as a coolant to manufacture plastic lumber. For the ET-1 extrusion process, water is used in cooling the feed section of the extruder barrel and does not come into contact with the plastic. Water is also used to cool the moldings after extrusion and does contact the plastic. The cooling is usually circulated in a closed loop system and is not discharged into sewers.

Cooling waters may be contaminated with residues associated with recycled plastic, such as food particles or pesticides. Waste water may also contain suspended monomers, co-polymers, polymers, additives, filler particulates, and solvents that are washed or leached from the cooling plastic.

Air Emissions

There may be air emissions from processing and extruding waste plastic; and volatile air emissions may be generated during the heating of plastics. The extruders are usually operated at temperatures to promote the thermal decomposition of plastic. Plastics are exposed to these temperatures for a minimal time to avoid or minimize decomposition of the plastic. Thermal decomposition by-products of waste plastic may include hydrochloric acid from PVC, aliphatic aldehydes and ketones from the polyolefins, and acrolein from traces of milk remaining in HDPE milk bottles.

A comparison of the processing of virgin and post-consumer HDPE showed that the odor of recycled resins compared very unfavorably with the virgin controls (Gibbs, 1990).

"Chemical cleaner" and "soapy odors" were commonly cited

reactions to the recycled polymers. In addition to odors, visual analysis of smoke from blowmolding recycled polymers showed that the recycled polymers exhibited severe smoke levels while virgin polymers exhibited no smoke (Gibbs, 1990). Odor and smoke production may result from incomplete cleaning and processing of HDPE resin before molding.

PLASTIC LUMBER PRODUCTS

Plastic lumber is a synthetic lumber made from commingled waste plastic. Several manufacturers are currently producing plastic lumber products using industrial scrap and post-consumer waste plastic. The lumber products chosen for this report represent different manufacturing technologies and different commingled post-consumer waste plastic.

Hammer's Plastic Recycling, in Iowa Falls, Iowa, is currently processing mixed waste plastic to produce park furniture, car stops, landscape timbers, pallets, and boat docks. Lumber products can be manufactured in lengths up to 12 ft. Thickness can vary from 1 in. to 4 in. and width can vary from 2 in. to 12 in. The lumber is manufactured using a minimum of 96 percent by weight commingled recycled plastic. Colorants, UV stabilizers, and other additives comprise the remaining 4 percent of the lumber product.

Rutgers University has been conducting research to establish technologies to facilitate widespread recycling of post-consumer plastic wastes. The lumber produced at CPRR has been used in park benches and for the construction of a deck. The sample compositions, called 100 percent NJ curbside tailings, were obtained from the rigid plastic waste stream following removal of PET and unpigmented HDPE. The 60/15/15/10 samples were manufactured using a mixture of 60 percent HDPE milk bottles, 15 percent detergent bottles,

15 percent NJ curbside tailings, and 10 percent LDPE pellets. The 60/15/12/10/3 samples were manufactured using a mixture composed of 60 percent HDPE milk bottles, 15 percent detergent bottles, 12 percent NJ curbside tailings, 10 percent LDPE pellets, and 3 percent HDPE base cups. The 50/50 samples were manufactured using a mixture of 50 percent HDPE milk bottles and 50 percent densified expanded PS. Lumber samples up to 6 in. x 6 in. in cross section and up to 12 ft long can be molded using the ET-1 technology.

TriMax lumber is manufactured using a proprietary process of the Trimax Corporation, a subsidiary of the Polymerik Company, in Ronkonkoma, New York. The TriMax process manufactures lumber-like products using commingled plastic waste, primarily HDPE and industrial scrap. TriMax lumber contains compatibilizers to bind mixed resins to form the lumber product (Plastics Technology, 1990a). In addition, reinforcing fibers and surface treatments are used to increase the tensile strength and flex properties of the lumber. TriMax lumber is available in a variety of nominal sizes in accordance with lumber industry standards with lengths up to 24 ft. Trimax lumber has been used for landscaping ties, retaining walls, park benches, decking, and fencing. Trimax lumber has also been used in marine construction for building docks, piers, and bulkheading.

National Waste Technologies is manufacturing plastic lumber using the ET-1 technology at their recycling plant. The plant will ultimately process 120,000 lbs/day of plastic. Both post-consumer plastic waste and industrial scrap can be used for lumber manufacture. Lumber samples up to 6 in. x 6 in. in cross section and up to 12 ft long can be molded using the ET-1 technology at a rate from 200 lbs/hour to 400 lbs/hour.

RECYCLED PLASTIC PRODUCTS FOR THE HOUSING MARKET

Suppliers of virgin resin expect orders for an additional 2 billion lbs of plastic construction materials in the 1990s, on top of 1990 business of 11.9 billion lbs (Leaversuch, 1991). This market will become a major source of plastic waste: the fraction of all plastic wastes (industrial and post-consumer) from building and construction uses is expected to increase from 2 to 8 percent from 1990 to 2000, the largest percentage increase of any waste generation sector (Curlee and Das, 1989).

Plastic lumber products appear promising as a substitute material in some of the new applications of plastic construction materials.

Leaversuch (1991) and others have identified the following:

- o 8 ft x 28 ft stress skin panels made of plastic insulating foam sandwiched between plies of wood or other materials will replace 2 ft x 4 ft wood building elements. Energy efficiency is promoted via fewer, tighter joints, the insulating quality of the PS or polyurethane (PUR) foam, or of other plastics that may be used, and reduced installation time and labor.
- o Plastics currently are little used in roofing systems. Seventy-five percent of the market is asphalt-glass fiber-reinforced tile; the rest is metal, wood, slate, or clay. There are opportunities for plastic and recycled plastic products since roofing is labor-intensive, with minimal integration of design. One company is testing a flame-retardant, UV-stabilized, glass-reinforced, polycarbonate-based material

made by the General Electric Company (GE), which is designed to resemble clay or slate. It is made in four foot square panels with nailing holes molded in. Matching guttering, solar heating, insulation, and skylighting products are expected to follow. Note that the lighter-weight plastic roofing could reduce load-bearing requirements in walls.

- o Increased use is expected of recycled plastic in polymer concrete, glass-filled vinyl modular panels or doors, panels composed of extruded PS and clapboard, and other construction-like applications, and of lumber made from plastics and other materials. Wall panels for homes can have wood, metal, or concrete skins bonded to an insulation foam core -- a key component in shell construction. Shell construction system "cuts utilities by 50 percent, reduces construction time, and yields more loadbearing strength," according to J. LeGrand of Stress Panels, Inc., a company working with Dow Chemical Co. (Leaversuch, 1991).
- o Garage doors: 95 percent are now steel or wood, and require one-half horsepower motors. BF Goodrich claims that lighter-weight compression-molded vinyl panels, and glass-reinforced injection-molded PVC pulleys, tracks, and springs would allow smaller motors (Leaversuch, 1991).
- o Plastic houses: GE Plastics is experimenting with model homes using virgin and recycled plastic,

including lumber-like materials, in innovative applications (GE Plastics, 1989).

The most promising applications for plastic lumber and similar materials appear to be garage doors, roofing systems, and filler in sheet-like material, such as stress-skin panels and insulating panels. However, further engineering is needed to integrate recycled waste plastic and required additives into technology developed originally for virgin plastics.

COMPARISON OF THE PHYSICAL PROPERTIES OF WOODEN LUMBER AND PLASTIC LUMBER

A comparison of the physical properties of wooden lumber and plastic lumber was undertaken by the Waste Management Institute (WMI), at the Marine Sciences Research Center (MSRC), The University at Stony Brook, New York, to determine the suitability of plastic lumber as a wood substitute. While wood has been used in construction and engineering applications for centuries, the use of plastic lumber is recent. Accordingly, data describing the engineering properties of wooden lumber are readily available while engineering data for plastic lumber products are limited.

Engineering data describing the physical properties of plastic lumber were obtained from various vendors. A complete listing of the engineering properties provided by the vendors is given in Appendix A. Engineering properties, including specific gravity, compressive strength, flexural strength, biological resistance, chemical resistance, and weathering resistance were chosen to compare the properties of each material (Table 2-1).

Table 2-1. Physical properties of wood and mixed plastic lumber.

Material	Specific Gravity	Parallel Compressive Strength (psi)	Perpendicular Compressive Strength (psi)	E ^a Value (million psi)
Plastic Lumber				
NWT	0.93	---	---	0.075
Hammer's	0.91-0.96	3,500	---	0.043-0.088
Trimax	0.5 (0.05)	1,740	690 (60)	0.45 (0.02)
Rutgers				
100%	0.93 (0.01)	3,166 (87)	---	---
60/15/15/10	0.89 (0.01)	3,900 (22)	---	---
60/15/12/10/3	0.89 (0.01)	3,900 (25)	---	---
50/50	0.08 (0.01)	4,120	---	---
Wooden Lumber ^b				
White Pine	0.35	4,800	440	0.99
Red Oak	0.63	6,760	1,010	1.82
Red Maple	0.54	6,540	10,001	1.64
N. White Cedar	0.31	3,960	310	0.10

^a Modulus of elasticity (E) is a relative measure of a material's stiffness.

^b Average coefficient of variation for physical properties of wood: specific gravity (10%), compression parallel to grain (18%), compression perpendicular to grain (28%), and modulus of elasticity (22%).

Specific Gravity

The specific gravity of a substance is the ratio of its density to the density of water. For wood, specific gravity is a good index of its mechanical properties. Generally, a wood specimen with a high specific gravity will also possess good mechanical properties. Specific gravities of the wood species shown in Table 2-1 were less than water and ranged from 0.31 for northern white cedar to 0.63 for red oak.

The specific gravities of plastic lumber samples were higher than wood yet less than water. The specific gravity of lumber samples ranged from 0.75 for Trimax lumber to 0.96 for Hammer's plastic lumber (Table 2-1). Unlike wood, specific gravity is not necessarily a good index of mechanical properties for plastic lumber. The American Society of Testing Materials (ASTM, 1988b) D-792-86 "Standard Test Method for Specific Gravity and Density of Plastics by Displacement" is recommended for determining the specific gravity of plastics.

Compressive Strength

The compressive strength of a material is the maximum load carried by a material at the point of deformation during a compression test. For plastics, ASTM (1988c) D695-85 "Standard Test Method for Compressive Properties of Rigid Plastics" is recommended for determining the compressive strength of plastics. The method determines the mechanical properties of rigid plastics when compressed at low uniform rates of straining or loading.

Clear straight-grained wood is used to determine fundamental physical properties for a particular wood species. There are variations due to the natural growth characteristics of

trees. Wood products may contain knots, grain irregularities, or pitch pockets, which will affect the lumber's physical properties. Compressive strengths of the wood products range from 3,960 psi for northern white cedar to 6,760 psi for red oak (Table 2-1). Compressive strengths for plastic lumber ranged from 1,740 psi for Trimax lumber to 4,120 psi for the Rutgers 50/50 mixture.

Flexural Properties

The modulus of elasticity is a measure of the relative stiffness of the material. The test provides an indication of the degree to which materials resist bending. ASTM (1988d) D-790 "Standard Test Methods for Flexural Properties of Unreinforced Plastics and Electrical Insulating Materials" is recommended for determining the flexural properties of plastics. A high modulus of elasticity indicates that the material resists bending more than a material with a low modulus of elasticity.

The modulus of elasticity for wood samples varies from 0.8 million psi for northern white cedar to 1.82 million psi for red oak (Table 2-1). In contrast, the modulus of elasticity for plastic lumber varied from 0.043 million psi for Hammer's lumber to 0.45 million psi for Trimax lumber. The modulus of elasticity for plastic lumber decreases as load increases whereas the modulus of elasticity for wood remains relatively constant under various loads.

Creep

Creep is defined as the permanent deformation of a material that occurs over extended periods while supporting a load. Deformation of a material can continue for years, even at low stresses. Creep increases with increasing stress. With

high stress, the material will fail. Fluctuations in temperature and humidity will cause creep to increase. For wood, a 50 °F increase in temperature can cause a two- to three-fold increase in creep (Forest Products Laboratory, 1987). Creep in plastics may occur at or below room temperatures. Field studies have not yet established how much plastic lumber deforms under load with time.

Biological Degradation

Molding and staining do not seriously affect the mechanical properties of wood; however, they do indicate that conditions are favorable for the development of decay fungi or soft-rot fungi. Decay fungi metabolizes the cellulose fraction of wood which gives wood its strength. Decay fungi can significantly reduce the mechanical properties of wood. Decay, however, can be controlled or prevented if the wood is kept dry.

Insect damage may occur in trees, logs, and unseasoned or seasoned lumber resulting in the loss of the mechanical properties of wood. However, proper wood treatment measures can largely eliminate insect damage.

Wood damage by marine-boring organisms is universal. Shipworms, worm-like mollusks including several species of Teredo and Bankia, are the most destructive marine borers. These organisms bury themselves in the wood and feed on the wood borings and organic matter extracted from seawater. The surface of the wood may only show slight perforations while the interior of the wood may be completely honeycombed resulting in the deterioration of the mechanical properties of the wood.

The natural resistance of plastic lumber to biological attack negates the need to treat the material with a biocide. Conventional wood piles are treated with copper-chromium-arsenates (CCA) and/or coal-tar creosote to prevent damage from borers. The life of the treated pile is influenced by the thoroughness of the treatment, the care used in avoiding damage to the treatment coating during installation, and the severity of the borer attack. Service records show that treated lumber pilings last from 10 years to 48 years in coastal waters (Forest Products Laboratory, 1987). Although the treatment results in longer life for the pilings, the treatment coatings may leach unacceptable levels of contaminants into the environment and may affect non-target organisms.

Chemical Resistance

Wood is resistant to many chemicals and has been widely used in the chemical processing industry for storage tanks and structures. Wood is superior to steel and cast iron for its resistance to mild acids and acidic salts. In general, alkaline solutions tend to be more destructive to wood than acidic solutions. Other chemicals, however, may degrade wood by either swelling or permanently damaging the wood structure. Water, alcohols, and some other organic liquids can swell the wood without damaging the wood structure.

Manufacturers claim that plastic lumber resists oil, salt, and other chemicals. Plastic lumber is also unaffected by alkalis and acids at temperatures up to 150.8 °F and most organic solvents at room temperature.

Environmental Weathering

Long-term weathering of wooden lumber results in color change and warping (Forest Products Laboratory, 1987). The color of wood is affected shortly following exposure to weather. With continued weathering, all wood turns grey; however, only the wood at or near the surface is affected. The affected region is primarily composed of partially degraded cellulose fibers and micro-organisms. The weathering process is slow -- on average one quarter of an inch of wood is lost in a century (Forest Products Laboratory, 1987). In relatively dry and moderate climates, the mechanical properties of wood show little change with time. Test results for very old timbers suggest that losses in strength occur only after several centuries of normal aging (Forest Products Laboratory, 1987).

The degree of warping in a weathered wood specimen varies with the density, width, and thickness of a board. The greater the density and the greater the width in proportion to the thickness, the greater the tendency to warp.

The eventual rate of weathering of recycled plastic products is affected by the past weathering history of the commingled plastics used during manufacture, the degree of thermal processing of the waste plastic during manufacture, and the meteorological variables following placement of the product. The past weathering history of any plastic scrap is important as the mechanical properties of stable polymers are known to degrade following UV exposure. As a result, plastic litter may not be a suitable feedstock for plastic recycling. Reprocessing plastic also markedly sensitizes polyolefins to photo-oxidation.

The susceptibility of recycled plastic products to UV degradation is also increased with reprocessing. Therefore, reprocessing plastic litter or plastic lumber may result in a product that may possess inferior engineering properties and be sensitive to weathering. The mechanical properties of polymers change during the processing of polymers into products due to mechano-oxidation. The introduction of oxygen species to the polymer, particularly hydroperoxides and carbonyl compounds, results in the decrease in the overall durability of the plastic product (Scott, 1978). Polymers, unlike metals, cannot be reprocessed indefinitely without the loss of performance. For example, the melt flow index of polyethylene markedly decreases on repeated processing (Sadrmoahaghegh and Scott, 1980). A combination of reprocessing and photo-oxidation of the polymer affect the mechanical properties of the polymer even more.

Plastic lumber is a new material and sufficient data are not available to determine long-term performance. The rate of weathering of the plastic lumber will depend on climate. Factors such as freeze/thaw, UV intensity and duration, and temperature will influence the rate and extent of weathering. The outdoor use of plastic lumber subjected to load, either constant or periodic, will likely result in changes in the engineering properties. Lifetime estimates of hundreds of years for plastic lumber manufactured using recycled plastic are premature without studies to evaluate weathering.

Fire Safety

Both wood and plastic will burn when exposed to heat and air. Thermal degradation of wood occurs in stages. Wood first becomes dehydrated at temperatures up to 302 °F. Wood charring occurs at temperatures ranging from 212 °F to 482

°F and active degradation occurs at temperatures from 536 °F to 932 °F. Finally, flaming is the combustion of volatile organic products of thermal degradation.

The flammability of plastic lumber will depend on the composition of plastics used in the manufacture of the lumber. The flash point of plastic lumber varies from 629.6 °F to 658 °F for National Waste Technologies lumber and for Trimax lumber, respectively (Appendix A). One of the most important problems associated with fires is the production of smoke. Smoke typically contains gasses, solid particles, and droplets of liquids and usually contains noxious and toxic substances. Most fire deaths occur as a result of exposure to smoke or the depletion of oxygen (Harwood and Hall, 1989).

Trimax lumber reports that thermal decomposition products of their plastic lumber include carbon monoxide, water, acrolein, formaldehyde and other organic vapors. The composition of the other organic vapors could vary widely due to the inhomogeneity of the mixed waste plastics in the lumber product. Commingled plastic waste may contain plastics manufactured using a variety of additives including UV stabilizers, antioxidants, pigments, and plasticizers. The production of noxious smoke resulting from the combustion of these materials may occur and warrants further study.

EFFECTS OF DEGRADABLE PLASTIC ON THE RECYCLABILITY OF PLASTICS

Environmental groups and recyclers have stated that using degradable plastics, polymers that contain additives designed to accelerate the deterioration of the product when it enters the environment, will interfere with recycling

efforts (Renfree et al., 1989; Sadun et al., 1990). Degradable plastics currently make up less than 1 percent of the plastics market (Mills, 1990). The use of degradable plastics, however, is increasing and many states require the use of degradable plastics for some packaging applications (US OTA, 1989). As a result, degradable plastics will most likely become increasingly incorporated into the commingled plastic waste used as feedstock for recycling efforts. The major concerns of the groups opposed to using degradables are that degradable plastics in the feedstock may result in difficulties processing the materials in extruders, and that products manufactured using material containing degradable plastics may accelerate the rate of deterioration of recycled plastic products once they enter the environment.

Degradable technologies are often applied to plastic products that are not usually targeted for collection for plastic recycling. Current collection and recycling efforts are focusing primarily on HDPE and PET bottles. Products targeted for degradable additives include LDPE and linear LDPE products destined for composts or landfills. In addition, plastic products, which comprise a main component of litter, are also targeted for degradable additives. Plastic garbage bags and yard waste compost bags, disposable diaper backings, and plastic six-pack beverage rings are among the products appropriate for degradable technologies. Although degradables represent a small percentage of the total plastic waste, it appears likely that degradables will be incorporated within the commingled plastic waste stream.

Processing commingled plastic waste containing degradable plastics using extruder technology may not be critical in limiting the recyclability of the plastic feedstock. The commingled waste plastic feedstock usually contains contaminants including paper, aluminum foil, food particles,

and textiles. The manufacturers of the ET-1 extrusion technology claim that these contaminants are not a problem in small quantities (Maczko, 1990). As the degradable plastic content of plastic waste is small, it should not present a major obstacle to recycling efforts. In addition, recent efforts at reprocessing starch-based degradable plastics have been successful. A Canadian reprocessing company claims to be the first North American recycler to recycle starch-based plastic scrap from diapers and garbage bag manufacturers (Plastics Technology, 1990a). Resource Plastics Corporation, Brantford, Ontario expects to have capacity to separate, clean, and repelletize the scrap starch-based resin for resale.

Since plastics containing degradable additives are a small percentage of the total commingled waste plastic, additives that initiate degradation may be diluted within the commingled plastic feedstock thereby reducing their overall effectiveness. Degradable additives are only effective if they are accessible to the environment. Following processing and extrusion, photodegradable or biodegradable additives may be lost through volatilization during manufacture or encapsulated within a recycled lumber product and rendered ineffective since they are no longer exposed to the environment.

ENERGY IMPACTS OF MANUFACTURE AND USE OF PLASTIC LUMBER

Several studies conducted in the last twenty years argue that recycling can save large amounts of energy (Pollock, 1987; Ross and Steinmayer, 1990; Stauffer, 1989; Powell, 1981; Young, 1991; US EPA, 1974). Many of these studies claim that plastics recycling can save a great deal of energy when the recycled plastic replaces virgin plastic (e.g., Milgrom, 1986; Gaines and Wolsky, 1983). Plastic

lumber and certain related products made by recycling plastic waste make energy comparisons difficult since it is usually unclear what materials, if any, are replaced by making and using the recycled plastic item.

The energy balance of a product refers to the overall, "cradle-to-grave" energy costs or savings associated with making and using it. In recycling plastics, for example, energy is used to run shredders, extruders, and cooling apparatus, to construct and heat the plant itself, to collect discarded plastics, and to transport materials. How much energy the manufacture and use of secondary materials from plastics saves or costs overall, however, depends on several other energy factors. It depends on what would happen if the original plastic wastes were not recycled (but instead were, say, incinerated). Estimates of overall energy costs or savings also depend on the application or end-use of the product (say, as energy-conserving insulation). Furthermore, energy balance claims must take into account the nature of the energy itself (whether, for example, it is high-quality electricity or low-quality, low-temperature heat).

Many technology-specific factors also affect energy balances. These include the particular plastic lumber manufacturing technology; the resin mix employed; the density, form, source, and degree of contamination of the plastics; the collection and sorting history; the size of the plastic lumber; and the species of any wood replaced.

The final factor on which claims of overall energy savings or costs depend is what flows of energy are counted in or excluded from the "system boundary" of the tabulations. For example, 1) some energy comparisons of wood and plastic count the energy embodied in the plastic feedstock but not

the solar energy embodied in the wood as energy costs of manufacture. 2) The treatment of indirect and remote energy impacts is problematic (for instance, should the analysis take into account the possibility that different load-bearing abilities of plastic lumber and wooden lumber could lead to different material requirements, and hence different energy draws, in certain construction applications)? 3) Some analysts prefer to measure the energy value of electricity at the outlet (i.e., according to its heat content, 3,412 Btu/kWh) while others prefer to count the energy used to make and transmit the electricity (11,500 Btu/kWh is often used). The three competing methods for calculating this value also yield different conversion factors (Perry et al., 1977). 4) Many net energy analyses subtract avoided energy costs from overall energy costs. While the same rationale seems to require counting any energy savings precluded by making and using plastic lumber, many energy studies fail to do so. 5) Many energy studies include as energy costs the energy used to construct buildings and equipment. Plastic lumber manufacture uses large amounts of water for cooling. Yet the energy used to build and operate water delivery systems (pro-rated according to the amount used by the plant) is rarely counted in energy studies.

The analyst must decide whether to charge each energy flow to plastic lumber, whether it represents a cost or a saving, and many other questions. Hence, overall energy costs must be discussed in light of these qualifications.

The direct energy requirements for making 1 lb of plastic lumber from post-consumer plastic waste are assayed to determine how much energy is used to make plastic lumber. The presence of significant quantities of mixed plastic waste is taken as a given, so that energy costs incurred in

manufacturing and using the original virgin plastics are excluded. Direct energy requirements include in-plant processing, general plant overhead energy requirements, such as for lighting and space conditioning, and transportation energy. Factors affecting direct energy use are evaluated and indirect energy requirements are also discussed.

The method used to assess energy requirements is called "process energy analysis," energy analysis that principally depends on measuring the energy flows taking place in plastic lumber manufacture directly. The alternative analytical method, "input-output analysis," employs national economic and energy data, sometimes of arguable applicability, showing levels of production, costs of shipments, and estimated energy equivalents, for hundreds of sectors of the economy. Since there is very little information on the energy used to make plastic lumber, a survey of plant energy consumption and other relevant data was taken in order to acquire information for process analysis.

The energy used to make and use plastic lumber is compared to that for making and using comparable products of virgin plastic and wooden lumber. Other factors relevant to energy usage, such as product lifetimes, energy recovery from incineration, markets, and applications with significant energy implications, etc., are discussed. The resulting comparison portrays the difference that the manufacture and use of plastic lumber could make to society's energy resources.

ENERGY SURVEY

A survey, "Plastics Recycling and Energy Use," was mailed to 53 plastics recyclers (Appendix B). These included

companies that make plastic lumber or similar items as a primary product, and several reclaimers whose product is used by such companies. Eighteen respondents have provided complete or substantial data. The survey strongly emphasized direct energy costs. These are the quantities of fuel, heat, and electricity actually used in the main steps of the recycling system (for example extrusion, plant heating and cooling, and transportation).

Respondents characterized their feedstocks by weight percentage according to resin, source, original form, and form delivered to plant. Other questions covered grade, color, and contamination restrictions, in-plant upgrading and pre-processing, intermediate form, if any (e.g., flake, pellet), and final output form. Respondents also provided statistics and descriptions of in-plant electricity use and in-plant fossil fuel use, production levels and capacities, and energy consumption attributable to stages of recycling operations and to general heating and lighting overhead. The only question most respondents did not answer concerned transportation energy, either because transportation was not part of company operations, or because records were unavailable. Detailed commercial rate schedules were obtained from the company's utility to determine kilowatt-hour consumption, and the resulting figures were confirmed with the company, whenever possible.

Most (14) respondents are fabricators or reclaimers using mixed post-consumer plastics wastes either alone, or in significant quantities combined with other kinds of plastic wastes. Examples of these latter wastes are densified or undensified clean or dirty films, post-consumer commingled PET/HDPE/PVC rigid containers, and post-consumer foamed PS. Some (4) respondents did not use significant quantities of mixed post-consumer plastic waste, instead making plastic

lumber largely from such components as pre-consumer rigid packaging and molded part scrap, post-industrial PP regrind, post-industrial and post-consumer PVC automobile trim, and post-consumer PET/HDPE bottles. In some of these cases the resulting mix of resins did not differ greatly from that found in mixed residential or at least commercial MSW plastics. In other cases, the feedstock was considerably more homogeneous.

Polyethylenes, and polyolefins generally, were the dominant resins for most manufacturers. While the balance between post-consumer and pre-consumer/post-industrial wastes varied greatly among manufacturers, only one respondent reported using virgin resins, and then only for 5 percent by weight of feedstock. It may be that other manufacturers use some virgin resins occasionally.

Three respondents said they incorporated small amounts (5 percent to 10 percent) of nonplastics such as wood or steel into their product. The steel was used in 13 in. diameter x 60 ft pilings, by far the largest products found in the survey.

For purposes of comparison and cross-checking, a few surveys (not included in the tabulations for plastic lumber) were sent to recycled plastics fabricators and reclaimers who make products other than plastic lumber. Other information about energy use in plastics recycling was obtained from equipment manufacturers, waste haulers, researchers, trade associations, and other sources.

The variety of manufacturing circumstances was so great that no two manufacturers can be compared directly. Any two manufacturers studied differ in at least one, and usually several, major areas: resin mix, resin sources

(post-consumer, etc.), restrictions on grade, contamination, or resins allowed, original and intermediate physical form (bales, flakes), presence and type of in-plant upgrading or pre-processing, type of extrusion, and accompanying heating and cooling equipment. These caveats must be taken into consideration when interpreting the aggregated survey data.

Direct Energy Consumed In-plant

The analysis of the survey found the average in-plant energy required to make 1 lb of plastic lumber to be 745 Btu, including both reclamation and fabrication. This estimate applies to the plant as a whole including, for example, energy to heat and run offices as well as the plastic processing equipment itself. Many plastic lumber systems consume from 415 to 880 Btu/lb, others fall in the range from 1,050 to 1,725 Btu/lb. These estimates do not apply to expanded polystyrene (EPS) and dirty agricultural film recycling. On average, it is estimated that 87 percent of in-plant energy is process energy and 13 percent overhead and other non-process energy, for full recyclers, reclaimers, and fabricators alike. This means that average in-plant process energy is approximately 650 Btu/lb. Electricity runs major process steps for most respondents. For full recyclers, an average of 19 percent of in-plant energy comes directly from fossil fuels, although this figure ranges from 0 to 49 percent in individual plants. None of these figures include energy embodied in the plastic itself.

The preceding figures count the Btu-value of electricity at the outlet. When electricity is counted at the Btu-value of the fuels used to generate it and transmit it to the plant (11,500 Btu/kWh is often used; Perry et al., 1977), the survey found that average in-plant energy is 2,060 Btu/lb of

product (with most plants consuming between 960 Btu/lb and 2,430 Btu/lb of product), of which 94 percent is estimated to be process energy. Again, these estimates do not apply to EPS and dirty agricultural film recycling.

Typically, 62 percent of in-plant process energy is consumed in fabrication steps, and 38 percent in reclamation. The reclamation fraction rises, if densification is used, as for film processing. These figures are based on survey data combined with information provided by manufacturers of complete plastic lumber systems. Survey data alone do not warrant firm estimates. Some recyclers contacted believed that reclamation and fabrication steps consumed roughly equal parts of in-plant energy, while other recyclers estimated the fractions at 0.25 and 0.75, respectively.

The allocation between process and non-process energies in-plant was derived as follows. Some respondents themselves estimated the fraction of total in-plant energy ascribable to overhead and other non-processing costs. For other respondents, the energy consumption data were such that this fraction confidently could be calculated. For example, some plants ran all process equipment on electricity, and virtually all non-process equipment on natural gas or other fossil fuels -- the exception being electric lighting; rough calculations show that lighting consumes perhaps one-half of 1 percent of plant electrical costs.

The estimate of 13 percent for non-process energy costs is the average of all the estimates respondent-generated and calculated. This estimate was then used to divide total in-plant energy costs between process and non-process functions for respondents whose data did not otherwise imply a division. For some services, such as fork-lift operations

and space conditioning, which also may contribute to cooling the extruded plastic, the boundary between process and non-process is obscure.

In some cases the reported energy consumption was lower than might have been expected on the basis of the energy consumption figures given in manufacturer product literature for similar or identical individual pieces of equipment. This can be attributed to synergistic effects of parallel production lines using certain equipment in common, scheduling and logistical arrangements to minimize down-time and equipment start-up time, deviation from manufacturer assumptions about cooling water temperature or about the balance between water cooling and ambient-air cooling, efficient conservation and re-use of waste heat, and waste stream control favoring resins that are less contaminated or otherwise easier to process.

No correlation was observed between Btu/lb and average production levels (lb/hour). The in-plant energy intensities given above include certain processing and overhead energy expenditures that occurred in non-responding plants. For example, part of the feedstock used by some respondents was pellet, regrind, or similar material reclaimed elsewhere (i.e., at a plant outside the system boundary of the direct energy analysis). Thus, two full recyclers reported that purchased pre- or post-consumer regrind formed 10 percent of feedstock. One reported using 50 percent regrind. Two fabricators purchased 100 percent plastic resins reclaimed elsewhere. In all of these cases, energy was expended in reclamation out of the system boundary; i.e., at non-respondent plants. The 62 percent fabrication/38 percent reclamation allocation of energy consumption was calculated from plants that did not use any material from non-respondent plants. This ratio was applied

to the energy used in non-responding plants to reconstruct how much energy would be used if all reclamation and fabrication occurred in responding plants.

In-plant energy use was high for respondent reclaimers due to the nature of the plastics concerned. Energy intensities, with electricity valued at 3,412 Btu/kWh, reported by two reclaimers of 100 percent EPS reported were 3.5 and 5.5 times the average for full recyclers. The energy intensity for a reclaimer of very dirty (up to 40 percent to 60 percent dirt) agricultural films was 2.2 times the full-recycler average.

Transportation Energy

Energy is used to collect plastics from residential, commercial, and industrial sites, to move plastics to a transfer station or MRF, and to bring them to the recycling plant. Energy also may be required to transport pellets and flakes from reclaimer to fabricator. Finally, energy is required to ship finished plastic lumber to distributors and/or application site. Additional energy may be consumed in on-vehicle densification, baling at transfer stations, segregation of plastics from mixed recyclables at MRFs, and so on, although the energy involved is not used for transport.

Determining how much energy is used in these operations, and deciding how much to attribute to plastic lumber manufacture and use, is difficult. This report excludes energy flows that occur in the normal course of events, irrespective of any plastic lumber manufacture. For example, it is assumed that all residential plastics discards are collected. Even when residential or commercial pickups are brought directly to the recycler under dedicated contract, it can be reasoned

that some or all of this energy would be consumed anyway to bring the plastics to a landfill, incinerator, MRF.

It is estimated that the energy to transport plastics can vary by as much as a factor of ten. For most enterprises studied, these energy costs appear to equal perhaps 10 percent of total in-plant energy consumption. The key to low transportation energy use lies in access to large post-industrial generators of plastics waste, and proximity to densely populated areas.

These estimates were derived from the following considerations. Respondents for whom an estimate could be made obtained 80 percent or more of their plastics from distances of 150 miles or less, and usually much less, 20 miles or so. This refers to distances from MRFs, transfer stations, or similar assembly points. Energy costs to bring materials to these points are not charged to plastic lumber. It is assumed that plastics having an average density of 150 lbs/yd³ are transported in fully-loaded vehicles that hold 30 yd³ of plastics and average six miles/gallon (mpg), using #2 diesel fuel releasing 138,690 Btu/gallon.

It is assumed these transportation energy costs also cover any shipping between reclaimer and fabricator, and densification occurring on the vehicle or at the MRF or transfer station. Energy costs of any other MRF operations are not counted. These assumptions suggest a typical transportation energy cost of 5.14 Btu/lb-mile. Based on respondent information supplemented by information from plastics recyclers in New York State, the average transportation distances are estimated as: 20 miles for recyclers in the suburbs of New York City using large fractions of mixed MSW plastics, and 100 miles for upstate recyclers and recyclers with more demanding resin

requirements. This yields a transportation energy cost of about 100 Btu/lb downstate and 500 Btu/lb upstate.

These calculations do not include any energy surcharges for indirect energy used to make the trucks, MRF's, and associated equipment themselves. Hence, total direct energy to make 1 lb of plastic lumber -- processing energy, overhead energy, and transportation energy -- is estimated in Table 2-2.

FACTORS AFFECTING ENERGY TO MAKE PLASTIC LUMBER

Energy intensities for making plastic lumber often range from 415 Btu/lb to 880 Btu/lb as noted previously. Special circumstances, however, lead to extremes of from 145 Btu/lb to 4,000 Btu/lb. Judging from respondent information and manufacturer literature, none of the process technologies studied (e.g., ET-1, Recycloplast, Bezner) appears to have a clear, generic energy advantage. Variations in feedstock composition and quality, ancillary processes (e.g., hydrocycloning, drying and washing), and other factors appear to dominate any generic energy advantages.

Respondents consistently identified these as the most energy-intensive processing steps: extrusion, drying and/or washing, and densification/size reduction. Fifty-three percent of respondents said energy costs were a critical factor in their operations, 26 percent found them important but not critical, and 21 percent found them minor. Some information is available on the energy flows attributable to individual process steps. The survey found that in-plant densification alone can require substantial energy, on the order of 900 Btu/lb for some machines.

Table 2-2. Total direct energy to make 1 lb of plastic lumber.

	Downstate Region	Upstate Region
Electricity: valued at		
3,412 Btu/kWh	845	1,245
11,500 Btu/kWh	2,160	2,560

According to several manufacturers, energy costs per pound rise as more thermosets and engineering thermoplastics are incorporated into plastic lumber. According to ET-1 literature, 20 percent or less non-thermoplastics is optimal although levels of up to 50 percent can be processed. Several recycling technologies that accept large amounts of thermosets are under development and are expected to significantly affect auto scrap recycling (Wood, 1991).

Recycling equipment for post-consumer processors tends to be bigger than recycling equipment for pre-consumer processing, owing to more rigorous processing environments and frequently larger throughputs. Even auxiliary equipment can be impressive in scale (for instance, a Herbold granulator weighs 44 tons). The energy required to make and operate such large equipment is not inconsiderable.

The following are suggested as the most promising measures for conserving energy in plastic lumber manufacture: 1) access to a large industrial chiller may reduce processing energy costs by 50 percent or more (this is an opportunity for "rust-belt" areas of New York State where chillers may have been built for large industries that now are underused or unused); 2) use of low-speed granulators (under 200 revolutions/minute [rpm], with outputs less than 440 lbs/hour) use significantly less energy, according to industry reports; 3) capture of extruder heat and re-use (e.g., in waste heat boilers and to dry plastics); and 4) better scheduling of operations to take advantage of night and off-peak electricity rates, and of savings from "just-in-time" scheduling.

SUBSTITUTION FOR VIRGIN PLASTIC AND WOODEN LUMBER

Developments in materials science and technology that are poised to revolutionize the construction industry may affect the energy concerns of this report and involve virgin plastics, engineered wood, and composites of plastics and other materials. Plastic lumber appears to have promise as a substitute material in some of the new applications.

Engineered Wooden Lumber

Recent technology in the wood products industry is replacing some of the lumber made from cutting up large older trees into smaller pieces, with small young trees, often of low traditional value, such as aspen, which are harvested, chipped, flaked, glued, and pressed to form boards. For example, one product, oriented strand board (OSB), now holds 20 percent of the market once held by plywood, which is made from peelings of big trees. Nearly 21 billion ft² of reference 3/8 in. plywood were made in 1990 (Pollack, 1991). Similar engineered wood products are available as replacements for regular lumber floor joists, roof trusses, and siding (Pollack, 1991). Some of these products have OSB cores with regular lumber flanges or veneer. A complete assessment of energy savings or costs due to the use of plastic lumber in place of wood would have to consider substitutions for both regular and engineered wooden lumber.

Virgin plastic applications are being developed rapidly in the housing and construction industry. Examples include virgin plastic panels, roofing systems, and garage doors. Plastic lumber may substitute in some cases.

Product Lifetimes and the Pallet Market

It is essential to take into account product lifetimes and patterns of use in comparing the energy draws of plastic lumber and wooden lumber. For example, if a plastic lumber picnic table can be made and delivered for the same total energy as an equivalent wooden picnic table, but lasts twice as long, the total energy per year of service is one-half as great. Given the variety of applications for plastic lumber and related products (Spaak, 1986), and corresponding wooden lumber products, it is not possible to assign typical or expected lifetimes. Research indicates this is so even for specific applications, such as park tables and benches, pallets, and railroad ties.

The expected or typical lifetime of wooden or plastic lumber varies enormously between applications and within individual applications. A wooden pallet may last a few days, a fence 20 years. The pallet's lifetime depends on the grade of hardwood or softwood used, any treatment or refurbishment undergone, the method of assembly and type of stringers used, the degree of rough handling by untrained or careless forklift operators, and the nature of the load carried, etc.

Similarly, lifetimes of plastic lumber will depend strongly on the resins and additives used, processing technology, exposure to soil or salt water, heat and cold, precipitation sunlight, and on other end-use characteristics. Although respondents' own estimates range from seven years to 50 years and up, reliable information is not available for plastic lumber in applications like highway sign posts, park benches, railroad ties, garden chairs, vineyard stakes, skids pallets, and bulkheads. Curlee and Das (1989) estimate life spans for virgin plastics at 25 years for building and construction uses and 10 years for furniture

and fixtures. However, lifetimes of comparable virgin products, even when known, may not match those of plastic lumber products. An examination of pallets, park benches, and highway and railroad applications is instructive in this regard.

A major manufacturer of HDPE foam injection-molded plastic pallets (not a respondent) uses 15 percent to 20 percent post-industrial reground HDPE and 80 percent to 85 percent virgin HDPE flake, and plans to make similar pallets for certain applications with these percentages approximately reversed. Recycled plastic is derived from milk-cases and open market sources, and from returned defective pallets, which are flaked in-plant. The other materials arrive flaked. The company does not use recycled plastic for certain specialty pallets requiring US Food and Drug Administration (US FDA) approval.

A plastic pallet generally weighs two-thirds as much as a similarly-sized wooden pallet. In some cases, plastic pallets weigh half as much -- e.g., some 16 ft² wooden pallets weigh 90 lbs, as opposed to 44 lbs for plastic. Energy savings for shipping alone might be assumed to be considerable. However, the situation is not so simple. According to members of the plastic pallet trade, plastic pallets last about 50 trips. Wooden pallets are often treated as one-way, one-use items, but, with reasonable care, may last three to five trips. There are also wooden-pallet refurbishers who strengthen old pallets for re-use or for new uses. These claims seem to suggest average lifetimes of perhaps three trips for wood and 50 for plastic.

Spokespeople of the wooden pallet industry say there is no typical pallet other than 48 in. x 40 in. grocery-type

pallet, and that lifetimes strongly depend on design, quality, care, and end-use. For grocery pallets, the industry suggests five to seven trips/year over approximately 1.5 years, for a total lifetime of 7.5 to 10.5 trips. These are regarded as low-quality pallets. Better-quality grocery pallets should last 42 trips. After about 24 trips, though, some repair might be expected -- a loose board or stringer. Higher-quality non-grocery pallets are reported to last 70, even 120 trips, again at five to six trips/year.

About half of the pallets (two to three billion total in the US with 534 million pallets produced annually and five to seven billion in use worldwide) are called shipping or single-use pallets; infrastructure is not generally in place for returning these pallets, which are often treated as expendable by receivers. The other half are referred to as returnable pallets.

According to persons contacted in the wooden pallet trade, plastics are not returnable. They creep, have low strength, and eventually give way. They do not last as long as some claim. While wooden pallet proponents acknowledge that plastics are washable and sanitary, they note that so are newly developed wooden pallets. These are treated with a sealer over the lumber or plywood, can be steam cleaned, and have passed tests simulating six years of rough handling. Proponents of wooden pallets stress that their product is repairable and that plastic is not, and that a specialty industry already makes a living doing just that. Even after the wood is useless as a pallet, it is said often to be recycled or incinerated. For these reasons, wooden pallet advocates argue that their product is more economical in dollars and in energy costs, especially if the higher-quality pallets are used.

Park Benches and Picnic Tables

Conflicting information was obtained on the in-service lifetimes of wooden and plastic lumber public park benches and picnic tables. One Long Island town's parks maintenance department says that tables and benches made of CCA-treated lumber last 15 years. The town has had a few recycled plastic tables and benches; after one year, they look new. This town experiences very little vandalism. Parks maintenance employees in a second Long Island town report that its CCA-treated wooden tables and benches last 10 years; however, many must be replaced annually due to vandals. Employees say that defacement of the town's recycled plastic tables and benches can easily be removed, and so do not need as frequent replacement. They also claim that plastic items are twice as heavy as wood: four employees are required to carry a plastic table, versus two for wood.

A third Long Island town has 15 wood benches and picnic tables. Four must be replaced every year, due to vandalism and impacts from cars. The oldest table is 13 years old. The carpentry foreman of a large county parks maintenance shop observes that cypress tables and benches weighing 100 lbs to 120 lbs installed in the 1930s are just beginning to show significant deterioration. The county at one time switched to Douglas fir, which lasted only four to five years. The county now uses South American Paulope wood tables weighing 250 lbs to 300 lbs.

Paulope tables/benches are virtually indestructible. They last "forever" (which is taken to mean 30 years at a minimum). Apparently the tables cannot burn. They cannot be easily vandalized. They can't be sawn in the county shop, and so must be bought pre-cut and/or pre-assembled.

One contact said "it's better than recycled plastic," which was regarded as prone to sag in hot weather, hard to cut, breaking saw blades, and leaving resin in the air when cut.

Highway Maintenance Devices

The highway department of a Long Island town is pessimistic concerning the lifetime of recycled and non-recycled plastic highway paraphernalia, such as barricades (sawhorses, hexagonal drums, cones). Plastic lumber can be used in some of these products. The town department uses no metal barricades or sign posts because they are promptly stolen. The hexagonal plastic barriers are said to shatter when hit by a car and will not re-stack, once hit. On the other hand, wood gear is repairable and stolen less often. In-service lifetimes could not be compared simply because the items in question are stolen so often. For example, of 100 cones placed for an event last year, 30 were left after one day. Maintenance employees thought this was better than average.

Railroad Ties

Some manufacturers claim that plastic lumber that is suitably formulated and possibly reinforced with steel can replace conventional railroad ties. Little information on this subject was found. The Long Island Railroad has 1.9 million ties under 701 miles of track (D. George, personal communication). Conventional ties are creosote-treated oak weighing 10 lbs/linear ft to 12 lbs/linear ft. The standard size tie is 8 ft 6 in. x 7 in. x 9 in. and weighs between 85 lbs to 102 lbs (American Railway Engineers' Association, personal communication). The Long Island Railroad (LIRR) reports a 30-year lifetime for conventional ties. Some

railroads report 35 years. In the next five years, the LIRR expects to replace 40,000 to 45,000 ties.

The railroad has tried limited amounts of the heavier African woods Azobe and Icki, concrete ties, and pressed, heated ties made from fiberglass resin and wood chips. The wood chips were ground from the railroad's own discarded ties. Product lifetimes are expected to exceed those for most wood products in marine and other aquatic applications, such as bulkheads, shoreline protection panels, and retaining walls along golf course ponds and canals. However, reliable information on this subject, too, is limited.

ENERGY COMPARISON OF PLASTIC LUMBER AND VIRGIN PLASTIC

The energy savings from manufacture and use of 1 lb of plastic lumber that replaces 1 lb of virgin plastic is estimated as follows. First it is assumed that 1 lb of plastic lumber replaces the production of 1 lb of individual virgin resins in the same ratios as in the plastic lumber. Accordingly, for each plant, net processing energy (NPE), net head of feed combustion (HFC), and product heat of combustion (PHC) are determined for 1 lb virgin plastic whose resin mix matches that of the input feedstock resins used to fabricate plastic lumber in the plant. The results (Table 2-3) represent energy values averaged across plants for virgin plastic replaced by typical plastic lumber.

The second step is to determine energy saved when plastic lumber replaces virgin plastic. This depends principally on the following: 1) any differences in post-production transportation energy; 2) differences in energy costs or savings incurred by the end-use (insulation, lighter garage

Table 2-3. Estimated energy values for virgin plastic matched in composition to typical plastic lumber (Btu/lb).

With Btu value of electricity of:	3,412	11,500
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Resins

NPE	6,870	10,600
HCF	17,570	27,100
PHC	12,770	19,700

Conversion: resin to product

In-plant	230	640
Transportation	300	300

NPE = net processing energy = energy content in fuels used in manufacturing, less heat of combustion of byproduct fuels not consumed in processing, HCF = heat of combustion of feedstocks, including oil and natural gas. PHC = product heat of combustion for all processing products except fuel byproducts. NPE is equivalent to processing energy, HCF to the primary energy foregone by physically sequestering oil and natural gas as plastic material (rather than using them as a source of energy), and PHC is the heat energy that would be generated if the product were incinerated. Sources are sometimes unclear how and whether certain energy flows. For example, transportation energy, energy embodied in the plants themselves, and energy changes accompanying changes in polymer structure are accounted for in the calculations. Moreover, a single source sometimes aggregates data from other sources calculated according to differing accounting systems.

Values are averages for non-polystyrene-only plants reporting sufficiently detailed resin proportions in feedstocks. For polystyrene only plants, values are 10,700, 23,600 and 17,800 Btu/lb, respectively. Energy values for individual virgin resins are from Curlee and Das (1989). Their data covers energy use through extrusion and subsequent pelletization (etc.) of the resin, but do not cover additional energy used to make the final product. In addition to providing energy intensities for individual resins, Curlee and Das (1989) also use 12,000 Btu/lb as a typical reference figure for manufactured plastics generally.

While it happens that NPE, HCF, and PHC averages weighted by production levels appear to fall within 10% of the values in Table 2-2, it was judged that the unweighted averages are based on somewhat more reliable reported information, and provide a better estimate of typical or reference plastic lumber.

NPE, HCF, and PHC apply to resin manufacture only (usually to the pellet stage). However, additional energy is expended to convert the resin to the finished product (and possibly in additional compounding and blending steps). For fabrication of virgin lumber-like products, it is assumed that (per pound) this in-plant energy equals 1/2 of the average in-plant energy used to fabricate reclaimed plastic into plastic lumber. The lower energy cost is assumed to be due to greater homogeneity, less contamination, greater efficiency from machinery "fine-tuned" to less variable operating conditions, etc. It is further assumed that 1/2 of the energy in resin manufacture (NPE) is electricity, 1/2 fossil fuel, and that, as with plastic lumber manufacture, 81 percent of the in-plant energy expended to convert the resin to the finished product is electricity, and 19 percent fossil fuel.

Transportation energy above refers to transportation (if any) from resin manufacturer to converter (including any intermediate steps for compounding, etc.). No data was found on this subject. It is assumed 300 Btu/lb for virgin plastic is used in New York State (the mean of the estimated "upstate" and "downstate" chargeable transportation energy costs incurred between the MRF or transfer station and the plant where the final product is made).

doors, etc.); 3) the relative lifetimes of the plastic lumber and virgin plastic products; 4) distinguishing between avoided energy consumption and avoided energy sequestration -- energy supposedly released by not sequestering the energy in the plastic itself, or avoided foregone energy; and 5) whether the plastic lumber is assumed to have the same fate as the virgin plastic it replaces (incineration, landfilling).

Per-mile post-production transport energy costs are assumed to be the same, since the densities of virgin plastic and plastic lumber products are close. Transportation energy costs incurred in making plastic lumber and virgin plastic are already included in the energy costs that are being considered. The only differences in transportation energy costs, therefore, would have to arise from differences in average shipping distance from the plant making the final product to the job site, including intermediate stops for distribution and retail sales. Virgin plastic products are often shipped long distances, although average figures were not found, especially for lumber-like virgin plastic products. Standard shipping distances for plastic lumber products are unknown; however, most plastic lumber manufacturers advertise regionally or nationally. Accordingly, it is assumed that overall transportation energy costs for making and using virgin plastic and plastic lumber are comparable.

Comparable virgin plastic and plastic lumber products are assumed to have the same end-use energy conservation characteristics (e.g., insulation value). Service lifetimes also are assumed to be comparable. Relevant energy savings can occur in two forms, avoided energy consumption and avoided energy sequestration. These affect society's energy resources in logically distinct ways. The former either

releases energy that would have been generated anyway for other uses in society, or makes it unnecessary to generate that energy in the first place. For example, recycling a plastic bottle takes less process energy than making a virgin plastic bottle. The difference improves society's energy picture, either by freeing that much energy for other uses, or by eliminating the need to make it at all.

Many energy studies uncritically apply the same reasoning to the energy embodied in the plastic itself, whether measured as the sum of heats of combustion of oil and natural gas feedstock, as product heat of combustion if incinerated, or in other ways, and include this energy in energy savings from recycling. This is misleading. It is true that recycling a plastic bottle improves society's materials picture by either freeing for other societal uses the raw material that otherwise would have been made into the virgin product, or by making the extraction and production of this material unnecessary. That is, recycling engenders avoided material consumption. It does not follow that the energy embodied in the material is saved at all (although the main use for the feedstock is conversion to fuels). If the feedstock is converted into a different product, the embodied energy would remain and no net energy benefit would accrue to society. In other words, there is no guarantee that less energy is sequestered. One need consider only avoided energy consumption -- the difference in total actual energy expenditures for virgin plastic and plastic lumber.

Table 2-4 compares total direct energy consumed to make 1 lb of virgin plastic with that required to make 1 lb of plastic lumber of matched composition. Total direct energy, as noted earlier, is the sum of process energy, overhead energy, and transportation energy through the manufacture of the final product. According to Table 2-4, compared to

Table 2-4. Estimated total direct energy costs for manufacture of virgin plastic lumber and secondary plastic lumber (Btu/lb).

With Btu value of electricity of:	<u>3,412</u>	<u>11,500</u>
Total direct energy costs		
Virgin Plastic	7,400	11,540
Plastic Lumber	1,045	2,360
	<hr/>	<hr/>
Avoided energy consumption	6,355	9,180
Energy-equivalent of avoided materials consumption		
Measured as HCF		27,100
Measured as PHC		19,700

Energy-equivalent of avoided materials consumption need not result in any actual energy savings.

manufacture of virgin plastic, manufacture of plastic lumber saves 6,355 Btu/lb for electricity valued at 3,412 Btu/kWh or 9,180 Btu/lb at 11,500 Btu/kWh. Since virgin plastic and plastic lumber are assumed to have roughly similar product lifetimes, post-production transportation energy costs, and end-use energy impacts (e.g., as insulation), energy differences from the use depend only on where the virgin plastic and plastic lumber products end up -- in an incinerator or a landfill. Four cases are distinguished:

Case 1: Burning Plastic Lumber vs. Burning Virgin Plastic

The only consideration is the differences in incinerator heat recovery. Energy recovery (PHC) for plastic lumber is assumed to be 5 percent less than for virgin plastic, owing to small amounts of dirt, glass, metal, and other contaminants in the former. In this case, virgin plastic saves 640 Btu/lb and 985 Btu/lb, depending on whether electricity is valued according to its heat rate at the outlet, or according to the heats of combustion of the fuels needed to generate and transmit it. However, when manufacturing energy differences are included, in this case plastic lumber saves 5,715 Btu/lb and 8,195 Btu/lb, respectively, from manufacture and use. Less energy is required overall to make and eventually burn plastic lumber than to make and eventually burn a similar virgin product.

Case 2: Landfilling Plastic Lumber vs. Landfilling Virgin Plastic

No differences in energy impacts.

Case 3: Recycling vs. Incineration with Replacement Virgin Plastic

Assume that the virgin plastic products already have been made and used, so that nothing can be done about the associated energy flows. Assume further that the choice is between, on the one hand, incinerating (with energy recovery) the discarded virgin plastics and making and using new, replacement virgin plastic products, and, on the other hand, recycling the discarded virgin plastics into plastic lumber (and then using it).

Net energy savings here equal the total direct energy to manufacture plastic lumber, plus energy recovered (PHC) by incineration of the virgin plastics. The result is -6,415 Btu/lb for electricity valued at 3,412 Btu/kWh, and -10,520 Btu/lb for electricity valued at 11,500 Btu/kWh.

This means that from the standpoint of society's overall energy resources, it is better to burn the (lumber-like) virgin plastic product and replace it with a new virgin product than to make and use the equivalent lumber-like product from recycled plastics.

Case 4: Recycling vs. Incineration without Replacement of Virgin Plastic

This scenario assumes, as in Case 3, that the virgin plastic discards are on hand, and that the choice is between recycling them and using the resulting plastic lumber, and burning them but not manufacturing the replacement virgin plastic product. The latter option might arise in a source reduction program, for example.

Here the energy advantage reverts to plastic lumber, at a rate of 985 Btu/lb and 1,020 Btu/lb for electricity at 3,412 Btu/kWh and 11,500 Btu/kWh, respectively.

The preceding energy use estimates compare plastic lumber to virgin plastic lumber. However, the discarded plastics could be recycled into items other than lumber, especially if any mixed plastics are suitably separated by resin and upgraded. It would be interesting to compare energy savings from recycling plastics into plastic lumber with energy savings from recycling substantially the same plastics into non-lumber plastic products. A good example would be the recycling of PET into carpet fiber. Such a comparison is beyond the scope of this report. Energy savings estimates have been made for various non-lumber products made of recycled plastics -- some were noted earlier. However, a direct comparison of these estimates with the report's results would not be meaningful, since the analytical methods and assumptions used are not easily made commensurable.

ENERGY COMPARISON OF PLASTIC LUMBER AND WOODEN LUMBER

The forest products industry has been said to use 2 percent of total US energy (Baker and Saeman, 1977). Lumber accounts for 5.4 percent of the energy purchased for manufacturing forest products. Plywood and composition board account for another 2.3 percent and 1.4 percent, respectively (Baker and Saeman, 1977). Several energy balance studies (Boyd et al., 1976) have compared lumber and other wood-based materials with steel, concrete, aluminum, brick, and other nonwood alternatives. Two advantages are claimed for wood: a striking superiority (Boyd et al., 1976; Baker and Saeman, 1977) in energy efficiency and in energy self-sufficiency (the degree to which energy needs are

provided "in-house" by wastes from wood harvesting or processing operations). As to energy efficiency, for example, steel floor joists, aluminum framing for exterior walls, aluminum siding, and brick siding are said to require, respectively, 50, 20, 5, and 25 times as much energy as their wood counterparts (Boyd et al., 1976). As to energy self-sufficiency, softwood and hardwood lumber and hardwood plywood and structural flakeboard are self-sufficient in the manufacturing process and generate a large surplus of fuel that can be used for industrial or domestic energy (Boyd et al., 1976). Energy self-sufficiency is less for softwood plywood, laminated veneer lumber, and for paper and pulp products generally.

No energy studies have compared wooden lumber with plastic lumber, although a few include some discussion of virgin plastics (e.g., Tenwolde, 1978). As noted, energy requirements of plastic lumber in this report exclude energy flows occurring before discarding the plastic. In other words, it is as if two "natural resources" are available -- wood in the forest, and piles of discarded plastics -- and that the question is whether, from an energy standpoint, to make and use wooden or plastic lumber for a given function. This means that energy embodied in wood (mostly from recent sunlight) and plastic (mostly from ancient sunlight) is not counted as an energy cost. However, such energy is taken into account as energy that might largely be recovered by burning.

For this report, softwood lumber is adopted as the standard of comparison for plastic lumber. Net energy requirements for oak flooring and hardwood plywood are comparable (perhaps 4 percent to 5 percent higher).

Differences in energy use when plastic lumber replaces wooden lumber principally arise from differences in energy use from the forest (for wood) or MRF/transfer station (for plastic) to the site of application; any differences in energy costs or savings incurred by the end-use; differences in product service lifetimes and product weights; and the ultimate fates of the products (landfill, incineration, recycling).

Differences in Energy Use -- Forest or MRF to the Application Site

Using data from Boyd et al. (1976), the net energy to harvest, manufacture, and transport to building site oven-dried softwood lumber is 1,455 Btu/lb, with electricity valued at the energy to generate and deliver it. This includes purchased and non-purchased energy, and fuels used in logging and transportation, electricity and heat at the mill, and various other energy charges, less available residue energy. The most comparable measure for plastic lumber is the sum of total in-plant energy (2,060 Btu/lb with electricity at 11,500 Btu/kWh), transportation energy up to the point of production (300 Btu/lb, using the mean of the upstate and downstate estimates), and transportation energy subsequent to production (assuming 1.25 Btu/lb-mile for truck shipments and an average shipping distance subsequent to production of 100 miles for plastic lumber destined for use in New York State). On this basis, wooden lumber saves 1,085 Btu/lb shipped to the job site.

Differences in Energy Costs or Savings Incurred by the End-Use

No significant energy differences are thought to arise from such end-uses as picnic tables. Even for insulation

applications, similar wood and plastic products are often available. Specific, reliable data were not found concerning the large energy savings claimed for virgin plastics in certain housing applications.

Differences in Product Service Lifetimes and Product Weights

Estimates of product lifetimes vary greatly. Three generic circumstances are considered: the plastic lumber is assumed to last half as long, just as long, or twice as long as the comparable wood product. It is assumed that 2.6 lbs of plastic are required per 1 lb of wood in the same application. This implies that total material requirements for similar plastic lumber and wooden lumber products in the same end-use and for the same total length of time in service are 5.1 lbs of plastic per 1 lb of wood for plastic lumber lasting half as long, 2.6 lbs of plastic per 1 lb of wood for plastic lasting just as long, and 1.3 lbs of plastic lumber per 1 lb of wood for plastic lasting twice as long.

Differences in energy use from the forest or MRF to the site of application; in energy costs or savings brought about by the end-use and in product service lifetimes and product weights together imply that for every pound of wooden lumber used for a particular purpose for a particular length of time, substituting plastic lumber products for the same purpose and the same length of time uses 11,600, 5,070, or 1,820 more Btus, depending on whether plastic lumber lasts half as long, just as long, or twice as long in that application. Plastic lumber would have to last 4.5 times as long as wood for these energy requirements to be the same.

Cradle-To-Grave Energy Comparisons

The comparison between wooden and plastic lumber is conceptualized as a choice between using plastic lumber and wood in a specific application, given an ample supply of wood and discarded plastic as existing "natural resources." As just noted, substituting plastic lumber for 1 lb of wooden lumber incurs net energy costs to society from the "cradle" (forest and MRF/transfer station) up to the end of the product service lifetime. The picture becomes much cloudier when the analysis considers whether using plastic lumber avoids the harvesting of the wood altogether or merely frees up other applications for wooden lumber, and how the wooden and plastic lumber is disposed. Six scenarios were examined.

Case 1: Use wood for the application, and landfill the discarded plastics

This is the base scenario, reflecting prevailing practice: there is no difference in energy balance to be computed.

Case 2: Use plastic lumber for the application, and leave the wood in the forest

This scenario costs 5,070 or 1,920 more Btus/lb of wood replaced than does the base scenario, depending on whether the plastic lumber lasts as long or twice as long as wood.

Case 3: Use wood for the application, incinerate the plastic discards that would have been made into plastic lumber in Case 2

This scenario yields 48,100 or 24,140 more Btus/lb of wood replaced than does the base scenario, depending on whether the plastic lumber lasts as long or twice as long as wood.

Case 4: Use plastic lumber for the application, make the corresponding amount of wooden lumber, but use it for another purpose, and then incinerate the wooden lumber

This option costs 2,860 more or yields 2,590 more Btus/lb of wood replaced than does the base scenario, depending on whether the plastic lumber lasts as long or twice as long as wood.

In nearly every set of circumstances just described, the manufacture and use of plastic lumber incurs a net energy cost. However, in Cases 2 and 4, it also is possible to recover energy by incinerating the plastic lumber at the end of its useful life. Two more scenarios result:

Case 5: Use plastic lumber for the application, leave the wood in the forest, and incinerate the plastic lumber

These circumstances yield 43,030 or 22,220 more Btus/lb of wood replaced, depending on whether the plastic lumber lasts as long or twice as long as wood.

Case 6: Use plastic lumber for the application, make the corresponding amount of wooden lumber, but use it for another purpose and then incinerate the wooden lumber and the plastic lumber

This scenario returns 45,237 or 26,730 more Btus/lb of wood replaced than does the base scenario, depending on whether the plastic lumber lasts as long or twice as long as wood.

The energy benefits in Cases 4, 5, and 6 occur many years after the plastic discards are recycled.

Still other scenarios may occur. The plastic may be recycled into a lower-grade form of plastic lumber. The "wooden vs. plastic lumber" scenarios may be crossed with the "plastic lumber vs. virgin plastic" scenarios by using wood for the application, recycling the corresponding quantity of plastic waste into plastic lumber, but using it in an application that replaces virgin plastic. When one considers that plastic lumber can be compared to plywood and engineered wood, the number of options becomes analytically unmanageable, and far exceeds the specificity of the little data that are available. These considerations illustrate the complexity of the question of whether recycling plastic into lumber saves energy. There is no single correct answer.

NEW YORK STATE IMPLICATIONS

The preceding analysis indicates that definitive implications of plastic lumber use and manufacture for New York State's energy resources cannot be drawn. However, maximum energy impacts on New York can be estimated in light of key characteristics of energy generation and use in New York State.

Renewable Energy and New York State Forest Industry

Lumber manufacture is 20 percent to 40 percent energy self-sufficient. Plywood manufacture is 50 percent energy self-sufficient. These fractions of total energy use come from heat and/or electricity produced by burning mill residues, harvesting residues, and wood grown specifically for fuel. These materials are often regarded as renewable, although their use may adversely affect ecosystem energy flows (e.g., by increasing soil erosion), and although renewing them may involve large energy inputs (e.g., as fertilizer).

It can be argued that energy derived from sources that replenish themselves relatively rapidly and more or less naturally, such as wood, water, and sunlight, should be accounted for separately from energy from comparatively nonrenewable sources. The relevance of renewable, self-generated energy to this report is shown by the fact that several studies conclude that the manufacture of virgin paper uses less purchased energy than the manufacture of recycled paper (Stauffer, 1989; Iannazzi, 1978; Franklin, 1990). Data available for this report do not lend themselves to such an accounting. For example, self-generated energy is often excluded from government energy statistics.

Use of Wood Wastes in New York State

Energy savings may accrue even after a piece of wood has served its principal, original use. Wood comprises perhaps 10 percent to 20 percent of the estimated 212 million tons of solid waste (85 percent MSW, 15 percent construction and demolition wastes) generated in 1988. In New York State, such wood is 56 percent harvested virgin wood (e.g., limbs,

trees), 25 percent mill residues (e.g., sawdust, veneers, plywood), 3 percent pallets, 15 percent construction and demolition wastes, and 1 percent other wood (e.g., home and business discards) (Donovan, 1991). Especially in the Northeast, where some 30 wood waste recycling plants operate, these materials may be used, for example, as boiler fuel, landfill cover, and manufactured wood products, in each case affecting energy expenditures that might occur if plastics or other materials were used instead.

Impact of High Energy Prices in New York State

One manufacturer of plastic pellets moved from New York City to Long Island in 1973 to cut energy bills 25 percent to 30 percent. The plant runs around-the-clock, and uses huge injection-mold machines with 200 to 300 horsepower motors. Although, Long Island Lighting Company energy conservation programs reduced the plant energy bill 2 to 4 percent, the manufacturer plans to leave the state, saying the South is much better when it comes to energy costs.

Major manufacturers of plastic lumber appear to be actively considering leaving Long Island for upstate New York or the South, and regularly raise concerns about high energy costs in conversation. Electricity costs are the major factor in high energy costs. Fifty-eight percent of electricity consumed in New York State is generated in-state from fossil fuels, 34 percent is generated in-state from primary sources such as nuclear and hydro, and 7 percent is imported (NYSEO, 1989). If the ratio 58/34 is applied across the board to imported and non-imported electricity, and if primary electricity is counted at its heat-content value (3,412 Btu/kWh) rather than at its fossil-fuel-equivalent Btu value, then Btus in electricity requirements become roughly 70 percent of the values described in this report.

Energy Impacts

If plastic lumber manufacture and use should become widespread in New York State, several of the scenarios previously identified concerning the substitution of plastic lumber for wood or virgin plastics will come into play immediately. While their joint energy impact cannot be estimated beforehand, it may be instructive to examine maximum impacts. The potential supply of plastic waste available for conversion to plastic lumber in New York State is at most 500 million lbs/year, assuming that the State generates approximately 1.5 billion lbs/year of plastic waste, one-third of which is available for plastic lumber. Total direct energy required to convert this to plastic lumber equals the energy equivalent of 205,000 barrels of oil.

Directly applying the results of the energy comparisons of plastic lumber with wood and virgin plastics, Tables 2-5 and 2-6 show maximum annual New York State net energy savings or costs arising from substituting plastic lumber for wooden lumber and virgin plastic. At best, plastic lumber can save annually the energy in 1.6 million barrels of oil; at worst, it can increase energy consumption the equivalent of some 900,000 barrels/year of oil. To keep these figures in perspective, note that total New York State annual primary energy consumption is equivalent to the energy in about 650 million barrels of oil. Thus, even in the most extreme case, manufacture and use of plastic lumber affects New York State energy resources by one-quarter of 1 percent.

Table 2-5. Maximum annual New York State net energy costs or savings from manufacture and use of plastic lumber to replace virgin plastic.

Scenario (details in text)	Barrels of Oil
Plastic lumber landfilled, virgin plastic that would have been landfilled	800,000 saved
Plastic lumber incinerated virgin plastic that would have been incinerated	710,000 saved
Given discards, make plastic lumber or burn discards and make replacement virgin product	910,000 lost
Given discards, make plastic lumber or burn discards, making no replacement virgin product	1,000,000 saved
For 500 million lbs/year of plastic lumber (estimated theoretical maximum). Electricity valued at Btus to generate and transmit it.	

Table 2-6. Maximum annual New York State net energy costs or savings from manufacture and use of plastic lumber to replace wood.

Scenario (details in text)	Barrels of Oil	
	Plastic lumber Lifetime as long as needed	Plastic lumber lifetime twice as long
Use plastic lumber, leave wood in forest	390,000 lost	170,000 lost
Use wood, incinerate the plastic discards	1,630,000 saved	820,000 saved
Use plastic lumber, use wood elsewhere, then incinerate wood	100,000 lost	90,000 saved
Use plastic lumber, use wood in forest, then incinerate plastic lumber	1,450,000 saved	750,000 saved

ECONOMIC ASPECTS OF PLASTIC LUMBER

Communities on Long Island and throughout the US are increasing recycling efforts through a variety of programs. Without a useful means of processing the materials as they are collected, recycling merely separates the trash before it must be landfilled or incinerated. Developing markets for recycled materials such as plastic lumber is necessary if recycling is to provide the benefits people expect. The emphasis here is on economic aspects of recycling, in particular the economic feasibility of developing markets for new products such as plastic lumber. If new markets of sufficient size are possible, communities may proceed with recycling plans with some confidence that the effort will not be wasted.

METHOD

The market assessment strategy be designed to evaluate a market that is growing quickly. The industry is new and dynamic and in many cases the products are still experimental. No ASTM specifications exist for plastic lumber. As recently as October 1989, the US Office of Technology Assessment (US OTA) could identify only four businesses using post-consumer waste to produce secondary materials (US OTA, 1989). A year later there were three firms on Long Island, and perhaps 36 across the country.

Most of the products in this new industry are themselves newly designed and produced and are unfamiliar to those who might come to use them. As is common in new industries, there is no uniformity of product from one firm to another. Output and markets for mixed-resin plastics are being developed by small firms, not the large oil and chemical companies and users of plastic packaging who are pioneering

the recycling of single resins, notably PET, HDPE, PP, PS, and PVC. The variety of new designs and production techniques among the different firms that characterize this stage of experimentation means that no industry standard yet exists which fully defines the product coming to market.

Product consistency is a problem even within a single firm making a product with mixed-resin feedstock such as plastic lumber. Small firms are subject to considerable variation in the proportions of various resins delivered to them as mixed plastic waste in successive batches from municipalities and other sources. The resulting variation in resin proportions incorporated into the final product undermines product consistency and adds to the difficulty of assessing the market for these products.

To address these obstacles a materials balance approach has been used. For mixed resin plastic, the potential supply of materials as feedstock from recycling has been estimated. The scale of output these input supplies can support is then estimated. For each material, products which might reasonably find a use on Long Island have been chosen. When potential physical supplies are derived, these estimates can be compared to the existing or anticipated potential demand for the product.

In this way the relationship between supply and demand in the markets for secondary products can be investigated. While it is not possible to estimate precise responses of demand and supply to product price because of the lack of product specification and consistency, a qualitative evaluation of potential market conditions can be derived from the materials balance approach. To this information, evaluations of markets expressed in relevant literature and

information provided in interviews with people involved with these products have been added.

For purposes of this economic analysis, Long Island is taken as a microcosm of the US economy, where recycling is increasing even as it is throughout the country. While the production of MSW per person is higher on Long Island than in most other places, and recycling rates for the subject materials are now somewhat lower, these particular conditions should not obscure the fact that communities all over the country are engaged in the same process of recycling and developing markets for products made from recycled materials. To some degree, markets in recycled plastic resins and the products made from them are regional and even national in scope. While there may be some gross export flows to balance supply and demand across regions, it is expected that these will be balanced by gross flows of imports so that Long Island will have no net flow of materials in or out of the region. Therefore, it is presumed that the potential Long Island demand for recaptured materials must be satisfied by local supplies of commingled plastic products generated.

As recycling spreads and new industries begin to emerge, a number of public policy issues arise. Some might argue that no special public policy should interfere with the spontaneous application of free market principles to firms and industries connected with capturing and reusing waste materials. Others propose a variety of policies designed to influence markets. In this connection, it is important to note the central finding in a study done for the US Environmental Protection Agency (US EPA) early in the history of recycling efforts: both as economic theory and due to measurement difficulties, it cannot be determined whether the market operating alone will necessarily result

in socially efficient prices for recycled materials (Anderson, 1978). Each proposal for intervention through tax, subsidy, or other public policy must therefore be evaluated directly.

PLASTIC RECYCLING MARKETS

Plastics are a relatively small fraction of total MSW generated in the US, but they attract disproportionate attention in part because the recovery rate for plastic is exceptionally low compared with other elements in the waste stream. Table 2-7 shows the composition of MSW and recovery rates for its various components in 1988.

Plastics contributed 14.4 million tons to MSW in the US in 1988, 8 percent of the total. But its recovery rate of 1.1 percent was among the lowest; only textiles, wood, and food wastes had lower recovery rates. Recycling plastics lags far behind the average rate of MSW recycling, 13.1 percent, and is overshadowed by rates of recovery for newspaper, aluminum, and non-ferrous metals. Total sales of plastics in the US in 1987 amounted to 57.3 million tons (Bennett, 1989a). The fact that only 14.4 million tons ended up discarded the following year is because many plastic products last a number of years before being discarded, and from the substantial growth in the use of plastic in recent years. Table 2-8 documents that growth since 1960 and indicates that plastic will continue to grow in importance in municipal wastes, although at a reduced pace. Figure 2-1 displays the same information graphically.

Many different products are grouped under the general name "plastic." As shown in Table 2-9, plastics embodied in durable goods accounted for just over 28 percent of all plastics discarded in 1988, while containers and packaging

Table 2-7. MSW materials generated and recovered: 1988.

Material	Generated (millions of tons)	% of MSW	Recovered (millions of tons)	% Recovered
Paper & paperboard	71.8	40.0	18.4	25.6
Glass	12.5	7.0	1.5	12.0
Metals				
Ferrous	11.6	6.5	0.7	5.8
Aluminum	2.5	1.4	0.8	31.7
Other nonferrous	<u>1.1</u>	<u>0.6</u>	<u>0.7</u>	<u>65.1</u>
Total metals	15.3	8.5	2.2	14.6
Plastic	14.4	8.0	0.2	1.1
Rubber and leather	4.6	2.5	0.1	2.3
Textiles	3.9	2.1	0.0	0.0
Wood	6.5	3.6	0.0	0.0
Other	<u>3.1</u>	<u>1.7</u>	<u>0.7</u>	<u>21.7</u>
Total nonfood wastes	132.1	73.5	23.1	17.5
Other wastes				
Food wastes	13.2	7.4	0.0	0.0
Yard wastes	31.6	17.6	0.5	1.6
Misc. inorganic wastes	<u>2.7</u>	<u>1.5</u>	<u>0.0</u>	<u>0.0</u>
Total other wastes	47.5	26.5	0.5	1.1
Total MSW	179.6	100.0	23.5	13.1

(US EPA, 1990)

**Table 2-8. Plastic as percent of total MSW generated 1960 - 1988
projections to 2010.**

Year	Plastic as Percent of Total MSW
1960	0.5
1965	1.4
1970	2.5
1975	3.5
1980	5.2
1985	7.2
1988	8.0
1995	9.3
2000	9.8
2010	10.3

(US EPA, 1990)

Figure 2-1. Plastic as Percent of Total
MSW Generated. 1960-1988
and Projections to 2010.

(US EPA, 1990)

Table 2-9. Plastics products in MSW, 1988 (in millions of tons and percent of generation)

Product category	Generation (millions of tons)	Recovery (millions of tons)	Recovery % of generation	Discards (millions of tons)
Durable goods ^a	4.1	0.1	1.5	4.1
Nondurable goods				
Plastic plates and cups	0.4	Neg.	Neg.	0.4
Clothing & footwear	0.2	Neg.	Neg.	0.2
Disposable diapers ^b	0.3	Neg.	Neg.	0.3
Other misc. non-durables ^c	3.8	Neg.	Neg.	3.8
Total Plastics				
Nondurable goods	4.6	Neg.	Neg.	4.6
Containers and Packaging				
Soft drink bottles ^d	0.4	0.1	21.0	0.3
Milk bottles	0.4	Neg.	1.0	0.4
Other containers	1.7	Neg.	Neg.	1.7
Bags and sacks	0.8	Neg.	Neg.	0.8
Wraps	1.1	Neg.	Neg.	1.1
Other plastic & packaging	1.2	Neg.	Neg.	1.2
Total Plastics				
Containers & packaging	5.6	0.1	1.6	5.5
Total Plastics	14.1	0.2	1.1	14.3

^a Plastics as a component of appliances, furniture, lead-acid batteries, and miscellaneous durables.

^b Does not include other materials in diapers.

^c Trash bags, eating utensils and straws, shower curtains, etc.

^d Includes bottles and base cups.

Neg. - Negligible

Details may not add to totals due to rounding.

(US EPA, 1990)

constituted nearly 39 percent of all MSW plastic that year. Despite the great variety of forms in which plastic can be found, recovery is concentrated in only a few items, notably soft drink bottles, rigid milk and juice containers, and lead battery casings. Indeed, the ability to recover and reuse plastic is severely limited. One industry analyst concluded that approximately 25 percent of plastic waste will be acceptable for reuse (Narayan, 1989). Citing technical limits, a recent major study concluded that at most 20 percent of all plastics can be recycled into new products (Resource Conservation Consultants et al., 1988). Based on current technology, Robert Bennett, a leading analyst of markets for recycled plastic, has concluded that the maximum potential market for all recycled resins in 1989 amounted to just 4 percent of all plastic produced that year (see Table 2-10 below), less than 20 percent of total plastic discards.

Whatever success might arise from recycling plastic cannot, therefore, be expected to provide more than modest relief of the waste disposal problem plastics pose for society. Nonetheless, plastic recycling will play a positive role in waste reduction programs and is certain to be a more visible aspect of recycling activity in general. And it is possible that technical developments and changes in industry policies in response to growing public pressure may well extend current limits on the potential for plastic recycling.

The variety of plastic products on the market reflects the variety of chemical forms different plastics embody. These differences reflect in the complex chemical characteristics of the particular resin used to make the material. The prospects for recycling plastic, and establishing markets for secondary plastics products, depend in great measure on the resin involved. Recycling efforts have been

Table 2-10. Use, recycled volume, and potential markets by recycled resin:
1989 (millions of pounds).

Resin	Actual Use	Amount Recycled	Recycled as % of use	Potential for Recycled Resin	Market as % of actual	Recycled as % of market
PET	1,095	190	9.97	529 ^a	27.77 ^a	35.92
HDPE	8,115	145	1.79	4,421	5.45	32.81
PP	7,246	62	0.86	767	10.59	8.08
PVC	8,307	5	0.06	494	5.95	1.01
PS	5,184	20	0.39	477	9.20	4.19
Total 5 resins	39,757	422	1.11	2,709 ^a	8.81 ^a	15.58
Total all plastics	66,826	422	0.63	2,709	4.05	15.58

^a Potential markets for recycled PET extend beyond virgin PET markets to substitution for certain textiles, polyesters, and polyurethane.

(Bennett, 1991a)

concentrated in a few resins, principally HDPE (milk jugs and detergent bottles) and PET (soft drink bottles). Table 2-10 shows the volumes of these and other resins used and recycled in the US in 1989, the most recent year for which data are available, as well as potential markets for the recycled resins as estimated by Robert Bennett.

Table 2-10 shows both significant room for growth in plastic recycling markets and the sharply limited degree to which these markets, even when fully developed, can contribute to relieving the flows of plastic into the solid waste stream. Current recycling rates for PET and HDPE supply only about one-third of their potential markets, while recovery of PVC could increase one hundred fold and still find potential markets. The five resins now recycled, taken together, supply only about 15 percent of their potential uses.

Still, recycling can hardly be relied on as the most important answer to the problem of plastic flows in MSW. While recycled PET can substitute for about 28 percent of virgin resins including some polyesters and PUR, the total market for the five most commonly recycled resins amounts to less than 9 percent of the annual market for these resins. Total recycled plastics accounted for only 0.63 percent of all plastic used in 1989 and even when estimated markets are fully tapped only 4 percent of the aggregate market in plastics will be supplied by recovered resins. Nonetheless, plastic recycling is spreading throughout Long Island and the US and will contribute a share to the resolution of solid waste problems.

PET and HDPE

Available capacity to process recycled bottle resins far exceeds available resin supplies. PET recycling capacity in

1990 was reported at 350 million lbs/year. A survey of major US scrap plastic bottle reclaimers undertaken by Resource Recycling (1991) revealed 519 million lbs annual capacity for both HDPE and PET in early 1991. PET capacity alone was expected to grow to 530 million lbs/year by the end of 1991 (Modern Plastics, 1990a). Available PET supplies in 1990 satisfied only about half that year's capacity.

The Council for Solid Waste Solutions (CSWS) estimated that in 1990 firms recycling post-consumer plastic, taken together, were operating at 66 percent capacity (CSWS, 1991), far below the 80 percent some have said to be required for profitable activity (Modern Plastics, 1990a). Meanwhile, Wellman, the largest processor of recycled resins in the US, reported very slow growth in curbside collection (Garbage, 1991) and industry analysts concluded that PET recycling rates were unlikely to rise much without new bottle laws (Modern Plastics, 1990a). Despite these problems, CSWS reports that plastic reclamation is a profitable activity (CSWS, 1991). Demand for recycled resins is high and every indication points to expanded growth for the industry.

The plastics industry has developed substantial recycling capacity in response to public concern that plastic is a major contributor to solid waste problems in the US. The industry hopes that by engaging in recycling, it can avoid limits on the use of plastic as governments at all levels grapple with waste disposal. Now, with excess recycling capacity, the plastics industry has initiated an ambitious program to promote recycling PET and HDPE containers. Du Pont, one of the leading manufacturers of resins used in plastic containers, and Procter & Gamble, one of the leading users of HDPE in consumer packaging, jointly announced with

CSWS a campaign to achieve a 25 percent recycling rate for plastic bottles and containers by 1995 (CSWS, 1991).

Virtually all post-consumer PET and HDPE reclaimed is in the form of bottles and containers used for food and household chemicals. Table 2-11 shows the 1989 recycling record for these items. Just over 10 percent of all household bottles and containers were recycled; the PET recycling rate was three times that of HDPE. If the 25 percent recycling target is to be achieved, major gains will be needed in HDPE collections. There is some reason for optimism since it has recently been reported that rigid HDPE containers are appearing as the most promising candidate for recycling (Modern Plastics, 1990b).

Almost all recaptured resins are separated and reused as a substitute for virgin resin in single-resin applications. While Federal regulations now severely restrict the use of recycled plastics in the production of food packaging due to the threat of contamination, PET is used more commonly to produce strapping, fiberfill, carpeting, and other products. In Spring 1991, the Coca Cola company began to use post-consumer PET as 25 percent feedstock for bottles using a new process developed by Hoechst-Celanese Corporation, Wilmington, North Carolina. If this process is economical, receives final approval from the US Food and Drug Administration, and is used throughout the soft drink industry, a substantial new market for recycled PET will emerge.

Manufacturers of containers for household and industrial chemicals want to use recycled HDPE for as much as 30 percent of the feedstock for new containers, as an inner layer laminated between two layers of virgin material (Modern Plastics, 1990b). Recycled HDPE is also used to

**Table 2-11. Use of PET and HDPE in bottles and containers, and recycling rates:
1989 (millions of pounds).**

	Use	% of Use	Recycled	Recycled as % of Various Flows
PET Total	1,905	100,000	190	
Soft drink bottles	680	35.7		27.9% of soft
Custom bottles ^a	260	13.6		drink bottles
	<u>940</u>	<u>49.3</u>		
HDPE Total	8,115		145	
Bottles	2,202	27.1		
Milk	720	8.9		20.1% of milk bottles
Other food	320	3.9		13.9% of food containers
Household chemicals	956	11.8		7.32% of food plus household chemicals
Pharmaceuticals	206	2.5		6.6% of all HDPE bottles and containers
All Consumer Bottles and containers	3,142		335	10.7% of all bottles and containers

^a Cosmetics, toiletries, pharmaceuticals, pads, and liquid.

(Bennett, 1991b)

produce drain and irrigation pipes, industrial pails and drums, pallets, and many other products.

Mixed Plastic Products -- Plastic Lumber

The strong demand for recycled PET and HDPE has implications for the scale of mixed-plastics manufacturing. A recent major study (PRMMDS, 1988) found that increased demand for recovered plastics has been concentrated in single-resin markets, and suggested that mixed-plastics supplies would not be so quick to develop. One industry analyst has estimated that 85 percent of recovered HDPE will be used in single-resin applications, while 10 percent will be upgraded through recompounding. Only 5 percent will enter the stream of mixed plastics for use in the manufacture of plastic lumber and other low-end products (Christiansen Associates, 1990).

Restricted HDPE supplies are an important determinant of the potential scale of mixed-plastics manufacturing, particularly in making plastic lumber. While considerable variation in proportions of different resins can be found in plastic lumber, polyolefins must contribute at least 50 percent to 65 percent of the feedstock (CA DC, 1988; MA DEQE, 1988). Since virtually no post-consumer LDPE is recaptured, HDPE supplies are essentially the sole source of polyolefin feedstock for plastic lumber (Modern Plastics, 1988). Other feedstock resins might be PVC, PET, and PS, and as much as 25 percent of the feedstock could be composed of dirt, paper, and other contaminants (Plastics Technology, 1990b).

Table 2-10 shows that 145 million lbs of HDPE were recovered in post-consumer recycling efforts in the US in 1989. If only 5 percent of recovered HDPE can be expected to enter

mixed-resin feedstocks, the 1989 volume of recycling would provide 7.25 million lbs of HDPE for plastic lumber. If HDPE is taken as the sole source of polyolefins, and polyolefins must be 50 percent to 65 percent of the plastic lumber feedstock, 7.25 million lbs of HDPE would be incorporated into from 11 million to 14.5 million lbs of plastic lumber product.

In actual practice, most producers of plastic lumber do not receive their entire feedstock from post-consumer sources. In response to a survey questionnaire circulated as part of this report (see Appendix C), manufacturers reported that as much as 80 percent of the recycled plastics they use come from industrial scrap, both HDPE and LDPE. Many were willing to use greater proportions of post-consumer sources as they become available.

Since industrial scrap provides a sizeable fraction of polyolefin feedstock for mixed-resin processes, post-consumer HDPE flows can sustain much greater production levels of plastic lumber. If one-half of polyolefin requirements come from industrial scrap and one-half from post-consumer sources, the 145 million lbs of HDPE recovered in 1989 could support twice the volume of plastic lumber estimated above: 22 million lbs/year to 29 million lbs/year.

What is the likelihood that this quantity of plastic lumber could find market outlets? Table 2-12 presents information on a number of products made from plastic lumber, showing the weight of each item and the annual market for selected products. A single car stop made from plastic lumber weighs 40 lbs. Each year 14 million car stops are bought in the US for new parking lots and to replace existing stops as they deteriorate. Currently car stops are usually made from concrete; however, if every car stop were made of plastic

Table 2-12. Weight and annual market potential for selected items made from plastic lumber.

Product	Weight^a (lbs)	US Market (Units of product per year)
Car stop	40	14,000,000 ^b
Speed bump	14	
Landscape tie (6 in. x 6 in. x 6 ft)	60	12,000,000 ^c
Lumber (2 in. x 4 in. x 10 ft)	25	
Marine decking (1 in. x 6 in. x 6 ft)	14	
Railroad tie	140	17,000,000 ^d
Picnic Table	300	
Bench	125	

^a interviews with manufacturers

^b Floyd Hammer interview

^c (Bennett, 1989b)

^d (Bennett, 1987)

lumber, 560 million lbs of plastic lumber would be incorporated into them, far more than the flow of plastic lumber anticipated, as previously calculated based on 1989 HDPE recycling rates. To use up the entire flow of plastic lumber that could expected to be generated from HDPE recycled in 1989, demand for plastic lumber car stops would have to penetrate no more than 5 percent of the market for car stops.

Similar calculations show that it would take a penetration of just 4 percent into the landscape tie market, or 1 percent of the railroad tie market, to absorb the entire calculated annual flow of plastic lumber. When all products made from plastic lumber are taken together, the potential market is vast in comparison with the anticipated supplies. There are several reasons to believe that the annual 22 million lb to 29 million lb flow of plastic lumber estimated above understates the potential supply through the 1990s. Until better sorting and cleaning technology is available, recycled HDPE will be plagued by impurities which will make it more difficult for producers to use in high-end products. Representatives of Wellman Inc. indicated that HDPE and PET supplies were subject to quality-related problems as increasing amounts were obtained from MRFs rather than in-store bottle-return machines (Plastics Technology, 1990b). Since impure HDPE is more likely to flow to mixed-plastic low-end feedstocks, it may be reasonable to expect that more than 5 percent of post-consumer HDPE will be best suited for plastic lumber in the near future.

Total collections of HDPE are also sure to rise well above the 1989 flow on which these calculations are based. If the 25 percent recycling target is met for all HDPE bottles and containers, the flow of post-consumer HDPE would quadruple for 1989 (see Table 2-11) and be higher still as HDPE use

increases in coming years. Even though anticipated HDPE flows in the 1990s could sustain an annual production of plastic lumber of 100 million lbs or more, Table 2-12 suggests that ample market outlets will be available in physical terms, without considering the potential in export markets. The flow of plastic lumber does not seem to be limited by physical constraints of potential use.

LONG ISLAND MARKETS FOR SECONDARY MATERIALS

Plastic recycling on Long Island lags well behind the national average, but is growing rapidly. In 1989 only 640 tons of plastic were recovered from Long Island MSW totaling 3.1 million tons, one-quarter the national recovery rate. Half the Towns on Long Island recycled no plastic whatever (Hartnett, undated). In 1990, plastic recycling efforts were better developed. With the closing of all Long Island landfills and a growing awareness of environmental needs, it is reasonable to assume that Long Island communities will soon reach or exceed national rates of plastic recycling.

Yet flows of recycled mixed-resin plastics should not prove difficult to absorb in Long Island markets in terms of physical units of output. Products incorporating mixed-resin plastics identified in Table 2-12 are all sold on Long Island and some of them, notably marine decking, picnic tables and benches for use in parks, and lumber for horse stalls, are in greater demand per capita on Long Island than elsewhere in the country. However, this does not guarantee a successful mixed-resin plastic lumber industry. The potential may not be realized for reasons of cost or because customers will not be persuaded to use the material for a number of reasons other than cost.

Markets for Plastic Lumber

Plastic lumber is expensive compared with the materials for which it substitutes. A 1988 market analysis in Pennsylvania showed that plastic lumber was three to five times the cost of wood (PRMMDS, 1988). Modern Plastics (1990b) reported that plastic lumber was twice as expensive as treated wood, and Robert Bennett's 1990 market survey of high volume commingled plastic products revealed that the cost of mixed plastic lumber was two to seven times more than comparable wood alternatives among treated lumber and landscape timbers (Bennett, 1991a). Interviews for this report revealed that mixed-resin plastic lumber is also significantly more expensive than metal and concrete for which it sometimes substitutes.

Manufacturers of mixed-resin plastic products claim that these items have a much longer useful life than competing materials. While it seems certain that this claim is true to some degree, the actual useful life of mixed-resin plastic products has not yet been established. Still, the fact that these products last longer and require less maintenance than their competitors has led plastic manufacturers to stress life-cycle costs rather than initial purchase price when comparing the cost of mixed-resin plastic products with wood, concrete, or steel substitutes. But until more technical information about mixed-resin plastic products is available, along with more testing and field experience, the importance of life cycle pricing as a mitigating consideration cannot be adequately assessed.

Despite such unfavorable price comparisons, mixed-resin plastic products have begun to command a market. While some producers believe that the mere fact of recycled content makes the product attractive to environmentally conscious

buyers, others doubt that such considerations can overcome price differentials. But products made from recycled mixed-resin plastics do carry relatively low maintenance costs since they require no painting and graffiti can be easily cleaned. Plastic lumber is durable under some circumstances compared with wood, being insensitive to rot, insects, and perhaps weather. Compared with concrete, plastic lumber is lightweight, requires less labor for installation, and it does not crack, crumble, or break as easily.

Many important barriers to market expansion for mixed-resin plastics continue to exist, however. Mixed-plastic products are new in the market. Consumers, business buyers, and government purchasing agents are unfamiliar with them and have no ties to their manufacturers. The industry is starting from scratch with an apparently relatively costly product.

Several studies have uncovered severe limits to the load-bearing capacity of plastic lumber, sharply restricting its usefulness in construction and in many consumer uses (PRMMDS, 1988). The structural integrity of mixed-resin plastic lumber concerns the plastics industry (CSWS, 1991). Uncertainty about the purity and structural characteristics of plastic lumber also creates liability concerns that deter potential business customers (US OTA, 1989).

One study revealed that 87 percent of Connecticut manufacturers of plastic products were uninterested in using secondary resins, even though many had tried them. Technical problems were most often cited, while only 9 percent explained their refusal by a belief that consumers would reject the product as inferior (Mt. Auburn Associates, 1989). Still, appearance is a barrier to household sales of many low-end mixed-plastics products. For technical reasons

color varieties are severely restricted; these products are black or very dark in color. When the feedstock mix contains paper, bits of metal, and other impurities, these items appear in the surfaces and edges of the finished product and can be unsightly, and possibly hazardous.

The plastics industry is acutely aware of the problems involved in establishing markets for mixed-resin products and is devoting resources to their solution. Some of these problems will likely be resolved by technical innovations in the relatively near future. Others will prove more intractable. As a complement to industrial activity, public policy can also contribute to the solution of some of the problems still confronting manufacturers of recycled mixed-resin plastic products.

PUBLIC POLICY RELATED TO COMMINGLED PLASTICS

Public policy should focus on a number of issues such as source separation, tax incentives, research and development, standards, content legislation, and small business and entrepreneurial programs.

Source Separation

Source separation of plastic waste in the MSW stream is an essential first step in the recycling process. Supplies of recovered resins are still far short of current industry demand. State and local governments can and should promote plastic recycling through bottle laws and mandatory source separation.

Taxes

Taxes are a controversial element of any industrial policy. Next to content legislation (see below), respondents to a survey questionnaire undertaken for this report cited tax credits as the most important contributor to the success of their business. Yet numerous studies have shown that investment tax credits, sales and property tax exemptions, and other business tax incentives have a negligible effect on investment behavior (PRMMDS, 1988; Leichter, undated).

Research and Development

Research and development is needed to solve a number of technical problems at every stage of the recycling process. Public funds have traditionally been used to promote scientific study of technical industrial problems, a practice which now should be extended, in co-operation with the plastics industry and users of plastic products, to mixed-resin plastic technology. Among issues often cited for study are techniques for source separation by resin and color, and production technology.

Standards

A number of issues related to standards need to be addressed by public officials. Source separation will be made easier if producers are required to label products according to resin content, and if products must be manufactured in such a way as to allow easy separation of the various resins contained in them when they are discarded.

Federal and State governments must also be involved in establishing engineering and environmental standards for products made from recycled mixed-resin plastics. To the

degree possible these standards should be national in scope since markets for the products extend beyond local and state boundaries.

Government agencies can assist in the development of markets by purchasing products made from mixed-resin recycled plastic. This activity will also contribute indirectly to market growth by bringing the public into contact with the products, and increasing public familiarity and acceptance levels.

The fact that products made from mixed-resin plastic have a significantly higher initial purchase price than competing goods will be a barrier to public agency purchases. Two methods can be adopted to surmount the problem. First, purchasing agents should be instructed to consider life-cycle costs in competitive bids. To the degree that this information is incomplete or continues to show a price disadvantage for products containing recycled materials, public policy might require that a certain fraction of each relevant product line be purchased from companies who manufacture the item out of recycled mixed resins. This fraction would be subject to competitive bidding from suppliers seeking the market. Many government agencies have content requirements for recycled paper, even when a price premium is involved, in the interests of promoting recycling. In the case of mixed-plastic products, highway and park uses seem most highly developed at present. Relevant departments at Federal, State, and local levels can take useful action, once appropriate standards are set. Targets would have to be established consistent with manufacturing capacity.

Content Legislation

Broader content legislation could require certain products to contain a minimum amount of recycled resins.

Manufacturers of household and industrial chemical containers could be required to use, for example, at least 10 percent post-consumer HDPE in their products, assuming that technical problems are resolved and adequate supplies of materials are available.

Such product content legislation is potentially sensible for single resins only, not for products made from commingled resins. However, to the degree that content legislation increases the fraction of HDPE and other polyolefins going to single-resin uses, feedstocks for mixed-resin plastic lumber will be reduced and the basis of that segment of the industry will be constricted.

Small Business and Entrepreneurial Programs

Small business and entrepreneurial development programs can be useful. While large corporations dominate the recycling markets and efforts to develop single-resin uses, small business characterizes the world of mixed-resin manufacturing. Existing programs should target this segment of the industry, actively make their services available, solicit proposals for support, and generally work together with the industry to promote effective and socially responsible solutions to its problems.

SOCIOLOGICAL ISSUES RELATED TO SECONDARY MATERIALS

The Absence of Consumer Resistance

The interviews and evidence collected for this report strongly indicate that consumer resistance will not be a substantial barrier to the introduction of plastic lumber products and is not likely to be significant for other recycled plastic products, with only a few exceptions (see below).

Most of the products are simply not sold to consumers. The three products which exemplify this are parking lot stops, speed bumps, and highway barriers. These items are not designed for private use and private citizens are rarely interested in the nature of the material used in them, either from an aesthetic or a practical (e.g. tax burden) point of view. They are the type of products consumers rarely notice even when displayed in public settings.

This pattern is generally applicable to recycled plastic products. It seems unlikely that secondary materials made from mixed plastic waste will ever be the highly visible packaging or decorative items to which consumers bring a strong set of preferences.

In the home improvement industry, which is potentially a very substantial market for plastic lumber and for other recycled plastic products, the decisions on the kind of construction (building) materials to be used are made by contractors and not by the individual householder who employs them. Even though the homeowner is the end consumer, the decision of what building material will be purchased lies with his or her contractor. For example, the use of plastic lumber as wall insulating material is a

decision usually made by a contractor rather than a homeowner.

The exception to this is highly visible construction such as sun decks. It seems likely that plastic lumber or other secondary materials from mixed plastic products will find a large market in this sort of construction, in which the decorative qualities of the product are a key element in the purchase decision. By current aesthetic standards, mixed plastic products are not aesthetically pleasing. Consistent coloring for plastic lumber can only be achieved during the production process itself. Painting or coloring this material once it is produced is not recommended. Therefore there is little opportunity to change or improve appearance. However, decorative applications constitute only a small portion of the potential market for plastic lumber and consumer resistance is therefore not a severe impediment to market penetration.

Substantial customer resistance might conceivably come from a strong environmental movement which opposes recycled plastics. Such an environmental movement does not currently exist and it is unlikely that such a movement is developing. This absence of resistance reflects the current thinking of environmental activists that recycling is the correct approach to the problem in plastics, and a collateral sense that such recycling does not exclude the search for renewable resources in this area. Therefore, one can believe that environmentalists will support programs which require a certain amount of recycled plastic content in government acquisitions, and even broad laws requiring minimal amounts of recycled products in private construction products.

Sources of Resistance in the Profit-Making Sector

The largest potential market for plastic lumber and for a considerable portion of other recycled mixed plastic products will be the for-profit construction industry. The marketing barriers in this sector are formidable, particularly if the mixed plastic manufacturers remain small with inadequate leverage for penetrating well-established business niches.

An important component of this problem is that plastic products must successfully compete with existing products made from other materials that are not in short supply and have significantly lower prices. Another equally important component is the fact that market relationships around existing products are often established on the basis of criteria that are not straight forward calculations of costs and benefits. For example, "trust" between a contractor and a particular supplier cannot be quantified, but survival in the market may depend on the maintenance of their relationship. The implication is that structural and price superiority of mixed plastics may be a necessary, but not sufficient condition for their success in the market.

The first and most important barrier is the cost of the plastic products. With some exceptions, the initial cost of these products is higher than competitive products. In particular, the price of plastic lumber is substantially higher than Douglas fir and other structural lumber readily available in a wide variety of outlets. For example, a 2 ft x 6 ft piece of plastic lumber costs approximately \$10 while a piece of pressure-treated wooden lumber of the same size costs approximately \$4 (84 Lumber, personal communication). As a consequence, those seeking to sell these products must

convince construction contractors that the long-term benefits outweigh the short-term price disadvantage.

The frequently made argument that plastic lumber in marine applications requires almost no ongoing maintenance costs, and has a longer life than wooden lumber may be of no concern to contractors who build marinas, particularly since the initial cost of plastic lumber is higher than existing materials. Their interest is to secure low costs for the materials they purchase. At this stage, as long as they are in accordance with guidelines, the lifespan of the materials is of no significance to the contractors. (If anything, these contractors have an interest in resisting more durable materials.) Therefore, the arguments which producers make for the superiority of plastics in marine applications are simply not effective on contractors; they will presumably continue to be ineffective until product specifications directly require the use of recycled plastic materials or specific guidelines with regard to durability are established.

A second source of resistance is derived from the lack of performance standards for plastic lumber, which is a great disadvantage to small companies. These small businesses are often incapable of financing the expensive process of testing and retesting the products to meet standards set for various applications.

Small businesses are also faced with the inconsistencies in the tested strength of their products. Secondary materials made from mixed plastic waste vary dramatically in their physical capabilities among manufacturers, among seasons, and from year to year. Clients are wary of becoming dependent on a product stream that may not meet standards

over a long period of time and in particular in an expanding market.

This product unreliability, whether real or perceived, strongly influences the construction industry, which operates within established networks for material supplies, time constraints, and great variability in terms of the volume of business. Contractors therefore tend to adopt a conservative stance: instead of using a product with qualities unknown to them, or risking an insufficient supply of the product at a critical moment -- when delays could prove extremely harmful to their business -- they choose to avoid the product altogether.

A third source of resistance is the existing supply networks for the products that mixed plastic manufacturers seek to displace. The construction industry has developed long-term interdependencies and economic connections with its suppliers, which insure that the needs of the construction companies are fulfilled in a timely and useful manner. As mentioned earlier, these business relationships are maintained and reinforced by the perception that such long-term connections are reliable and trustworthy, and are further perpetuated by the development of personal relationships between business partners. In essence, mixed plastic suppliers have to replace these established networks of trust with a new set of networks, a task which takes considerable time. Existing market relationships are an obstacle, particularly for those plastic suppliers without previous reputations in the construction industry and/or the resources to assure prospective customers of the same long-term supply relationships currently maintained with lumber yards and other suppliers.

The industries that currently supply virgin plastic or wooden lumber products are large, with usually prodigious research resources and can quickly respond to competitive threats. The moment plastic products become a feasible substitute, these companies can be expected to (and already have begun to) improve their own product and/or reduce their cost to make the penetration by plastics more difficult. To the extent that the recycled plastic products industry remains small, it may be unable to match these technical innovations. Therefore, any initial advantages are likely to be overcome by responsive and powerful competitive lumber industries.

THE POLITICS OF GOVERNMENT PURCHASES OF PLASTIC PRODUCTS

It would appear that government agencies would be an ideal target for a market of secondary materials made from mixed plastic waste because they are not entrapped in the short-term cost equations of for-profit construction companies, and because governmental commitment to recycling should be reflected in its purchasing policies. However, this has not been the case, even for products such as speed bumps, highway barriers, or parking lot stops which have a very large government market.

One important dimension is the purchasing process of the government. Even though governmental agencies are far more sensitive to the potential advantages of secondary plastic products, and are perhaps willing to experiment, much of the work they do is done under contract with private construction companies. As a result, purchasing of plastic substitutes for existing wooden products tends to devolve back to private sector profit-oriented organizations. For reasons already mentioned, the logic of changing to these new products will be lost on private businesses; instead

they will tend to preserve existing market arrangements. Unless governmental agencies provide their private contractors with specific product guidelines that include secondary plastics, it will be difficult for the substitution to take place.

Government agencies, whether they procure products or services directly or through profit-seeking subcontractors, have highly complicated specifications for acquisitions that have worked against plastic manufacturers trying to promote plastic lumber products. Most specifications were written with specific products in mind. As a result, it is not clear to purchasing agents that recycled plastic products are acceptable substitutes, even when these products have the capacity to meet the necessary specifications. This is a consequence of a large number of specifications which have become entrenched in government regulations over the years. Even though most specifications contain clauses indicating that a comparable product can be substituted, the companies interviewed found that it was very hard for their products to qualify as "comparable." An example was given by a plastic recycler who had tried to make stop sign poles out of plastic lumber.

The final impediment to government purchases of recycled plastic products is the lack of an organized and coordinated lobbying effort that would result in the inclusion of plastic products in the written product specifications. A long-term lobbying process, much like that undertaken by large corporations is often necessary for governmental agencies to modify regulations. While the resources needed for this lobbying effort are not comparable to those for large national companies, the process still involves a long-term effort involving meetings with governmental agencies, appearances at hearings, informal discussions with

acquisition officers, and formal presentations during the specification process.

The absence of an industry-wide association that could act as a collective representation of the current small-sized plastic manufacturers of secondary materials implies that, at best, a lobbying effort will be sporadic and may have great difficulty making large-scale changes in the current restrictive regulations.

POTENTIAL FOR SUCCESSFUL GOVERNMENT POLICY-MAKING IN THIS AREA

The growing awareness among the general population about the necessity for recycling, and the favorable attitudes towards plastic recycling among citizens and government policy makers suggests that new government initiatives aimed at encouraging the purchase of recycled products are a logical first step in overcoming the resistance to mixed plastic products in both the private and public sector. The following standards would be most effective assuming that small companies with limited resources continue to be the predominant type of business in the recycled plastic industry.

Standards

Government agencies and policy makers should be encouraged to develop industry-wide standards for certain products, particularly plastic products that must meet strength and durability standards of wooden lumber products. Due to the technical complexity of demonstrating consistent adherence to these standards, governmental agencies would have to systematically establish a set of testing procedures.

Government action to stabilize the feedstock for products made from mixed plastic waste and to standardize the process by which they are manufactured would reduce the perceived risk of prospective clients. Such governmental action would require overseeing feedstocks of various manufacturers and licensing the manufacturing process to ensure that the product conformed to the government standards. Although most waste streams are under governmental supervision or even ownership, the jurisdictions controlling recycling have tended to be local governments whose policies have varied widely. Therefore, this supervision would have to be initiated at the state level, even if implementation were left to municipalities.

Finally, the government could set standards of minimum recycled content in products acquired by executive agencies. This requirement could increase in scope as the mixed plastic industry proved itself capable of meeting or exceeding current guidelines for product quality. This would result in the government encouraging the development of high quality post-consumer plastic products, and the introduction into markets currently dominated by non-recycled products.

COMMINGLED PLASTIC WASTE SUMMARY

Engineering properties of mixed waste plastic lumber show that they most closely match those of softwoods such as northern white cedar or eastern white pine. The compressive strengths of plastic lumber are comparable to these softwoods. The specific gravity of plastic lumber, however, is up to three times that of the softwood lumbers. Due to the low modulus of elasticity for plastic lumber, additional structural support members would be required to prevent excessive bending. Therefore, a structure made with plastic

lumber would be considerably heavier than a comparable wooden structure.

A characteristic of plastic lumber as an engineering material is its resistance to decay and boring organisms. Thus, a major benefit might be that of replacing chemically treated wood in uses such as marine construction and highway sound barriers.

Energy losses or savings from the manufacture and use of plastic lumber are difficult to measure and depend on a number of factors including product lifetime, whether it would be recycled, landfilled, or incinerated after use, and whether the plastic lumber replaces a virgin plastic or a wooden product, and energy used in transportation steps.

The actual manufacture of plastic lumber from existing discards takes less energy than making a comparable virgin plastic product from raw materials, and more energy than making a comparable wooden product from raw materials.

The "life-cycle" picture is much more complex. For example, if one assumes the plastic lumber lasts as long as virgin plastic lumber and up to twice as long as wooden lumber:

- o Energy would be lost, all things considered, if, instead of burning the discarded virgin plastics (with energy recovery) and making a new virgin plastic product, the discards are recycled into plastic lumber. Energy is gained, however, if the discards are recycled into plastic lumber, instead of burning the discards but without making the replacement virgin plastic product.

- o Energy would be lost if, instead of the traditional practice of using wooden lumber and landfilling plastic discards, plastic lumber is made from the discards and the wood is left in the forest. However, energy is saved if the plastic lumber ultimately is burned (with energy recovery). Energy is also saved, compared to the traditional practice, if wooden lumber is used but the plastic discards are incinerated (with energy recovery).
- o Energy would be saved (compared to the traditional practice) if, both the plastic lumber is made from the discards, and ultimately burned with energy recovery, and at the same time the wooden lumber is also manufactured, used in some other application, and itself ultimately burned with energy recovery.

Energy costs or savings in such scenarios may be incurred at times or in regions far removed from the time and place of the actual recycling.

Under the most optimistic set of assumptions, manufacture and use of plastic lumber to replace wooden lumber could save New York one-quarter of 1 percent of the total State energy consumption annually (equal to 1.63 million barrels of oil). Under the least optimistic set of conditions, manufacture and use of plastic lumber to replace virgin plastic or wooden lumber could result in energy costs to the State of 910,000 and 390,000 barrels of oil, respectively.

There are many important economic issues that must be resolved for successfully marketing plastic lumber. Collection of plastic waste materials for recycling is small

compared to the amount generated. The total amount of recycled plastics contributes only 4 percent of the potential and 0.6 percent of the actual plastics market.

To date, markets for recycled single resin plastic have had more success than mixed plastic products, which may be due to bottle bill laws that lead to better collection of single resin PET beverage containers and to the plastics industry focusing recycling technologies on single resin plastics. Marketing problems that arise with products made from commingled plastics include inconsistency in feedstock, unpredictable performance, and a lack of suitable engineering specifications and government regulations. An important issue related to the marketability of plastic lumber is whether market outlets are available. Conceivably, demand for plastic lumber would have to penetrate only 5 percent of the market for car stops, 4 percent of the landscape tie market, or 1 percent of the railroad tie market to absorb the entire calculated potential annual amount of plastic lumber which could be produced at current recycling rates. The potential market is enormous compared to projected supplies.

Marketing problems associated with plastic lumber include that it is expensive compared to wooden lumber, concrete, and other materials for which it can be used as a substitute. However, product lifetime must also be taken into consideration with the initial cost of a material; the average lifetime of plastic lumber and other products made from commingled plastics is undetermined. Other factors such as plastic lumber's low maintenance costs are also significant considerations. Additionally, marketing problems may arise due to a reduced aesthetic appeal: there is a lack of available color variations (black or very dark

colors), and impurities such as bits of paper, metal, etc. can be seen within the material.

A notable marketing advantage for plastic lumber over items made from virgin plastics or other material is that it is appealing from an environmental standpoint to many consumers. Some in the industry argue, however, that this advantage is limited; consumers may not buy recycled products that are more costly than nonrecycled products.

Changes in public policy could greatly improve the marketability of plastic lumber. These include more source separation programs at the municipal level, tax incentives, continued research and development, establishment of government standards and engineering specifications, willingness of the government to use plastic lumber, broader content criteria to require certain products to contain a minimum amount of recycled resins, and development of small business and entrepreneurial programs.

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INCINERATOR ASH

PHYSICAL, CHEMICAL, AND ENGINEERING PROPERTIES

The combustion of MSW at waste-to-energy facilities results in the production of ash. Incineration ash is generally a composite of different residues collected at several locations within the facility. Incineration ash usually consists of an amorphous, glass-like material composed of minerals, metals, organic carbon, dirt, and grit (US OTA, 1989). Combined incineration ash is composed of two distinctly different ash fractions, bottom ash and fly ash. Bottom ash is formed following combustion of the solid waste in the boiler. Uncombusted residue that falls onto the grate at the base of the boiler is referred to as bottom ash. Bottom ash accounts for approximately 85 percent of the total ash stream. Visually, bottom ash is similar to a grayish silty sand with gravel, containing pieces of scrap metal.

Fly ash is the portion of the ash that becomes entrained and transported within the combustion gas stream and is removed from the gases by the pollution control devices. The pollution control devices remove the particulates by either electrostatic charge in electrostatic precipitators or by filtration in baghouses. Fly ash is composed of very fine particles, with a significant fraction less than 100 μ in diameter. Lime is often added to the combustion gases prior to the particulate collection devices to remove acid gases. The added calcium oxide or calcium hydroxide is trapped by the particulate collection devices along with the combustion particulates and becomes part of the fly ash. Fly ash containing lime is referred to as scrubber residue. Fly ash has a fine powdery appearance and accounts for the remaining 15 percent of the total ash stream.

Incineration Ash Composition

Incineration ash particles are composed of a variety of major, minor, and trace elements (Table 4-1). Metal content of incineration ash is affected by the composition of the incoming solid waste and the pollution control technology. Metals are not necessarily equally distributed between the fly ash and bottom ash. Fly ash is enriched in volatile metals including lead, cadmium, mercury, and zinc while bottom ash is often enriched in less volatile metals including aluminum, chromium, iron, and nickel (US EPA, 1987; Sawell and Constable, 1988).

Organic chemicals are also found in incineration ash (Table 4-1). Like metals, organics are preferentially distributed between bottom and fly ash. Dioxins, furans, and PCBs are enriched in the fly ash while PAHs and phthalates are concentrated in the bottom ash (US EPA, 1987).

Concentrations of dioxins and furans have been shown to be present in lesser quantities in the fly ash of modern waste-to-energy facilities than in fly ash from older facilities due to more efficient flue-gas management (air pollution control technology) (Visalli, 1987).

COMPARISON OF ENGINEERING PROPERTIES OF ASH AND NATURAL AGGREGATES

The use of incineration ash as an aggregate substitute or aggregate product in construction applications requires that both the environmental and engineering properties of the ash are similar to or better than natural aggregate. The physical properties of ash determine its leaching characteristics, use, handling, and disposal. A variety of engineering tests are available to determine the engineering properties of incineration ash including gradation

Table 4-1. Concentrations of substances in MSW bottom and fly ash.

Substance	Fly Ash	Bottom Ash	Substance	Fly Ash	Bottom Ash
Inorganics (ppm)					
Aluminum	5,300-176,000	5,400-53,400	Vanadium	22-166	53
Antimony	139-176,000		Vanadium	2-380	
Arsenic	15-750	1.3-24.6	Zinc	2,800-152,000	200-16,700
Barium	88-9,000	47-2,000	Organics (ppb)		
Beryllium	ND-4	ND-0.44	Acenaphthalene	ND-3,500	37-390
Bismuth	36-100		Alkanes	50,000	
Boron	35-5,654	85	Anthracene	1-500	53
Bromine	21-250		Benanthrene	0-300	
Cadmium	5-2,210	1.1-46	Benzo(k)fluoranthene	ND-470	
Calcium	13,960-27,000	5,900-69,500	Benzo(g,h,i)perylene	0-190	
Cesium	2,100-12,000		Benzo(a)pyrene	ND-400	
Chloride	1,160-11,200		Biphenyl	2-1,300	
Chromium	21-1,900	13-520	Chlorobenzenes	80-4,220	
Cobalt	2.3-1,670	3-62	Chlorophenols	50.1-9,630	0
Copper	187-2,380	80-10,700	Chrysene	0-690	ND-37
Gold	0.16-100		Di-n-butyl Phthalate	ND	360
Iron	900-87,000	1,000-133,500	Dioxins		
Lead ^a	200-26,600	110-5,300	2,3,7,8-TCDD	0.4-42	0.04-0.7
Lithium	7.9-34	7-19	Total PCDDs	5.23-10,883	ND-110
Magnesium	2,150-21,000	880-10,100	Fluoranthene	0-6,500	110-230
Manganese	171-8,500	50-3,100	Fluorene	0-100	ND-150
Mercury	0.9-47	ND-1.9	Furans		
Molybdenum	9.2-700	29	2,3,7,8-TCDF	0.1-5.4	ND-10
Nickel	9.9-1,966	9-226	Total PCDFs	3.73-3,187	ND-65
Phosphorus	2,900-9,300	3,400-17,800	Naphthalene	270-9,300	570-580
Potassium	11,000-99,000	920-14,500	Phenanthrene	21-7,600	500-540
Selenium ^a	0.48-15.6	ND-2.5	Phthalates		
Silicon	1,783-266,000	133-188,300	Bis (2-EH)	85	2,100
Silver ^a	ND-700	ND-38	Butyl benzyl	ND	180
Sodium	9,780-49,500	1,800-33,300	Diethyl	6,300	
Strontium	98-1,100	81-240	PCBs	ND-250	ND-180
Tin	300-12,500	40-800	Pyrene	0-5400	150-220
Titanium	50-42,000	3,067-11,400			

^a Regulated under the RCRA Extraction Procedure (EP) Toxicity Test (40 CFR 261.24).

ND = not detected

(US EPA, 1987)

characteristics, moisture content, organic content, gravimetric determination, and durability.

Gradation

Gradation (ASTM C136) is a test to determine the particle size distribution of the aggregate material. Aggregates that contain an even gradation of size fractions tend to be relatively stable, resistant to erosion, can be densely compacted, and will develop high shear resistance and bearing capacity.

The size distribution of the less than 3/8 in. fraction of six combined ashes studied by Roethel et al. (1987) showed that 67 percent to 89 percent of the ash was in the sand size range; 4.4 percent to 28 percent in the gravel size range; and 3.8 percent to 6.3 percent in the silt size range. Other ashes have been shown to contain high (10 percent to 15 percent) percentages of fine-ash particles (Chesner, 1988). High concentrations of fine-ash particles in the aggregate would render the ash unacceptable as an aggregate without further processing.

Moisture Content

The moisture content (ASTM D2216) of an aggregate will affect the weight, volume, and ability to process and use the material in various construction applications. The moisture content of ash depends on the method of ash quenching and draining at the waste-to-energy facility. Studies have shown a wide variation in the moisture content of ashes collected from different facilities. Moisture contents of incineration ashes ranged from 2 percent to 50 percent while the moisture content of natural materials generally ranges from 3 percent to 11 percent (Chesner,

1989; Roethel et al., 1986). The moisture content of quenched ash is significantly higher than that of natural aggregate used in construction. If moisture content is too high to meet portland cement specifications, then it should be dried or blended with drier aggregate material (Table 4-2).

Organic Content

Organic impurities in the aggregate used in construction applications may adversely affect the performance of the material. The Percent Organic Matter Test (ASTM 2974) provides an approximate determination of the presence of organic impurities in the aggregate. Unacceptably high organic contents of aggregates may affect the strength and hardening of concrete. Results of several studies have shown that the average organic content of ash ranges from 3.7 percent to 19.8 percent (Chesner, 1989; Roethel et al., 1986). The organic content in ash exceeds organic impurity aggregate criteria for almost all applications (Chesner, 1989). As such, minimum organic content criteria will need to be established for ash aggregate.

Gravimetric Characterization

Gravimetric characterization of an aggregate material includes a determination of the unit weight (ASTM C129), specific gravity (ASTM C127), and absorption testing (ASTM C128). Absorption tests predict the change in the weight of the sample as a result of water absorbed in the pore spaces within the particles. Aggregate materials with high absorption can be expected to exhibit greater susceptibility to freeze-thaw problems. Ash is highly absorptive (4 percent to 15 percent) compared to natural aggregates that could render it susceptible to frost damage (Chesner, 1988).

Table 4-2. Summary listing of engineering concerns associated with the physical characteristics of ash.

Characteristic	Concern	Corrective Measure(s)
High Fines Content	Minus 200 sieve too high for use as an unbound aggregate, or in bituminous or portland cement applications	Blend with other natural aggregate materials; use coarser bottom ash fraction; further process ash into straight sized aggregates
Moisture Content	Too high for use in bituminous or Portland cement applications	Dry ash or blend with drier aggregate materials
Organic Content	Too high for use in Portland cement aggregate applications as measured by organic impurities	Blend with other aggregates; consider performance based specification
High Glass Content	Potential difficulty in asphalt paving applications (i.e., stripping stability)	Blend with other aggregates; add anti-stripping agents
Marginal Durability	May not pass existing specifications	Blend with other aggregates; consider performance based specifications
High Absorption	Frost susceptible in unbound applications, high asphalt cement demand in bituminous concrete applications	Blend with other materials; place above groundwater level in unbound applications; consider addition of absorption resistant additive
Swelling Properties	Volumetric expansion with time; potential dimensional instability in aggregate or final portland cement or bituminous cement products	Store ash to permit hydration reactions to complete; use bottom ash -- less susceptible than combined ash
Pozzolanic Properties and Scrubber Ash	Cementitious reactions alter properties of materials; stockpile and storage problems due to cementing of particles; hydration reactions could impact dimensional stability of portland cement or bituminous cement mixes	Use bottom ash without scrubber and baghouse or precipitator ash
High Water Soluble	Salts could potentially inhibit Portland cement reactions; potential efflorescence in final products; anticipated swelling due to salt (see Swelling Properties); leaching of salts could result in metal corrosion problems	Use of bottom ash only reduces water soluble component; for corrosive problem do not apply in unbound form above metal structure without proper cathodic protection

Unit weight measurements provide a means to classify aggregate materials as either lightweight, normal weight, or heavyweight. Unit weight and void content are properties that determine the ease with which particles can be manipulated in portland cement concrete, and determine the workability and strength of the concrete mix. Mean unit weights of ash samples range from 64 lbs/ft³ to 77 lbs/ft³ (Chesner, 1989). Unit weights of natural aggregates range from 80 lbs/ft³ to 130 lbs/ft³. The results indicate that ash can be characterized as a lightweight aggregate.

Durability

Durability of aggregate materials is determined by conducting soundness testing (ASTM C88), abrasion testing (ASTM C131), and break down testing (NJ DOT A-8). The soundness test subjects the aggregate to cyclical expansion and contraction forces associated with the freezing and melting of water. Aggregates that readily break down during the soundness test may be a problem when exposed to severe weathering. The Los Angeles Abrasion Test measures the ability of the aggregate material to maintain its physical integrity under defined abrasive conditions. The lower the percentage of aggregate wear as measured by the abrasion test, the greater the concrete strength and durability. The break down test was developed by the New Jersey Department of Transportation (NJ DOT) to evaluate the potential aggregate degradation due to material handling, field compaction, and exposure to weathering. The lower the percentage of breakdown in sizes, the more durable the aggregate.

Results of soundness testing of ash show that the fine and coarse fractions of the ash yielded values well below usual soundness specifications (Chesner 1989). The soundness of

both the coarse and fine ash fractions ranged from 1.9 percent to 3.5 percent loss while the specification limits for natural aggregates ranges from 15 percent to 45 percent loss.

Specifications for natural aggregates for the Los Angeles Abrasion Test range from 20 percent to 45 percent loss by weight. Results of testing for incinerator ashes show that the material is marginal, either exceeding or falling within the high range of typical permissible specifications (Chesner, 1989).

New Jersey has established a 25 percent loss as a maximum limit for break down of aggregate materials. Results of testing for incinerator ash show that although the percent loss for most samples fell below the 25 percent criteria established by NJ DOT, they are close to this maximum specification limit (Chesner, 1989).

Applications and Limitations of Ash Aggregates

Results of engineering studies show that ferrous-free, minus one-half inch incinerator ash can be used as a substitute for natural aggregate in construction applications (Chesner, 1989). Ash may be used as an engineering material in either particulate form as fill or road base or in bound applications including bituminous concrete or portland cement.

Although ash possesses many suitable properties for use as an aggregate substitute, several properties of ash may negatively affect its engineering properties. Table 4-2 lists engineering concerns associated with ash use and possible corrective measures. Although incineration ash possesses many suitable engineering properties, which allow

for its use in construction applications, it also contains metal and organic constituents that may limit its use based on environmental concerns.

LEACHING OF INCINERATION RESIDUES

Numerous studies have shown that metals in ash are leached into solution using a variety of leaching protocols. The leachability of a metal from incineration ash depends on many factors including the chemical form of the metal, availability for leaching (surface or matrix associated), pH of the leaching solution, ionic strength of the leaching solution, and liquid to solid ratio of the leaching test (Park, 1987; DiPietro et al., 1989; van der Sloot and de Groot, 1989). As no one test can adequately address all these variables, incineration ash has been subjected to several leaching protocols to better understand the leachability of metals and organics from ash (Table 4-3).

A wide variety of leaching protocols have been used to determine the leachability of metals from incineration ash (Table 4-3). These tests are designed to predict the leachability of metals subjected to a variety of environmental conditions. Two of the most common leaching tests applied to incineration residues, the Extraction Procedure Toxicity Test (EP Tox) and the Toxicity Characteristic Leaching Procedure (TCLP) are designed to determine whether wastes exhibit hazardous characteristics when subjected to acidic conditions similar to those which may be present in a mature municipal solid waste landfill. The tests consist of mixing the wastes with deionized-distilled water with the pH adjusted to pH 2.8 (TCLP) or pH 5.0 (EP Tox) with acetic acid and mixed for 24 hours. The leachates are then analyzed for eight metals and up to 38 organic compounds. A waste is considered hazardous

Table 4-3. Summary of leaching testing procedures.

Leaching Test	Leaching Solution	Initial pH	L:S	Contact Time (hr)	Solution Renewal	Number of Extractions	Mixing
TCLP	Acetic Acid	2.8	20:1	24	No	1	Tumbling
EP Tox	Acetic Acid	5.0	16:1-20:1	24	No	1	Stirring
ASTM DID	Distilled Deionized water	5.6	4:1	48	No	1	Tumbling
ASTM SAR	Synthetic acid rainwater	3.5	4:1	48	No	1	Tumbling
Sequential Extraction	M ₉ CL ₂ Acetic acid NH ₂ OH-HCl HNO ₃ /H ₂ O ₂ HF/H ₃ BO ₃	Variable	Variable	Variable	Yes	5	Shaking
Cascade DID	Distilled Deionized water	5.6	10:1	24	Yes	4	
Cascade SAR	Synthetic acid rainwater	3.5	10:1	24	Yes	4	Tumbling

if the concentration of the constituent in the leachate exceeds a value equal to 100 times the US Drinking Water Standard. For incineration ash, lead and/or cadmium concentrations in the leachates generated from fly ash frequently exceed the regulatory standards for toxicity (Hahn and Sussman, 1988; US EPA, 1987). Lead and cadmium concentrations in combined ash and bottom ash leachates exceeded the regulatory limits for toxicity much less frequently than fly ash.

Lead and cadmium are usually enriched in incineration ash (Table 4-1). The major sources of lead and cadmium in MSW include batteries (lead-acid and household), consumer electronics, glass and ceramics, plastics, and pigments (Franklin Associates, Ltd., 1989). The high concentrations of lead and cadmium in incineration ash are cause for concern since both these metals have exceeded regulatory limits for toxicity when subjected to the EP Tox and TCLP leaching protocols. The leachability of lead and cadmium, as with all metals from incineration ash, is primarily influenced by solution pH. Fly ash, due to the presence of scrubber residue, is usually highly alkaline. Bottom ash is the least alkaline of the ash components while the alkalinity of combined ash is intermediate. Both combined ash and fly ash can neutralize acidic leaching solutions. As such, resultant leachate solutions in contact with these ashes are usually alkaline.

Figure 4-1 shows the results of lead and cadmium analysis of leachates generated using the EP Tox, TCLP, ASTM DDW, and ASTM SAR leaching protocols. Cadmium leaching from incineration ash occurs at pH < 6 levels. At pH > 6, cadmium concentrations in leachates are very low (Roethel et al., 1991; US EPA, 1990). Like cadmium, lead is also

Figure 4-1. Metal release vs leachate pH.
(Chesner and Roethel, 1991)

leached at pH < 6 levels. In contrast, lead is also leached at a pH > 10. Lead concentrations in leachates are low within the pH range of 6 to 10.

The use of the EP Tox and TCLP tests for regulating the disposal of incineration residues has been criticized as they do not subject the ash to leaching conditions present in an ash monofill. The EP Tox test, using an acidic leaching solution, may overestimate the metal concentration of monofill ash leachates. The range of concentration of metals in monofill leachates is shown in Table 4-4. The metal concentrations reported in ash monofill leachates are lower than EP Tox limits and occasionally higher than US Drinking Water Standards. Leachate from ash monofills primarily contains high concentrations of soluble salts including sodium, sulfate, calcium, and potassium.

Results to date indicate that there is little cause for concern about the leachability of organics, most notably dioxins and furans, from incineration ash (Table 4-4). Both laboratory studies and analysis of leachates collected from ash monofills indicate that organics, including dioxins and furans, are relatively insoluble in water and are not present in high concentrations in leachates (Sawell and Constable, 1988; US EPA, 1987).

STABILIZATION AND LEACHING OF INCINERATION ASH BLOCKS

Due to the expense and environmental concerns associated with landfilling ash, research programs are investigating the potential for using incineration residues to manufacture ash blocks. Research has shown that incineration ash has engineering properties that allow for its use in construction (Roethel et al., 1986; Chesner, 1989).

Table 4-4. Range of concentrations in leachate at ash monofills.

Substance	Concentration ^a	Drinking water standards		EP Tox limit
		Denmark	USA	
Arsenic	0.005-0.218	0.05	0.05	5.0
Barium	1-2.48		1.0	100
Boron	<0.02-0.76	1		
Cadmium	<0.0001-0.044	0.005	0.001	0.1
Calcium	21-3200	200		
Chromium	<0.002-1.53	0.05	0.05	5.0
Copper	<0.0005-24	0.1		
Iron	0.168-121			
Lead	<0.0005-2.92	0.05	0.05	5.0
Magnesium	0.09-41	30		
Manganese	0.103-22.4			
Mercury	<0.00005-0.008	0.001	0.002	0.2
Molybdenum	<0.03			
Nickel	<0.005-0.412	0.05		
Potassium	21.5-4300	10		
Selenium	0.0025-0.037		0.01	1.0
Silver	<0.001-0.07			
Sodium	200-7300	175		
Sulfate	310-4900	250		
Zinc	<0.01-0.32	5		
Benzaldehyde	ND-0.008			
Biphenyl	ND-0.051			
Dimethyl	ND-0.120			
propane diol				
Dioxins (ng/l)				
Total	0.06-543			
2,3,7,8-TCDD	0.025-1.6			
Ethyl hexyl	ND-0.08			
phthalate				
Furans	0.04-280			
total (ng/l)				
Hexa tiepane	ND-0.082			
PCBs (mg/ul)	<1			
Sulfonylbis	ND-0.011			
sulfur				
Thiolane	ND-0.400			

^aConcentrations reported ppm (mg/l) except for PCB, dioxins, and furans; ND (not detected). Data represent samples taken from range of monofill ages and operating conditions.

(Forrester, 1989; Hjelmar, 1987; US EPA, 1987)

Particulate incineration ash can be combined with cement and stabilized to form a solid block. The stabilization process has been shown to effectively prevent the release of metals from the stabilized incineration ash blocks, and may provide an alternative method for the disposal or reuse of incineration ashes (Roethel et al., 1987).

Cement-based stabilization technologies have been applied to various energy-related combustion by-products to produce a solid block for reuse as a reef-building material (Parker et al., 1981; Price, 1987; Kalajian et al., 1990). Initial studies focused on the stabilization of coal fly ash using a mixture of coal fly ash, flue gas desulfurization waste, lime, and cement to form a solid block. Similarly, oil fly ash has been successfully stabilized to form solid blocks using coal fly ash, lime, and cement (Mazurek, 1984). Both stabilized waste materials had sufficient engineering properties to be used as a material for artificial reef development. Both laboratory and field studies have shown that contaminants of environmental concern are effectively retained within the stabilized ash blocks.

Laboratory studies also showed that incineration ash could be combined with cement to form a solid block (Roethel et al., 1986). Engineering studies showed that the blocks had engineering properties that would allow for their use in a variety of reuse applications. Due to concern about the potential for contaminants leaching from the stabilized ash blocks, a variety of leaching protocols have been used to determine the leaching behavior of contaminants associated with ash blocks.

Leaching of Incineration Ash Blocks

The leaching of contaminants from stabilized ash blocks in contact with water is primarily controlled by three mechanisms: dissolution, diffusion, and surface wash-off (van der Sloot and de Groot, 1989). Surface wash-off is the rapid release of contaminants weakly bound to the surface of the block. Dissolution involves the interaction of the block surface with water in which the block surface is slowly leached by the water. Diffusion-controlled release of a contaminant involves the movement of solubilized contaminant in the pore water within the block.

Tank-leaching studies are the best method available for studying these leaching mechanisms. Tank-leaching studies involve submersing a block sample in well-mixed water and periodically withdrawing samples of water for chemical analysis (Breslin, 1986; Roethel et al., 1986). The water in the tanks is frequently changed to avoid saturation effects that may affect leaching processes. The data from the tank-leaching study may be used to identify the mechanism of leaching for contaminants. Chemical availability of a contaminant, physical properties that retard leaching of the block, and chemical retention of the contaminant are three mechanisms that limit the leachability of contaminants from ash blocks. A variety of physical and/or chemical properties of the block including temperature, chemical speciation of a contaminant, redox potential, pH, porosity, and permeability affect the leaching of contaminants.

Results of laboratory tank leaching studies performed on stabilized incineration residues show that metals are effectively retained within the cementitious matrix of the block (Roethel et al., 1987; Park, 1987). Copper, lead, and

cadmium leaching was found to be low and decreased with time (Park, 1987). Factors including solution pH, cement content, and metal speciation were identified as controlling the rate of release of metals from ash blocks.

BLOCK-MAKING TECHNOLOGY

Combined incineration ash used in the following demonstration programs were collected from mass burn incinerators that do not use acid gas scrubbers that inject lime into flue gas to trap acid gasses. As a result, these ashes did not contain scrubber residue. Research has shown that scrubber residue in ash used to manufacture blocks can adversely affect the engineering properties. Calcium salts in scrubber residue (composed of fly ash, unreacted lime, and calcium salts) hydrate when wetted resulting in volume expansion producing cracks in cement-based stabilized ash products. Collecting the bottom ash separately from the fly ash for aggregate processing, not currently the industry practice, would eliminate this problem.

One of the objectives of research at WMI is to manufacture incineration residue products using existing block-making technology as reef-building material and to construct a boathouse. In the case of block making, for either reef or construction-quality blocks, the technology is well established. The incineration ash blocks used for the ash demonstration programs were manufactured at conventional cement block-making facilities.

Ash collected at the waste-to-energy facility must be processed prior to block manufacturing. Initial processing involves removal of metal, both ferrous and non-ferrous. Ferrous metal may be removed at the facility using electromagnets. Additional metal may also be removed during

the screening. Ash for use in block manufacturing must be screened to a particle size less than 3/8 in. The screening removes oversize material, omitting materials that may damage block making machines or molds during block manufacturing. In general, the higher degree of ash preprocessing, including metal removal and screening, the better the quality of the resultant block.

A simplified schematic of the block-manufacturing process is shown in Figure 4-2. The mix components are usually fed in weighed amounts from storage hoppers into a mixer. Water is then added to the mix to adjust the moisture content. For ash block manufacture, the method for determining the proper moisture content of the mix was adjusted. For cement block manufacture, a conductivity meter is used to determine the proper moisture content of the cement-aggregate mix. Due to the high soluble salt content of the ash, which interfered with the conductivity meter operation, a flow meter was used to determine the proper amount of water added. The well-mixed materials are then transported via a conveyor belt to the feeder of a Besser Vibrapak block-making machine. A block mold is positioned on a steel pallet in the block machine while material is fed into the mold box by vibration. The material is then quickly vibrated and compacted into the mold consolidating the material into blocks. After compaction, the mold lifts, and the pallet holding the blocks emerges from the machine as a new pallet is positioned beneath the mold box for the next molding cycle.

At full capacity, a block-making machine can produce as many as 1800 blocks/hour. The pallets holding the blocks are stacked and transported to curing chambers where the blocks are steam-cured for 12 hours. Cured blocks are unracked,

Figure 4-2. Simplified schematic of block-making process.

depalletized, and stacked by a cubing machine as cubes of interlocking blocks on carrying pallets.

ENVIRONMENTAL IMPACTS OF ASH-BLOCK MANUFACTURING

The greatest potential for exposure to contaminant release from block making is associated with activities prior to the stabilization of the ash. Activities including ash transportation, processing, and storage pose the greatest exposure risk (Koppelman and Tanenbaum, 1990). Both stockpiling ash and processing ash before block manufacture may generate leachate and fugitive dust. Proper storage and processing of ash in enclosed facilities and maintenance of the ash in a moist state may reduce the dusting and leaching problems. Ash can be stored in hoppers at the block-making facility to minimize dusting and exposure to rainwater. Ash is wetted after it is transported to the mixer and remains damp throughout the block-making process. Following curing the blocks, leaching studies show that contaminants are retained within the block thereby minimizing contaminant leaching (Roethel et al., 1987).

Care should be exercised when handling the ash blocks at construction sites. In particular, dust masks should be worn when cutting or breaking ash blocks to prevent dust inhalation. Also proper handling of the final disposition of the ash block at the end of its useful life needs to be discussed to ensure minimal exposure to fugitive dust during and following demolition of ash-block buildings.

PLACEMENT AND MONITORING SECONDARY ASH BLOCKS

Several research programs are currently ongoing investigating the use of incineration residues as a substitute for natural aggregate in the manufacture of

concrete blocks (Roethel et al., 1987; Mahoney and Mullen, 1988). Successful laboratory studies have led to the initiation of field demonstration programs to evaluate the engineering and environmental acceptability of blocks manufactured using incineration ash in lieu of natural aggregate. The following is an overview of the status of several ongoing or proposed field demonstration programs evaluating the chemical and engineering properties of incineration ash blocks.

Incineration Ash Block Reef Placement and Monitoring Activities

A research program was initiated at WMI at MSRC, The University at Stony Brook, New York to examine the feasibility of using stabilized incineration residues in a variety of applications instead of landfilling the particulate residues. Results of laboratory studies showed that stabilized incineration residues possessed strengths which would allow for their use in a wide variety of applications. The stabilized residues were subjected to several regulatory extraction protocols and in no instance did the metal concentrations in the leachate exceed regulatory limits for toxicity (Park, 1987). Bioassays using marine phytoplankton did not reveal any adverse impacts to biological reef communities exposed to leachates prepared using the stabilized incineration residue blocks.

During the Fall of 1986, blocks destined for reef construction were manufactured in Alpena, Michigan. The block mix consisted of 63.8 percent screened ash; 21.2 percent crushed ash; and 15 percent portland cement Type II, with a total mix moisture content of 10.2 percent. The well-mixed materials were hopper fed into the Besser Vibrapak block making machines which produced stabilized

incineration residue blocks. Approximately 60 stabilized reef blocks were manufactured for physical and chemical evaluation.

On April 27, 1987, 30 stabilized incineration residue blocks and 30 standard cement blocks were submerged in 26 ft of water in Conscience Bay, Long Island Sound, New York. The blocks were arranged underwater to produce two separate structures, one constructed using stabilized incineration residue blocks and one constructed using cement blocks, approximately 10 ft apart. Divers have periodically returned to the reef site to study the interactions of the stabilized incineration residues with the marine environment.

The 28-day net unconfined compressive strength of the stabilized incineration residue blocks prior to seawater submersion was 1,120 psi, a value that far exceeds the minimum unconfined strength value of 300 psi recommended for marine disposal (Table 4-5). Results of unconfined compression testing of incineration residue blocks retrieved from Conscience Bay showed that the blocks retained 85 percent of their initial strength after 1,695 days of seawater submersion.

Analysis of the elemental composition of the stabilized incineration residue blocks submerged in Conscience Bay was performed to detect any release of metals from the blocks to the surrounding seawater. Results showed that even after prolonged seawater exposure, these metals of environmental concern were effectively retained within the cementitious matrix of the blocks (Breslin et al., 1988). Analysis of the dioxin and furan content of blocks before and after submersion in the sea showed that these organic components

Table 4-5. Engineering criteria for residue block secondary products.

Secondary Product	Compressive Strength Criteria	Compressive Strength Achieved
Artificial reef blocks	300 psi ^a	800-1,200 psi
Shore protection devices	3,000 psi ^b	3,200-4,200 psi
Construction blocks	1,000 psi ^c	1,620-2,570 psi

Both the recommended criteria and achieved values are obtained using a 28-day unconfined compressive strength test according to ASTM C39 testing protocols.

^a (Woodhead *et al.*, 1984).

^b US Army Corps of Engineers.

^c Underwriters Laboratory Specification 618.

were also effectively retained within the residue reef blocks (Roethel et al., 1990).

The reef structures were rapidly colonized by a wide variety of marine organisms. Metal analysis of digested tissues of organisms removed from the residue reef structures showed that metals of environmental concern were not elevated in tissues of organisms removed from the residue reef structure (Breslin et al., 1988). Recently, similar results were obtained using mussels as indicator organisms.

To date, no adverse environmental impacts have been observed at the Conscience Bay reef site. Continued monitoring of the reef site is planned to obtain data to more clearly define the long-term effects of stabilized incineration residue blocks in the marine environment.

INCINERATION ASH CONSTRUCTION BLOCK MANUFACTURING

The favorable physical and chemical properties of the stabilized incineration residue blocks used for artificial reef construction led to an investigation to determine whether incineration residues could be used in lieu of natural aggregate to manufacture concrete masonry blocks. During September 1988, blocks were again made at the research facilities of the Besser Company at the Alpena Community College in Alpena, Michigan with a goal to produce construction-quality blocks with incineration residues replacing natural aggregate using conventional block-making equipment.

Combined incineration residues were collected during August 1988 from a waste-to-energy facility in Baltimore, Maryland. The combined residues were processed at the Alpena facility to obtain screened and crushed ash. Five incineration

residue construction block mixes were tested to determine their suitability for fabricating construction blocks (Table 4-6). For all five mixes, a 3:1 (volume:volume) ratio of the screened residue to crushed residue was used to form the combined ash sample. The 3:1 ratio reflects the volume of the screened and crushed components of the total unprocessed combined ash sample. Three sand contents (25 percent, 33 percent, and 50 percent) for the mixes were investigated. Fifteen percent by weight portland cement Type IP was added to each of the combined residue and sand mixtures. Type IP portland cement is a pozzolan cement containing from 15 percent to 40 percent coal fly ash. The moisture content of the 33 percent sand mixes (mix A, B, and C) was varied to determine an optimum moisture content for block making. In addition, Acme-Hardesty superplasticizer was added to the mixes to allow them to flow more easily.

Unconfined Compressive Strength

The unconfined compressive strengths of the construction blocks were determined after one and 28 days (Table 4-6). According to Underwriters Laboratories Specification 618, concrete masonry units produced using incineration residues as an aggregate require an average unconfined compressive strength of 1,000 psi and a minimum strength of 800 psi (Table 4-5). The 28 day unconfined compressive strengths of the incineration residue blocks easily exceeded the average strength criteria. The unconfined compressive strengths of the 33 percent sand mixes were shown to increase with increasing moisture content (Table 4-6). As the moisture content of the mix increased from 6.4 percent for mix C to 8.7 percent for mix B, the one day unconfined compressive strengths likewise increased from 829 psi to 1,330 psi, respectively. Compressive strengths of the blocks also

Table 4-6. Compressive strengths of Alpena 88 construction blocks^a.

Sample Batch	Moisture ^b (%)	Sand (%)	Unit Weight (%)	1 Day Compressive Strength (psi)	28 Day Compressive Strength (psi)
A	8.3	33	37.84	1,010 ± 330	2,190 ± 39
B	8.7	33	39.59	1,330 ± 255	2,570 ± 42
C	6.4	33	36.57	829 ± 15	1,620 ± 148
D	5.6	50	39.47	1,680 ± 12	2,570 ± 98
E	8.7	25	38.15	1,080 ± 18	1,990 ± 29

^a Construction blocks (8 in. x 8 in. x 16 in.) were fabricated on August 24, 1988.

^b Moisture content were measured after heating the sample to 230°F for 24 hours.

increased as the sand content of the mix increased from 33 percent to 50 percent.

Fire Resistance Testing

During October 1988, 32 construction-grade incineration residue blocks were shipped to Underwriters Laboratories, Inc., Northbrook, Illinois to undergo fire resistance testing. The Underwriters Laboratories Standard UL 263, Fire Tests of Building Construction and Materials, evaluates the length of time a wall assembly will contain a fire, retain structural integrity, and tests the wall assembly's resistance to a hose stream. Results showed that the passage of flame to the unexposed surface of the wall assembly constructed using the incineration residue blocks did not occur during the two-hour fire exposure. In addition, transmission of heat through the wall assembly did not raise the temperature of the unexposed surface at any one point more than 325 °F above the initial temperature and the average temperature did not exceed 250 °F above the ambient temperature during the initial two-hour fire exposure. Finally, the wall assembly withstood the hose stream test without developing through openings or penetration of the water stream. These findings compared favorably with conventional cement blocks.

Boathouse made from Cement Blocks with Ash

The physical properties of blocks produced using incineration residues as a substitute for natural aggregate meet or exceed existing standards for use as a construction material. Further physical evaluation of the construction-quality incineration residue blocks is continuing at the Department of Civil Engineering at The University at Buffalo, New York. Further investigations of the chemical

and environmental properties of the blocks are being performed at WMI. To more fully evaluate the potential for the use of residue blocks as a building material, a boathouse has been constructed at MSRC using masonry blocks fabricated using incineration residues. More than 14,000 incineration residue blocks were manufactured using bottom residues and combined residues at Barrasso and Sons, Inc. Islip Terrace, New York, for use in the boathouse construction (Figure 4-3). Unconfined compressive testing of the blocks showed strengths exceeding 1,200 psi after seven days curing. A comprehensive monitoring program including in-door air quality and soil quality, is being conducted in and around the boathouse to further evaluate the environmental acceptability of residue blocks as a construction material.

INCINERATION ASH IN SHORE PROTECTION DEVICES

Concrete, due to its physical properties and its adaptability to various designs and shapes, is widely used in coastal and waterfront construction. Applications include docks, piers, and wharves at port facilities, bridges, outfall structures, and erosion control structures. The durability, strength, and economy of concrete make it ideal for the marine environment. Although concrete is already one of the most popular materials for coastal construction, its unique properties will result in increased usage in the future (Moffat and Nichols, 1983).

Marine uses of concrete will increase even assuming conservative estimates for a rise in sea level. A rise in sea level would cause a need for gradual shoring or reconstruction of port and waterfront facilities and increased efforts in erosion control (National Research

Figure 4-3. Boathouse made from incineration residue blocks.

Council, 1987). As one would expect, the greatest level of construction activity in response to rising sea level would most likely occur in the highly developed and populated coastal urban centers (Titus, 1986). Thus, the areas requiring the largest volume of construction materials for marine applications would coincide with the areas experiencing the greatest difficulty disposing of incineration residues. Development of secondary materials using incineration residues for marine construction would provide a needed resource which may alleviate the need to dispose of particulate incineration residues. The WMI recently completed a research program funded by the New York Center for Hazardous Waste Management, The University of Buffalo, New York to design and evaluate shore protection devices containing incineration residues (Swanson et al., 1992).

The objective of the investigation was to develop ready-mix material using incineration residues that meet design criteria established by the US Army Corps of Engineers (US ACOE) for erosion control concrete armor units. The ready-mix material can be poured into molds and cured allowing a greater variety of products to be manufactured. The concrete armor units require the highest standards of strength and durability since they are most often used in high energy wave environments.

The first phase of the program showed that combined incineration residues can be blended with cement and additives to form a product that exceeds the US ACOE strength criteria for use in the manufacture of tetrapods and pilings. Working with an industrial partner, Hazcon, Inc. from Brookshire, Texas, researchers at WMI evaluated the effects of adding their patented additive Chloranan to the mix. Chloranan alters the morphology of the bonding

crystals formed when the cement cures produce a denser material with enhanced strengths.

A series of mix designs were developed incorporating Chloranan at a constant cement to admixture ratio of 10:1. Table 4-7 shows the compressive test results for a variety of residue/cement/Chloranan/water mix designs. Three of the mix designs tested exceeded the recommended compressive strength criteria of 3,000 psi (Table 4-5). The optimum mix design shown had an unconfined compressive strength of 4,200 psi using a cement addition well within the range used in commercial applications.

The chemical properties of those mixes that exceed the US ACOE physical requirements have been evaluated. Bench-scale leaching tests revealed that metals of environmental concern were retained by the stabilization process. Seawater diffusion studies indicated that calcium was being released and magnesium was being absorbed from seawater. There were no other metals observed diffusing from the stabilized material into the seawater. Bioassay analyses showed that the incinerator residue does not appear to be toxic to the marine organisms studied (Swanson et al., 1992). Plans are currently being developed for a second phase of the program to evaluate the performance of shore protection devices.

ENERGY IMPACTS OF MANUFACTURE AND USE OF CONSTRUCTION BLOCKS FROM INCINERATOR ASH

What is the impact on energy resources of using incinerator ash as a substitute for natural aggregate in construction blocks? To answer this question, energy use for ash blocks must be compared with that for "regular" blocks from "cradle to grave," including extraction of raw materials,

Table 4-7. Compressive strengths of mix designs incorporating chloranan.

Mix Design	Cement (%)	Water/cement ratio	Compressive Strength (psi)
I 1	33	0.40	4,020
I 2	28	0.70	2,880
I 3	23	0.69	1,900
I 4	23	0.60	2,110
I 5	23	0.51	2,860
I 6	20	0.72	1,260
I 7	17	1.00	690
I 8	23	0.49	4,200
I 9	20	0.50	3,190
I 10	17	0.50	2,680

The Chloranan to cement ratio was held constant at 1:10.

The compressive strengths were determined after 28 days curing.

manufacture, transportation, application, and disposal or recycling.

What counts as "cradle" and "grave" depends on the nature and purpose of the study. For example, do the energy impacts of the use of ash blocks begin in the cradle of the original garbage, before incineration, or in the cradle of the ash stream collection points in the incinerator? Respectable arguments can be given both ways. Conceptual, political, and regulatory considerations bear on this and other system boundary issues. For example, are ash blocks recycled products that count towards meeting statewide goals for municipal recycling rates, or purchases of recycled products? The manufacture and use of ash blocks might be seen as a form of recycling if the crucial consideration is held to be that the ash otherwise would end up in a landfill. If the overriding consideration is held to be (as it is by opponents of incineration) that the original garbage otherwise would not be burned to begin with, ash blocks might not be seen as recycled products. The definition of recycling continues to be a contentious matter generally. In fact, several national advisory committees have come to conflicting conclusions, when a conclusion could be reached at all (Reaven, 1990).

Excluded from consideration in this report are energy expended, generated, or saved in the incineration process itself, or prior to it (e.g., in collecting MSW). The production of large amounts of ash is taken as a given; the research task is specifically to ascertain whether turning the ash into construction blocks saves (or costs) energy compared to placing the ash in a landfill or ash monofill.

This assumption is fitting on several accounts. Many incinerators already are operating in New York State. Also,

the advantages or disadvantages of ash blocks have not to date significantly affected decisions to build (or not build) incinerators. Even if the availability of this form of ash recycling influenced such a choice, the energy impacts of the block-making technology mattered far less than its cost or state of technological readiness. In addition, the energy assessment of incineration is itself a complex, much-debated topic that only can be addressed by comparing incineration with various recycling and composting alternatives across the entire waste stream spectrum, a project far beyond the scope of this report. Finally, while each broad waste management program will, by affecting the composition of the wastes entering them, affect the energy consumed by and recovered by incinerators, these differences scarcely matter to the energy requirements of recycling the resulting ash.

DIFFERENCES IN PROCESSNG ENERGY

The processes use standard masonry fabrication equipment and standard raw materials (primarily portland cement), with combined incinerator ash replacing some or all natural aggregate materials. Discussions with one of the ash block manufacturers (Barrasso and Sons), and with many researchers and engineers engaged in evaluating ash block and regular masonry technology, clearly showed that there is no reason to think that processing energy requirements for ash blocks differ significantly from those for regular blocks. On the basis of these discussions, it was determined that a step-by-step process energy analysis was not needed in this report.

Ferrous metals normally are removed at the incinerator, but in some circumstances may be removed at the block fabrication facility or an intermediate location. The

energy expended in ferrous removal (and any energy saved by avoided production of metal from virgin ore) is excluded from this report because ferrous metals are assumed to be removed even if the ash is landfilled. In addition, the impact of any ferrous removal on energy used to transport ash to a landfill is insignificant on a per-pound-transported basis.

DIFFERENCES IN TRANSPORTATION AND EXTRACTION ENERGY

Table 4-8 compares the energy draw of the two kinds of blocks. The results are derived as follows.

Construction Blocks

It is assumed there are shipments of 1,080 8 in. x 8 in. x 16 in. two-core blocks (about 52 percent solid) by flatbed tractor-trailer or self-unloading boom truck at 4 mpg of #2 diesel fuel for regular blocks, 4.25 mpg for ash blocks. The blending rate would be such that regular blocks weigh 42 lbs, ash blocks 36 lbs. Seventy percent of the weight of ash blocks is combined ash (on a per-pound-of-ash-used basis, the results presented in the table are largely insensitive to this percentage). Each pound of ash used in a construction block is assumed to substitute for 1.2 lbs of natural aggregate. On these assumptions, transportation energy is 0.766 Btu/lb-mile for regular blocks and 0.794 Btu/lb-mile for ash blocks. Note that the higher mileage in trucking the lighter ash blocks is more than offset by the greater efficiency on a per-pound basis in trucking the regular blocks.

Table 4-8. Energy comparison: regular blocks and incinerator ash blocks.

In Btu/lb of incinerator ash used in construction blocks

	If regular blocks used	If ash blocks used
Chargeable extraction energy	312	0
Raw material transport to fabrication plant	0.7/mile	0.1632/mile
Block manufacture	same for both kinds of blocks	
Transport blocks to job site	0.919/mile	0.794/mile
Transport raw ash to landfill	0.632/mile	not applicable
Final disposal of used blocks	insufficient data to estimate	

Raw Ash

Twenty two ton shipments of combined ash with ferrous removed and with a moisture content of 20 percent, in 38 yd³ capacity trucks containing about 28 yd³ actual material and obtaining 5 mpg, would yield 0.632 Btu/lb-mile. Mileage is based on Baker and Saemans (1977) and Chesner (1990) and discussions with waste haulers, trucking associations, and construction block businesses, and on interpolations of mileage between zero-load mileage and maximum-load mileage. Mileage is affected by such factors as load weight, truck type, stop-and-go traffic, and number of stops.

The energy impacts of substituting ash blocks for regular blocks depend on the distance from the incinerator to the landfill or ashfill to which the ash would be sent otherwise; the distance from the incinerator to the ash block fabrication plant; the distance from the fabrication plant to the job site; and, the distance from the sand or gravel pit to the fabrication plant. Typical distances estimated for the fabrication plant to the job site are 20 miles for the two kinds of blocks, and, for the sand or gravel pit to the fabrication plant distances are 25 miles for Long Island and 40 miles elsewhere in New York.

Overall energy savings per pound of ash used in blocks can then be estimated for ash blocks made at or adjacent to the incinerator, and for ones made at an existing regular block facility 20 miles away. Results are in Table 4-9.

These results show that the energy advantage of making ash blocks at or near the incinerator is negligible, and that the energy advantage of having a source of aggregate close by (as on Long Island) is also negligible. Energy savings from avoided extraction of natural aggregate are exceeded by

Table 4-9. Overall energy savings as a function of distance to landfill.

Distance to Landfill or Ashfill (miles)	Btus saved per pound of ash in blocks			
	Blocks made at incinerator		Blocks made at existing plant	
	upstate	LI/NYC	upstate	LI/NYC
0	360	350	373	363
50	392	382	405	395
100	423	413	436	426
200	486	476	499	489
400	613	603	626	616
1,000	992	982	1,005	995

energy savings from avoided transportation to landfills when the landfill is 570 or more miles away. If the landfill is nearby (50 miles or less), 80 percent or more of energy savings derives from avoided extraction of natural aggregate.

Figure 4-4 displays annual energy savings (in barrels of oil-equivalent) as a function of daily tons of ash converted into blocks. For the landfill 200 miles away, recycling one ton of ash into construction blocks saves energy equivalent to that in seven gallons of #2 diesel fuel. The potential energy savings from using incinerator ash in construction blocks are a very small fraction of New York State's total annual energy consumption (equivalent to the energy in 650 million barrels of oil). One reason is that a few gallons of gasoline can move a great deal of ash. An estimated 2,000 gallons would bring all of Long Island's 1,000 daily tons of ash 200 miles; accordingly, the transportation energy expenses avoided by making and using ash blocks are less than might be thought. In any case, energy savings are maximized for incinerators furthest from landfills/ashfills that will accept their ash. From an energy point of view, such incinerators should be the first candidates for this technology.

INDIRECT DIFFERENCES IN ENERGY CONSUMPTION

The applications of ash blocks do not appear to have an impact on energy use. The building energy insulation characteristics of regular blocks and ash blocks are considered to be identical. Engineering test data (compressive strength, etc.) also are comparable, so that no difference in service lifetimes is expected (Roethel et al., 1987). For the same reason, energy consumed in drilling and other masonry work should be unaffected.

Figure 4-4. Potential Annual Energy Savings
From Use of Ash Blocks

Also, one might argue that if production and use of ash blocks become sufficiently widespread (perhaps due to regulatory mandates), other construction materials that do have different energy draws might be displaced. For example, concern for forest resources conceivably might foster a trend to home construction with ash blocks instead of wood, assuming that perceptions of health problems do not arise for the blocks.

Some indirect energy impacts might emerge as a result of differential energy costs for pollution control. For example, one might argue that by sequestering heavy metals, and by optimally mixing different incinerator ash streams, the ash blocks avoid the need for more costly and energy-intensive measures to control or prevent potential pollution had the ash been sent to a landfill or ashfill. The avoided measures might involve landfill lining, leachate treatment, cover, and dust control requirements. Any such energy impacts are likely to be overshadowed by the energy costs of pollution control equipment in the incinerator itself.

What happens to the rubble from a demolished building made of ash blocks? Regulations may prohibit use of standard construction and demolition debris landfills. Special, energy-intensive treatments and dust control measures may be ordered. Alternatively, used blocks could be crushed and re-used as gravel for roadbase material, or perhaps in new construction blocks. Presumably the crushing and screening processes would be the same as for conventional concrete, which is being crushed and re-used in a few localities on a limited basis (Donovan, 1991). Whether such applications meet existing engineering specifications is unclear. For ash blocks, questions about energy-intensive treatments and dust control measures might also arise.

Energy impacts might also develop if "trash-for-ash" exchanges include provisions for production of ash blocks, even if they are to be stored in a landfill. In such a case, energy impacts associated with other options for managing the original solid waste might have to be included in the system boundary of the energy analysis.

Energy impacts of other technologies for using incinerator ash may also be of interest. For example, road surface applications raise interesting thermodynamic issues about the relative merits of "concentrate and contain" versus "dilute and disperse" as general waste management strategies. Landfilling concentrates and contains ash; road application dilutes and disperses it (irreversibly). Ash blocks fall between these extremes. An energy study of ash management options from this point of view, encompassing similar "concentrate or disperse" options for recycling plastics, organics, glass, and composites would be most valuable.

ECONOMIC ASPECTS OF ASH

The market assessment has been designed in light of the fact that ash-based incinerator products are new and in many cases experimental. The New York State Department of Environmental Conservation (NYSDEC) and other agencies have not yet approved the general use of the material. Blocks incorporating incinerator ash are still undergoing extensive testing to establish their properties while potential producers and buyers await the results. Use in roadbed, landfill cover, and other products is no further along. In a strict sense there is no market for incinerator ash.

Method

The methods follow those used for the economic aspects of products made from recycled plastic waste. A materials balance approach has been used and as with the previous economic analysis of products made from recycled plastic waste, products that might find local use have been chosen. Presumably, all ash generated on Long Island must find a productive outlet in Long Island markets, and demand for ash-based products must be satisfied by local supplies.

INCINERATOR ASH RECYCLING

Basic data concerning material flows of the market for incinerator ash are taken from a study of incineration on Long Island (Chesner Engineering, 1990). In 1990, five waste-to-energy facilities were in operation with a processing capacity of approximately 4,000 tons/day (tpd) of refuse. An additional 3,000 tpd capacity was expected to be added by 1995, bringing the total MSW bound for incineration on Long Island to about 7,000 tpd by mid-decade (Chesner Engineering, 1990).

How much incinerator ash will this capacity generate? When this is known, the volume of ash-based products that could be brought to market can be estimated and compared with the existing or potential market capacity on Long Island. The comparison will provide a basis for judging the feasibility of finding market outlets for incinerator ash.

Table 4-10 shows the composition of incinerator ash and the relation between waste burned and the resulting ash stream. Approximately 25 percent of the weight of MSW incinerated remains as ash. The ash is not uniform, but is composed of several constituent parts, only one of which, identified in

Table 4-10. Incinerator ash material balance summary.

Ash Streams	Facility Size			Fraction of Stream
	750 tpd	1500 tpd	2250 tpd	
Combined ash	188	375	563	1.00
Bottom ash	159	319	478	0.85
Fly ash	28	56	84	0.15
Ferrous metal	44	88	132	0.23
Oversize reject	15	29	44	0.08
Aggregate product	101	201	302	0.54

(Chesner Engineering, 1990)

Table 4-10 as "Aggregate Product," might be used as secondary material to produce new goods for the market. Since 54 percent of combined ash is aggregate product, it can be concluded that approximately 13.5 percent of the weight of MSW burned remains as potential input for ash products.

Long Island's current 4,000 tpd incinerator capacity generates some 1,000 tpd of combined ash. Fifty four percent of this ash, or 540 tpd, is aggregate product suitable as input for further production. Is it reasonable to expect that local users might require 540 tpd of this input under any reasonable assumptions about market development? Several products might incorporate aggregate product. This report will consider two: blocks for ordinary construction, and blocks for artificial reefs. It should be recalled, however, that neither of these uses is now permitted.

INCINERATOR ASH BLOCKS

A construction block made with incinerator ash weighs about 36 lbs; 55 blocks weigh one ton. Aggregate product accounts for some 70 percent of the weight of a block. If aggregate product from incinerator ash is used to make blocks to the complete exclusion of natural aggregate, using 540 tpd of aggregate would require about 771 tons of blocks/day, or about 42,430 blocks/day.

Block-making machinery currently in use on Long Island can produce 1,800 blocks/hour/machine. At this rate, the entire daily production of ash aggregate on Long Island could be incorporated in 24 machine hours, or the output of three machines working a single eight-hour shift, well within current capacity.

If it is assumed that incinerators operate throughout the year at an average 80 percent of rated capacity, current Long Island incinerator use generates 157,680 tons/year of ash aggregate. If this were incorporated into blocks as a complete substitute for natural aggregate, 12.4 million blocks/year would result.

The entire New York City metropolitan area market for blocks has been estimated at 25 million/year (anonymous). Long Island, with about 20 percent of the area's population, then provides an annual market of some five million blocks. The potential Long Island market for construction blocks is clearly inadequate to solely provide an outlet for ash aggregate.

If ash aggregate substitutes for only 25 percent of natural aggregate, the limitation of the local market is all the more sharp. Almost 50 million blocks/year would be required to absorb the ash aggregate of current incinerators, ten times the local market.

This result is consistent with the findings of the Long Island Ash Management Study, which concluded that "without the development of new market strategies, ash use can only be expected to divert a portion of the marketable ash generated into construction applications" (Koppelman and Tanenbaum, 1990). Table 4-11 shows potential ash utilization in the variety of possible uses estimated in the Ash Management Study.

Of all possible uses, ash incorporated into concrete for construction purposes is a small proportion. Landfill uses for daily and final cover offer considerably more potential. New York State law mandates that Long Island landfills be closed, so this outlet for ash aggregate in the long-term

Table 4-11. Potential quantities of ash that could be substituted for natural aggregate use on Long Island.

Application	Estimated^a Market Capacity
Bituminous concrete	89,000 tpy ^b
Portland cement concrete	85,000 tpy ^b
Daily landfill cover	325,000 tpy ^c
Final landfill cover	525,000 tons ^d
Landfill stabilization	2,625,000 tons ^e
Artificial reef	4,900,000 tons ^e

^a Quantities reported in tons per year (tpy) or tons. Note that bituminous concrete and portland cement concrete figures are based on annually recurring consumption. The daily and final landfill cover market represents a fixed quantity market that will be exhausted during the next two to five years. The landfill stabilization and artificial reef market is also a fixed quantity market.

^b Based on total potential market and a 25% blend of ash with other aggregate materials and a 25% application rate (i.e., percentage of construction application using ash).

^c Based on total potential market and a 100% use (i.e., no blending) and a 50% application rate.

^d Based on total potential market and a 70% blend of ash and other materials and a 50% application rate.

^e Based on total potential market and a 70% blend and 100% application rate.

(Koppelman and Tannenbaum, 1990)

will be closed. But, in the short-term, there could be a large market for final cover as landfills close on Long Island. If significant new markets for ash aggregate are to be created, they must involve new products.

ARTIFICIAL REEFS MADE WITH INCINERATOR ASH

Ash aggregate used to produce blocks for the construction of artificial reefs would not compete with any current activity, since artificial reefs are not now constructed. As Table 4-11 shows, reef capacity for Long Island would absorb 4.9 million tons of ash aggregate. Reef production, however, affords a "one time only" outlet rather than the recurring markets for ash used to make construction blocks.

Still, the "one time" building of reefs would absorb Long Island's incinerator ash aggregate for quite some time. If all ash aggregate were directed to reef production, it would take 31 years to incorporate the current annual ash flow of 157,680 tons into reefs. In this time other uses might be developed or other solutions to waste disposal might be found to substitute for incineration.

Yet as Long Island's incinerator capacity increases by 75 percent to 7,000 tpd by mid-decade, the ash flow will correspondingly outstrip market outlets, and the period when reef production might alleviate the ash disposal problem will be shortened proportionately. Short-term policies may be found which will facilitate absorption of some ash aggregate into products thereby diverting it from landfill; however, in the long-term adequate outlets for ash do not seem to be available. If this is true for Long Island, it must be more so for inland communities with no local opportunity for reef building.

Even in the short-run, serious obstacles remain before any ash aggregate can be diverted from landfill to useful purpose. Public policy can contribute to solving these problems through supporting research and creating markets for uses proven to be environmentally neutral.

PUBLIC POLICY RELATED TO ASH-BASED PRODUCTS

The following identifies existing barriers to marketing ash-based products and policy recommendations for stimulating market development.

Knowledge of the environmental impact of ash use is incomplete. Further testing is essential.

When technical and environmental standards are set government can create markets in two ways: through content legislation in which producers are required to use a certain fraction of ash aggregate as a substitute for natural aggregate in the production of construction materials; and through government purchase of blocks made with ash aggregate to create artificial reefs.

Even when preliminary standards are set, manufacturers and private users of products containing recycled incinerator ash are likely to seek limited liability for any damages. The issue of liability protection will need attention.

But, as has been shown, even in the best policy environment, markets for ash aggregate can provide relief from landfill disposal only in modest and short-term ways. The underlying situation is one in which the anticipated generation of incinerator ash will far outstrip the capacity of markets to absorb the supply.

SOURCES OF SOCIAL RESISTANCE TO THE USE OF INCINERATOR ASH

One of the primary assumptions of some environmental groups in recent years is that incineration is a dangerous process and is harmful to the environment. This opposition, which is both national and international, has occurred on Long Island. Local resistance on Long Island to incineration has been powerful and widespread and has affected a number of policy decisions. For example, in 1987, NYSDEC denied a permit for the construction of an incinerator at the Brooklyn Navy yard. In August 1990, the Town of North Hempstead canceled a contract for the construction of a waste-to-energy facility after spending approximately \$12 million for research and planning. A long-term campaign against this project was carried out by the New York Public Interest Research Group (NYPIRG), Citizens for a More Beautiful Port Washington (a 5,000 member organization), and other local activist and environmental groups. In the Town of Islip two incinerators had been planned; however, after completion of the first, the second was postponed indefinitely while recycling programs were expanded. In the Town of Brookhaven plans to construct an incinerator were stopped. Instead, an agreement was reached with the Town of Hempstead. Brookhaven's trash is to be incinerated in Hempstead with the resulting ash being placed in Brookhaven's ashfill.

These local actions indicate that there is formidable public effort aimed at opposing the incineration process including the development of ash-based products. In some cases, resistance to ash products is derived directly from an overall aversion to incineration; in other cases, opposition is related more specifically to the ash products themselves. Opponents usually have two major concerns with incineration: the emissions, which may have toxic properties and also may

contribute to the greenhouse effect, and the cost of incineration facilities.

While stringent US EPA emission regulations are in effect for incinerators, there is considerable doubt about their effectiveness. A chemist, who wishes to remain anonymous, was interviewed for this report and said that some of the problems associated with incineration involve dioxins and furans in the emissions. He added that US EPA emissions testing fails to reflect daily operating conditions. State and Federal regulatory requirements include periodic examinations of the stack emissions. Generally, incinerators are tested when new and operators usually know in advance when additional testing will occur. Therefore, it is difficult to discern whether there are differences between usual daily conditions and when the incinerator is tested.

Resistance to Cost of Incinerators

Incineration facilities are very expensive to build. This cost is an easy target for local opposition and environmental groups although costs are often met through long-term municipal bonds. The lack of any real comparative cost data on large-scale recycling efforts aids oppositional arguments (see Denison and Ruston, 1990). The Town of North Hempstead's waste management plan predicts waste management costs of about half that contained in the previous Town plan that included a mass-burn incinerator (anonymous). The report on the pilot recycling program of East Hampton also predicts considerable savings with the use of intensive recycling compared to incineration (anonymous); however, many survey respondents doubt the feasibility of such intensive recycling programs, particularly those respondents generally in favor of incineration. This results in the two

groups disagreeing on relative cost-benefits of opposing waste management strategies.

Legislation preventing the siting of ashfills over the Long Island deep-recharge aquifer system compound the expense of incineration. Incinerators on Long Island will increasingly have to rely on off-island transportation of ash. This is expensive; current costs run approximately \$160/ton. Because these contracts have to be negotiated with other localities often in other states, they present an unpredictable cost variable for future incineration. In addition, some states have already adopted legislation to prevent the importation of ash, and it is conceivable that others may follow in the future in response to local opposition. In fact, one anti-incineration activist interviewed said that "the ash was perceived to be the Achilles heel of the industry." Considering that there is resistance to ash, ashfilling, and ash-based products, it may be impossible to distinguish between that which is genuinely fueled by the nature of the ash itself, from that which is opposition to incineration in general.

Moreover, those who believe that recycling is a necessary part of modern economies are unsupportive of incineration because it discourages recycling by externalizing the cost of waste disposal away from the industries which produce it. Incineration may also provide for the continued over-exploitation of raw natural resources by industry. At the same time the amelioration of the municipal solid waste problem with incineration actually adds to environmental problems rather than attacking them at their source.

A municipal official from the Town of North Hempstead, critical of mass-burn incineration, spoke of it as a "quick fix" and distinguished between different ways of approaching

recycling saying that with the use of incineration, a certain mindset would evolve of only recycling items that were not good to incinerate, rather than incinerating only those items that could not be recycled.

An official of the New York State Commission on Water Needs of Long Island spoke of the need for industry to adopt an entirely new approach to the production process. He spoke of "industrial metabolism" wherein the process of production would be a circular one, introducing items designed to pass through a second stage of production after their first use, rather than the current linear resource-product-waste stream process.

A secondary consequence of mass-burn incineration is establishment of minimum feedstock requirements. Many municipal contracts with incineration firms stipulate a minimum feedstock, and opponents to incineration argue that the incineration process becomes self-perpetuating as municipalities attempt to direct a sufficient part of their waste stream to their incinerator. Mass-burn incinerators do not operate efficiently if they are run at substantially less than their full design capacity. This creates an institutional incentive to continue incineration even beyond the point when other processes may exist to accommodate some of the waste stream. In other words, when incineration is in place it may secure the conditions for its own perpetuation.

TRANSFER OF RESISTANCE FROM INCINERATION TO ASH PRODUCTS

Safe products using incinerator ash should be seen as a way to reduce part of the hazard in the incineration process. But, the notion of neutralizing or stabilizing toxicants in ash is viewed with considerable doubt by the public.

There is skepticism about the efficacy of the process that supposedly immobilizes heavy metals in ash products, and of the evidence that indicates the process remains effective over the long-term. Critics argue that the tests conducted thus far have mainly been related to leaching in landfills and to ash-based cement blocks in water. While they agree these studies show no dangerous impact, they observe that the longest study has only been for four to five years, and that the toxic consequences of leaching may not reach measurable levels for a longer period of time. Critics also argue that there has been no testing of airborne pollution for at least three different possible scenarios: in buildings that use cement blocks and have enclosed spaces; during the handling or transportation of manufactured products; and during construction processes, which could expose workers and/or bystanders to toxic releases (these are now part of ongoing studies). Concerns about these ash-based products are fairly uniform in character and widespread among those who oppose incineration.

Anxieties dealing with ash-based products are most focused on roadbed applications. Many of those interviewed fear that using ash in roadbeds would lead to heavy metals leaching into the soil and ultimately contaminating the Long Island aquifer. While there may not be scientific evidence to support this view, the scientific evidence against it is insufficient to allow a risk of this sort.

Beyond these specific concerns about the toxicity of the ash product, resistance is also linked to the more general opposition to incineration. Two plausible links between potential resistance to ash use and anti-incineration sentiment are noted. The first is the notion that the existence of usable products will justify incineration, which is itself undesirable. Thus, opponents might imply

that it is better not to have useful end-products of incineration because any beneficial consequence of incineration will allow those who support incineration to gather even more political and economic support to perpetuate incineration despite its purportedly harmful consequences notably the greenhouse effect, potentially toxic emissions, and the continued over-exploitation of natural resources. These opponents may feel that although ash-based products can be proven safe, useful, and non-toxic, the negative consequences may outweigh their use.

This logic can be extended to a more political argument of the same tenor. Ash is considered the most visible and expensive consequence of incineration. The absence of suitable landfill area for ash on Long Island has resulted in a major transportation problem and a much wider public understanding of the health hazards involved. The physical existence of ash, which can be tested and proven dangerous, provides residents, environmental activists, and municipalities with a strong argument against the incineration process. The contribution of incinerators to what has been identified as the greenhouse effect is more difficult to document. The emission of air-borne toxic gases in itself has not been an obstacle for incineration. In essence, the existence of toxic incinerator ash constitutes a concrete issue around which one can mobilize opposition to incineration.

By stabilizing ash into "alleged" non-toxic blocks, manufacturers have eliminated the key argument against this process. Nevertheless, technical solutions to the concrete problems of ash disposal will not resolve the opposition to incineration, since this opposition is deeply rooted, and the commitment to recycling is viewed as contradictory to incineration. Environmental groups, and other opponents of

incineration are likely to interpret changes in ash handling procedures as attempts to subvert their own recycling efforts without addressing their fundamental concerns.

INSTITUTIONAL RESISTANCE TO ASH AS A PRODUCT

Beyond the articulation of anti-incinerator sentiment into anti-ash product sentiment, there are a number of more focused institutional barriers to the introduction of ash products. These institutional barriers fit into two broad categories: the issue of product liability, and government regulations that limit the types of product used in various construction applications.

Product Liability

The product liability issue originates from the unproven possibility that ash products, particularly ash-based cement blocks, may have some residual toxicity. There are concerns that both the possibility of heavy-metal leachates and airborne contaminants from long-term applications of ash-based products may eventually lead to liability lawsuits. This problem is well publicized in the private sector, and particularly among the incineration industry and its associations. There are cases in which possible construction applications have been foregone because the officials of the incineration facilities themselves were afraid that toxicity problems would eventually emerge and they would be liable for suits brought by consumers.

The broader implications of these examples are that the private sector will view ash-based products as too great a risk to take for what is probably only marginal savings in the short-run. The private sector, in this case the construction industry, can only be motivated by the logic of

substituting a less expensive product for a more expensive one. Currently, product liability costs are unknown and estimated to be high. The possibility of expensive product liability suits therefore creates a disincentive for their generalized use, particularly important for manufacturers who hope to find private sector niches.

When environmental groups have shown a tendency to lessen their opposition to ash use schemes, they have demanded that the liability issue be resolved in predetermined ways. For example, it was suggested in the interviews that ash be used only in limited applications where it can be monitored and, if necessary, eventually removed. This included the stipulation that it be determined who would have responsibility for removal prior to its use. They implied that municipalities should not be liable for applications of ash, but rather that responsibility should lie with the incineration industry. Interviews with the Environmental Defense Fund, Citizens' Campaign for the Environment, and NYPIRG said this, as a demand common to all three.

Government Regulations

The second set of institutional barriers involve government procedures for approving products for certain public uses or for public-regulated uses. The most vivid example is the use of combined ash in roadbeds, a process which is strictly controlled by the New York State Department of Transportation (NYSDOT), Highway Division. Current acquisition procedures are very well defined. The use of locally based products is well established. The introduction of ash as an alternative roadbed product would involve a major alteration, not only in bureaucratic procedures but also in existing raw material procurement networks (from gravel to ash). Such changes are hindered

primarily by institutional inertia; the extent to which institutional and political action would be necessary to overcome is unknown.

There are many agencies capable of resisting such a change, and the chances of one deciding to do so, for any of a large number of reasons, is quite high. Therefore, it is inevitable that introducing ash-based products into publicly regulated construction applications will be difficult.

Ash-based products face two sets of problems, which together form an imposing barrier to their introduction. Part of the public sector, particularly those citizens who are mobilized around environmentalism, oppose incineration as an overall waste management strategy including the use of the ash by-product. Private companies and public institutions that control the purchase of ash-based products appear to be extremely cautious about using them, partly in response to the potential for product liability lawsuits as a result of public opposition, and partly because the labyrinth of governmental procedures necessary to follow to substitute ash-based products for existing products is complex and "delicate" enough to allow for significantly influential resistance even from relatively "minor" agencies in the government.

To overcome these barriers a comprehensive program may be needed. Since the future of ash use schemes depends on a variety of issues not yet determined that may deal with governmental decisions, private industry, and environmental groups, a singular prediction of social and institutional responses to these products is premature. Therefore, an assessment of existing trends that have been observed among these groups follows.

Given the complex set of bureaucratic and institutional changes necessary for implementing ash use schemes, it is unlikely they can be in operation for at least a couple of years, certainly not on a large-scale. With the most favorable circumstances, ash use schemes cannot be considered an immediate solution to the problem of ash disposal on Long Island.

IMPLEMENTATION PROPOSALS

The present climate of resistance to incineration is partially offset by a number of positive trends that appear to be leading to a more receptive environment for the implementation of ash-based products. For example, some environmentalists seem to be lessening their opposition to ash-based products apparently due to a developing understanding that ash-based products need not be harmful, and due to the difficulty in sustaining political opposition against them merely on the basis that their origins are from incineration. On Long Island, this lessening of environmental opposition is indicated by the following evidence: members of local environmental groups such as Citizens' Campaign for the Environment have explicitly stated that they would not be opposed to incineration as a process if it was integrated with recycling and other waste reduction efforts, and if there was sufficient data reassuring the safety of the process and the disposal of ash. A similar position was articulated by an Environmental Defense Fund representative at a conference organized by WMI, as well as environmental chemists from The University at Stony Brook who have been active on issues of waste management and incineration.

A second example is that government agencies have become more flexible about the adoption of guidelines, or at least

there are some indications that such a change may be occurring with the application of political or economic pressure. One noteworthy aspect of this is the broad emergence of waste management planning at the Federal, State, and local levels, such as the 1989-1990 Draft NYSDEC Solid Waste Management Plan. As these efforts most likely continue, it would appear inevitable that ash-based products would eventually become part of such planning. While the NYSDEC draft Solid Waste Management Plan has not yet been implemented and there are no present guarantees that it will be adopted on a broad basis, its existence may indicate a long-term trend toward coordinated comprehensive recycling and waste management efforts. It seems likely that incineration, and consequently ash disposal, will be an integral part of any plans emerging from the NYSDEC program, eventually resulting in a more widespread receptivity to ash-based products.

A third encouraging trend indicating that there may be more receptiveness to ash-based products is the current attitude of large businesses about using ash as a building or roadbase material. Due to the potential of this product as a profitable alternative, businesses are beginning to look with considerable favor on such a replacement. Unlike government agencies and environmental groups, private businesses are not deterred by the stigma of product's incinerator-origins, nor by the undocumented fear of residual toxicity. However, this tendency toward private use and production of ash-based products has, until now, been limited by the threat of liability lawsuits incineration companies or manufacturers of ash-based products would face, should such products become entangled in toxic waste controversies. For this reason, the latent market and the potential manufacturing applications of ash

will not become apparent without a resolution of this threat.

Given these trends, there are three plausible scenarios for the near term:

- o the development of local or state comprehensive recycling and waste management plans that incorporate incineration as an integral part of their programs;
- o the privatization of waste management, including incineration and ash disposal; and,
- o no change in the present situation.

Elements illustrating the realization of each of these scenarios already exist. To a large extent it is a matter of policy to facilitate or hinder the development of one or the other.

NIMBY

In the past, not in my backyard, (NIMBY) has been described as public outcry against various waste management strategies and facility sitings. It is often suggested that people refuse to take responsibility for producing waste by opposing the implementation of management strategies (i.e. the siting and building of a waste-to-energy facility) in their own communities. It is further suggested that regardless of the waste management option chosen, or by whom, its implementation will inevitably be resisted by the public.

Independent sociological research shows that residents participating in NIMBY movements interpret the manner in which plans for incinerators are designed and implemented, and the NIMBY syndrome accusation itself, as "industry's frame of democracy" (Walsh et al., 1991). In other words, these residents believe that industry formulates policy in an undemocratic manner and adopt the NIMBY syndrome as an attempt to discredit opposition.

The research from this report has overwhelmingly shown NIMBY to be a misleading concept for understanding public reaction to issues surrounding waste management. The respondents indicated that when public outcry, or rejection of management plans occurs, it is most likely a result of the way in which plans were formulated, proposed, and implemented, which indicates that NIMBY is a political position demanding respect for democratic processes. Several respondents in local governments argued that cooperative relationships with their constituents could be cultivated through education, providing the opportunity for public participation in decision making.

This research confirms that public response to ash use proposals will be a result of the way these proposals are developed and introduced. The dissemination of information as well as the use of public forums and public feedback to make policy decisions relating to ash use is likely to significantly reduce the possibility of the public rejecting applications of ash after the infrastructure for use is in place.

INCINERATOR ASH SUMMARY

The successful use of secondary materials made with incineration ash requires that they meet or exceed existing

engineering and environmental standards. Engineering criteria for materials used for artificial reef development, shore protection devices, and construction blocks are well established, and these strength criteria define the minimum for successful product performance for each application. The environmental criteria applicable to the use of incineration ash in secondary materials are not well established. Several regulatory leaching protocols such as the EP Toxicity Test and the TLCP leaching protocol were not designed to evaluate the leachability of metals from a product destined for marine use. Sea water or fresh water tank leaching studies or modified ASTM leaching techniques using sea water or synthetic acid rain are more useful techniques to determine the leachability of metals from stabilized products for marine or terrestrial use. Since one test may not be sufficient, it is recommended that several leaching protocols be used to evaluate the leachability of metals from incineration residue secondary products.

From an energy standpoint, processing energy requirements of ash blocks are not significantly different from regular construction blocks. Energy savings are negligible when assuming the manufacturing site of ash blocks is at or near the incinerator. Energy advantages of having a source of aggregate nearby are also negligible. Overall, some energy is saved by avoiding the extraction of natural aggregate and by averting transportation of the ash to landfills. For a landfill 200 miles away, recycling one ton of ash into construction blocks saves energy equivalent to seven gallons of #2 diesel fuel.

Potential energy savings for New York State from using incinerator ash in construction blocks are small. Energy

savings are generally maximized for incinerators at a great distance from landfills.

Potential markets for incinerator ash are insufficient to absorb a significant fraction of the ash now generated on Long Island. The problem will intensify as planned new incinerator capacity comes on-line through the 1990s.

The market for secondary products made of incinerator ash is inadequate to contribute significantly to the landfill problem posed by incinerator ash. The best way to address the problem is source reduction.

Social acceptance of construction materials made with incinerator ash may be a function of the method in which ash block proposals are developed and introduced. The dissemination of adequate information and the use of public forums to involve communities in policy decisions on ash use may be significant in reducing public opposition.

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TECHNOLOGY TRANSFER

The plan that will be followed to transfer information and technology on secondary materials will focus on sharing the results of this report with public interest groups, the scientific community, and representatives in industry, management, and government. This report's findings will be discussed both verbally and in written form through public outreach programs (at workshops, and in literature), and formal education involving lectures and course work at the secondary and college levels. Dissemination of the results of this report will be conveyed to industry, managers, policy makers, and the scientific community through journals, the "Waste Management Research Report," seminars, and by participation of WMI on numerous advisory boards.

The following are a list of activities that have already been carried out by WMI and are planned to be undertaken in the near future to transfer information about the findings of this report.

Accomplishments

- o In 1990, an issue of the "Waste Management Research Report" was devoted to secondary materials. This issue was a cooperative effort among WMI, Cornell Waste Management Institute, and the New York State Center for Hazardous Waste Management at the State University of New York at Buffalo.
- o In June 1992, WMI was involved in a national lecture series to several hundred people about secondary materials at a conference sponsored by the US EPA.

- o In September 1992, WMI attended the 11th National Recycling Congress and gave a presentation on secondary materials.
- o In October 1992, WMI participated in a conference with representatives of the Italian government on waste management issues and was involved in a presentation on secondary materials.
- o In Fall 1992, WMI participated in a retraining program for unemployed engineers that encompassed teaching about secondary materials.
- o WMI has been involved in speaking about secondary materials to a number of public groups including Rotary and Garden clubs, and organizations such as the Citizens Campaign for the Environment.
- o In Spring 1992, WMI was part of a panel discussion which testified on the use of secondary materials as part of a larger discussion on recycling before the New York City Council.
- o In January 1993, WMI was involved in a plastics recycling symposium sponsored by the New York City Office of General Services. The findings of this report were discussed as part of a larger topic on examining innovative ways the City can use recycled plastic.
- o Secondary materials and related issues are covered in courses offered as part of the Waste Management Institute Certificate program at The University at Stony Brook, New York. The findings of this

report will be incorporated in these lectures in the future.

Goals

- o A peer-reviewed journal article based on this report will be written for submission to a publication on waste management that has a broad readership.
- o The findings of this report will be the focus of an upcoming special issue in the "Marine Sciences Research Center Bulletin" (circulation of 2,000), which has wide distribution, including to secondary schools.
- o On completion of this report, WMI, in cooperation with the New York State Center for Hazardous Waste Management at the State University of New York at Buffalo and the State University of New York at Syracuse, will publish the findings of this report in one of the upcoming volumes of the "Waste Management Research Report" (circulation of 7,000, mostly in New York State).
- o A comprehensive distribution list of people recommended to receive a copy of this report will be submitted to the New York State Energy Research Authority as a requisite of this report's completion.
- o WMI will work to develop opportunities for implementing demonstration programs for both plastic lumber and incineration ash. It is conceivable that meaningful opportunities will

arise as plans move ahead to stabilize Long
Island's shores following the devastating
Nor'easter of December 1992.

CONCLUSIONS

Secondary materials can and must play an important role in New York State's and indeed the Nation's overall waste management plans. This report, which has investigated two very different secondary materials, identifies a number of opportunities and problems associated with using such products. The opportunities for using waste materials to create new products are many and it would appear that entrepreneurs are eager to invest in such endeavors. However, without proper regulatory controls, product performance standards, and competitive pricing, a capricious public probably will not support secondary materials. At present, the public is enthusiastic about supporting "environmentally-sound" purchasing practices but altruism can be expected to be short-lived if government, business, and industry fail to provide high quality, beneficial products at a price the public can afford.

Both plastic lumber and stabilized ash products appear to have potential markets. Perhaps the greatest opportunities in the short-term are in publicly funded construction programs that advertise and demonstrate the benefits and opportunities of these products. Such projects also have the advantage that while these secondary materials are in the formative stages of development, their general locations and uses would be well-known. If for any reason it proved necessary, recall could be achieved relatively easily and inexpensively. For both plastic lumber and stabilized incineration ash products, marine construction and highway applications appear are ideal public works projects. Seawalls, jetties, fishing reefs, highway barriers, and roadbed applications are ideal uses for incineration ash aggregate products. Docks, piers, highway sound barriers,

parking stops, and park furniture are all excellent uses for plastic lumber.

Plastic lumber's resistance to decay and boring organisms may be its primary asset. Plastic lumber, as an engineering material, still has a number of uncertainties including consistency of content, tensional, compressional, and flexural strengths. Perhaps the greatest concern is that of property retention -- particularly since manufacturers refer to the material as "lasting for decades to centuries." The material may last but it is not so clear that desirable or essential engineering properties will be retained.

With regard to achieving high quality products, single resin products are superior and sorting resins is still a concern. The voluntary resin identification codes are important, particularly as long as hand sorting is necessary. Marking the plastics more clearly so individuals can see the numbers even on small packages would be helpful.

While contamination of the plastic lumber product by small quantities of inappropriate resins or even degradable resins does not appear to be a major problem due to the processing techniques, the quality of the product can only be improved by achieving as much consistency as possible.

Ash construction materials have a longer and more rigorous engineering testing program supporting them than plastic lumber products. Ash can be considered a lightweight construction material. The organic and calcium contents in ash seem to be the most serious technological limitations to its use. However, with a good prescreening program, these problems may be overcome. There is public concern that knowledge of long-term effects using incineration ash construction materials is imprecise. Despite the efforts to

simulate long-term effects, few are convinced that the physical and chemical stabilization will endure.

Tests to date indicate that from the point of view of public health and the environment, both plastic lumber and stabilized ash are relatively neutral. Neither will be a source of toxic materials although there is some concern about how well contaminants can be cleansed from the plastic containers used to formulate plastic lumber.

Neither stabilized ash nor plastic lumber appear to make much of an impact on overall energy savings. Overall, secondary materials as represented by the two products examined in this report could have some beneficial effect in waste quantities or deferring waste disposal. At this time, it would seem that beneficial economic impacts reside predominantly in avoided costs of taking up landfill space. To improve public acceptance and the market potential of secondary materials, a number of activities on behalf of business and government could be beneficial including:

- o industry should emphasize development of useful, relatively long-lived products;
- o industry and government should create product performance criteria;
- o government should provide rigorous testing and demonstration programs; and
- o government and industry should work to improve public outreach and educational programs.

Industry Should Emphasize Development of Useful, Relatively Long-Lived Products

The purpose of developing secondary materials is to reduce the size of the waste stream. Unless a secondary material replaces a product that would be made anyway or diverts wastes to a useful, more enduring form, the size of the waste stream is only temporarily diverted or deterred. Thus, to be of value, manufacturers of secondary materials should focus on practical, durable products or products that would otherwise save a natural resource. Products that are gimmicks, that exploit the public's eagerness to participate in improving the environment will in the long-term only be detrimental.

Industry and Government Should Create Performance Criteria

Stringent performance criteria for secondary materials are essential. Good data on engineering properties, durability, and lifetime maintenance are as important and perhaps more important than those for standard materials. People must be confident that they are investing in high quality materials that are safe and sound. Today, product labeling of these formative materials is often lacking or perhaps misleading. The so-called "green" labeling of products is more a sales gimmick than an honest assessment of product content and performance. Industry and government should work closely to resolve these problems if recycling, reuse, and secondary materials are to make any significant contribution to reducing the waste stream.

Government Should Provide Rigorous Testing and Demonstration Programs

Waste management is largely a governmental activity. The government has established various criteria and standards in the waste field. In the case of solid waste, the government has established the general hierarchy of waste reduction, recycling/reuse, incineration, and landfilling. With regard to recycling/reuse programs, the government has been aggressive in establishing collection programs but has been less aggressive in helping to determine how these collected materials might be used. However, entrepreneurs have attempted to develop markets, and products that take and use the collected material.

New products such as plastic lumber and stabilized ash, however, will not reduce the waste stream unless the public accepts them. Demonstration programs for testing and displaying the utility of secondary materials are needed. Where successful, such programs would help create interest in the materials and establish competitive pricing with alternative products.

Government-sponsored use of secondary projects should be encouraged. Incentives might be offered to various governmental departments to try these alternative secondary materials. For example, NYSDOT could have used plastic lumber as a substitute for the CCA-treated wooden lumber that was recently installed for miles along the Long Island Expressway. The Boathouse, an experimental incineration ash block building, recently constructed at MSRC is an excellent example of a beneficial demonstration program. The Boathouse is used in a real-life, not a laboratory setting. The public can directly assess the value of the structures and the use of a waste product. The State would be well-

served to try some incineration ash in highway projects as well.

There is a program sponsored by the New York State Department of Economic Development whereby an industrial partner working with others can obtain a grant to explore the emerging issues surrounding the development of secondary materials. Unfortunately, small start-up businesses that are entering the secondary materials markets cannot afford to help support research nor are they likely to be interested in funding research that may in fact find negative aspects of the product they are attempting to develop.

Thus, the State should fund independent research without matching industrial support, to demonstrate and test secondary materials.

Government and Industry Should Work to Improve Public Outreach and Educational Programs

Outreach and education are important aspects of informing people as to the need to develop, market, and use secondary materials. Ash stabilization research and production of plastic lumber have come from innovative individuals, universities, and small businesses -- from people aware of waste management issues, not from large businesses and industries.

In fact, much of the awareness of and concern about environmental issues has come from the bottom up. Education and outreach can broaden the base of ideas, opportunities, and innovative uses of secondary materials. Programs should target small business interest groups looking for new ventures, retail businesses looking for new product lines,

and individuals who have a special interest in using the materials. Public pressure to develop and use secondary materials may in fact help to alleviate many of the bureaucratic barriers that currently resist developing and trying these products.

Secondary materials -- waste materials that are used to make a product different in form or use from the product made of virgin material -- are relatively new in the marketplace. Technologies were evolving even as this report was prepared. New and better products are being developed. Although a number of concerns with these materials have been identified in this report, many of them are expected to be overcome -- perhaps quite soon. Opportunities are indeed optimistic.

It should be emphasized that waste prevention/reduction is the principal goal of the waste manager. While recycling/reuse is an important part of any overall waste management program, in a sense it only delays what ultimately will be destined for the waste stream. Most materials cannot be reused indefinitely. If we are to succeed in reducing the waste stream significantly, we must not be too comfortable with recycling.

APPENDIX A

PHYSICAL PROPERTIES OF PLASTIC LUMBER

NATIONAL WASTE TECHNOLOGIES - SYNTAL PLASTIC LUMBER

Dimensions: One plastic board 1.5 in. x 5.25 in. x 47 in.
Composition: 100% post consumer plastic/no additives
Odor: slight to no odor
Specific gravity: 0.93
Melting point: 325-370 °F
Flash point: 630 °F
Flex Strength: 4,300 psi
Shear Strength: 2,850 psi

HAMMER'S PLASTIC RECYCLING PLASTIC LUMBER

Dimensions: 12 ft maximum length/ 1, 2, 3, 4 in. width; 2, 4, 6, 8, 10, 12 in. thickness
Composition: minimum 96 percent by weight ABS, Acetyl EVA, HDPE, LDPE, LLDPE, Nylon, PET, polyester or LCP, PP, and PS;
4 percent color and additives: UV stabilizers
Color: Black, Brown, and Grey
Density: 57-60 lb/ft³
Compressive strength: 3,500 psi
E value: 43,000-88,000 Wood has relatively constant E at various load; Plastic E value decreases with increasing load

TRIMAX PLASTIC LUMBER

Dimensions: standard lengths available to 24 ft./1, 2, 4, 6 in. thick; 4, 6, 8, 10 in. width
Moisture content: Negligible
Density: 44-50 lb/ft³
Specific Gravity: 0.75 (0.05)
Modulus of Rupture: 2,940 (155)
Modulus of Elasticity: 0.45 (0.02) million psi

Compression parallel to grain: 1,740 (100) psi
Compression perpendicular to grain: 690 (60) psi

Shear parallel to grain: 740 (30) psi
Impact bending: 7,500 (800) psi
Tension parallel to grain: 1,250 (110) psi
Odor: Slight
Specific Gravity: 0.6-1.0 depends on formulation
Flash Point: Ignites at 658 °F

RUTGERS PLASTIC LUMBER

100% Curbside Tailings

Specific gravity: 0.931 (0.01)
Compressive Modulus: 89,600 (523) psi
Yield Stress: 2,707 (99) psi
Compressive Strength 10 percent: 3,166 (87) psi

60 percent HDPE, 15 percent Detergent bottles, 15 percent tailings, 10 percent LDPE pellets

Specific gravity: 0.891 (0.01)
Compressive Modulus: 111,625 (3,544) psi
Yield Stress: 3,252 (13) psi
Compressive Strength 10 percent: 3,901 (22) psi

50 percent HDPE milk bottles, 50 percent expanded polystyrene

Specific gravity: 0.806
Compressive Modulus: 164,000 psi
Yield Stress: 4,100 psi
Compressive Strength 10 percent: 4,120 psi

APPENDIX B

ENERGY SURVEY

PLASTICS RECYCLING AND ENERGY USE

Please complete and return to:

Professor S. Reaven
Secondary Materials Project
Waste Management Institute
State University of New York
Stony Brook, NY 11794-5000

You need not identify yourself or your company. Please be as specific as you can without giving proprietary information. In any case, information that might apply to or identify individual plants or companies will be kept confidential; only statistical and general results will be published.

RECYCLING PROCESS

(1) Basic process technology (e.g., extruder; Recycloplast):

(2) Resin(s) used [please either check or give percentages (preferably by weight) if available; ignore any resins used in trace or very small quantities]:

LDPE___ PS___ PET___ HDPE___ PVC___ PP___

Other___ Multilayer___ Nonplastics___

(3) Source: [check or give percentages (by weight) if known]

Postconsumer___ Preconsumer___ Virgin___

(4) Original form [check or give percentages (by weight)]:

___ Mixed MSW plastics
___ Bottles, containers only or predominantly
___ Film/bags only or predominantly
___ Foamed polystyrene only or predominantly
___ Other (describe)___

(5) Form delivered TO the plant [please check or give percentages (by weight)]:

whole unbaled___ whole baled___ flaked___ ground___

pelletized___ shredded___ compacted___

other (describe)___

Please describe grade, color, or contamination restrictions on the plastics you accept _____

(6) In-plant upgrading: please list pre-processing steps such as washing, air or water sorting, etc. _____

(7) Intermediate form: at your facility, plastics are converted either before or after extrusion, molding, etc. to flake _____ pellet _____ fiber/fluff _____ Other _____

(8) Final output form:

_____ plastic lumber

_____ flake, pellet, granulate (circle which)

_____ product (e.g., tray, mat)

_____ other (describe) _____

(9) Number of main machines (e.g., extruders): _____

(10) Production CAPACITY [please indicate units, such as tons or products per hour]: _____

(11) Product lifetime: do you have a rough estimate as to how many years your product might be expected to last in a typical consumer application? If so, please fill in at least one of the blanks:

at least _____ years

at most _____ years

ENERGY USE

Note: these questions are phrased in terms of kilowatt-hours of electricity, gallons of oil or gas, etc. However, BTU figures may be used if more convenient; if so, please indicate.

Facility energy consumption

(12) Electricity: The plant used _____ KWH (or \$ _____) of electricity over a time period of _____ days of operation. During this time, roughly _____ tons of recycled plastic were produced [or roughly _____ product units were made].

(13) This electricity was used [check all that apply, or, if possible, estimate rough percentages]:

_____ in the main plastics recycling conversion process, such as extrusion
_____ in other plastics recycling processing steps, such as baling or flaking
_____ in heating rooms, lighting offices, and other general "overhead" energy costs

(14) Fuel: Oil _____ Gasoline/diesel _____ Natural gas _____
Other _____

The plant used _____ gallons/cubic feet (or \$ _____) of _____ [type of fuel] over a time period of _____ days of operation. During this time, roughly _____ tons of recycled plastic were produced [or roughly _____ product units were made].

(15) This fuel was used [check all that apply, or, if possible, estimate rough percentages]:

_____ in the main plastics recycling conversion process, such as extrusion
_____ in other plastics recycling processing steps, such as baling or flaking
_____ in heating rooms, lighting offices, and other general "overhead" energy costs

Transportation energy (if known)

This refers to gasoline/diesel used in collection, distribution, and other transportation activities outside the recycling facility.

(16) _____ gallons of fuel were consumed (or \$ _____ spent, r _____ vehicle-miles driven) in transportation activities over a time period of _____ days of activity. During this time, roughly _____ tons of recycled plastic were produced [or roughly _____ product units were made].

Major power-consuming plastics recycling equipment:

(17) Please list what you regard as the most energy-intensive plastic recycling processes, steps, or pieces of equipment. After each item, please indicate the power source [E=electric, G=gasoline/diesel, O=oil, NG=natural gas]:

(18) [Optional]: Please indicate the highest temperature reached by the plastics being recycled _____°C/_____°F

(19) What opportunities, if any, do you see for reducing energy use in your operations?

(20) We are interested in your general impressions how significant energy costs are overall for your business:

- _____ a major, crucial factor
- _____ a significant but not a crucial factor
- _____ a minor factor
- _____ unsure; don't know; it depends

(21) Kindly note any other energy-related factors (e.g., is your product itself being recycled, or recyclable? does it have energy-saving end-uses (e.g., insulation, landfill cover)? is electricity generated on-site? do you have information on energy costs for products similar to yours but not made from recycled plastic?

If you need more space for this or other questions, kindly do so on the other side of this page.

Thank you very much for taking the time for our survey!

APPENDIX C

MARKETING SURVEY

MIXED PLASTICS RECYCLING STUDY QUESTIONNAIRE

What products do you currently produce using mixed-resin recycled plastics?

plastic lumber	_____	marine piles	_____
car stops	_____	benches	_____
speed bumps	_____	picnic tables	_____
landscape ties	_____	other (indicate)	_____
marine decking	_____		_____

What is the weight of recycled plastic incorporated into one unit of your product?

Product	Unit Dimensions	Weight of Recycled Plastic
plastic lumber		
car stops		
speed bumps		
landscape ties		
marine decking		
marine piles		
benches		
picnic tables		
other (indicate)		

How many tons of recycled plastics did you incorporate in 1989? _____
1990? _____ anticipated 1991? _____

What % of the plastic feedstock you use is

virgin _____% industrial scrap _____% post consumer* _____%
*post-residential or other end user

What % of recycled plastic you use do you get from

industry scrap _____% direct from municipalities _____% other post-consumer sources, including privately
operated MRFs _____%

6. Do you sort the mix? yes no
If you do sort, what resins do you pull out and what do you do with them?

What do you do with the remaining mix?

7. What do you pay for recycled plastic (excluding transportation)?

Resin	Price (cents/lb)	
	clean and pellitized	raw
HDPE		
LDPE		
PET		
PS		
unsorted/comingled		
other/name		

8. If you buy raw recycled resins, how much does it cost you to clean and prepare the feedstock for use (in cents/lb)?

9. What do you pay for transportation of recycled plastic you buy (in cents/lb)?

10. What is the ratio of cost of recycled resin to virgin resin for

Resin	cost of recycled/cost of virgin
HDPE	
LDPE	
PET	
PS	
unsorted/comingled	
other/(name)	

11. As recycling becomes more common, increasing supply, and the use of recycled resins in manufacturing expands, increasing demand, how do you expect the price of recycled resins to change?

Price will:

Indicate which resins are in each category

 go up

 stay about the same

 go down

2. As recycling becomes more common, HDPE, PET, and PP will be pulled out of the waste stream more than some other resins. This will change the composition of the remaining unsorted mixed resins. How sensitive is your production process to these composition changes for the products you manufacture using unsorted mixed resins?

Product	Sensitivity to Composition of Mixed Resins						
	7	6	5	4	3	2	1
	(very sensitive)						(not sensitive)
plastic lumber							
car stops							
speed bumps							
landscape ties							
marine decking							
marine piles							
benches							
picnic tables							
other (indicate)							

13. For each item you produce, please indicate the % of total sales generated by consumers, industry, and government.

5 OF TOTAL SALES

Product	consumers/households	industry	government
plastic lumber			
car stops			
speed bumps			
landscape ties			
marine decking			
marine piles			
benches			
picnic tables			
other (indicate)			

14. Considering all products you make out of recycled plastic, what % of your total sales is generated by

consumers/households

industry

government

15. Of the total plastic incorporated into your product, what % can you accept as recycled unsorted comingled feedstock?

Product	% of plastic as recycled unsorted
plastic lumber	
car stops	
speed bumps	
landscape ties	
marine decking	
marine piles	
benches	
picnic tables	
other (indicate)	

16. Please give an estimate of the % of your production cost (per dollar of output) associated with each cost item shown

Cost Item	Percent of total cost		
	lumber	assembled benches/tables	marine piles
plastic feedstock			
electricity			
other material inputs			
labor			
unskilled			
skilled			
capital costs			
building			
machinery			
all taxes and fees			
other (specify)			

17. If you would double the scale of your operation (including building and machinery), what would probably happen to your unit cost?

- _____ unit cost would go down
- _____ unit cost would stay about the same
- _____ unit cost would go up

18. For the products you manufacture, please indicate the competing product and material and compare your price with the competing product or material of comparable size

Product	Dimension	Price	Competing product/material	Dimension	price
plastic lumber					
car stops					
speed bumps					
landscape ties					
marine decking					
marine piles					
benches					
picnic tables					
other (indicate)					

19. Have you met resistance when marketing your products made from recycled plastics? ☐ Yes ☐ No.
If so, how would you weigh the following factors?

Factor contributing to buyer resistance	Scale of Importance of factor						
	7	6	5	4	3	2	1 0
	(very important)			(not important)			
cost							
concern for the environment							
lack of standards							
the product is unknown							
concern for human health							
other							

Please comment on resistance to sales you have experienced, and what you think might be done to overcome it.

20. What have you found to be the main selling points of your product against the competition?

21. What are the main barriers that need to be overcome before the industry using mixed resin recycled plastics for manufacturing can become well established?

22. Please rate each of the listed public policy options as to its potential importance for the success of your business

Policy option	Scale of importance of factor							
	7	6	5	4	3	2	1	0
	(very important)							(not important)
investment tax credits								
other tax incentives								
public support for research								
content legislation								
industrial revenue bonds								
job development assistance								
low interest loans								
economic development zones								

23. Other than the policy options shown above, what do you think will be needed to promote the successful development of industry using comingled recycled plastics as feedstock for manufacturing?

24. Would you like a copy of the results of this study sent to you at no charge?

_____yes

_____no

Please send to:

APPENDIX D

PERSONS CONTACTED

Ambrosino, S., Alpine Plastics Processing Machines Company,
Natick, MA

Amidon, A., Moore Recycling, Council for Solid Waste Solutions
P.O. Box 136, Hancock, NH 03449

Antonelli, L., Recycling Coordinator, Town of Oyster Bay
Oyster Bay, NY 11771

Atwater, P., President, R2B2, Bronx, NY

Baker, A., USDA Forest Products Laboratory, Madison, WI

Barmakian, A., President, Plastic Pilings, Inc., Rancho
Cucamonga, California

Barnett, R.K., Supervisor/Smithtown Department of Environment
& Waterways, Donald A. Devine Bldg., 124 West Main Street, P.
O. Box 575 Smithtown, NY 11787

Barrett, R., Mobil Chemical Company, Pittsford, NY

Baskind, W., Green Tree Plastics Technology, Inc., Woodland
Hills, California

Beatty, C., University of Florida, Gainesville, FL

Bennett, R., University of Toledo, OH

Blair, H., Phoenix Recycling Corp., 2019 County Rd-C2,
Roseville, Minnesota 55113

Bonhotal, J., Extension Support Special, Solid Waste, Cornell
Waste Management Institute, Cornell University, 468 Hollister
Hall, Ithaca, NY 14853-3501

Bowyer, J., University of Minnesota, St. Paul, MN

Brett, J., Plastics, Inc., St. Paul, MN

Brewer, G., Earth Circle, 1229 Park Rowq LaJolla, CA 92037

Bright, F., Laidlaw Environmental, Inc., Columbia, SC

Brodsky, B., Town of Hempstead/Solid Waste Management
Authority 220 Plandome Rd. Manhasset, NY 11030

Brow, C., California Division of Recycling, Sacramento

Brown, K., National Waste Technologies Inc., Ronkonkama Recycling Facility, 934 Easton St., Ronkonkama, NY 11779

Campbell, E. NYS Department of Economic Development, Long Island, NY.

Chesner, W., Chesner Engineering, Commack, NY.

Christiansen, E., Christiansen Associates, P.O. Box 7364, Toledo, OH, 43615

Christy, J., Browning Ferris Industries, Hempstead, NY

Cobb, K., Cornell Waste Management Institute, Cornell University, 468 Hollister Hall, Ithaca, NY 14853.

Coburn, R., NYS Department of Economic Development, Albany, NY

Colin, M., Pilot MSW Compost Project, Santa Barbara, CA

Collins, J.F., Manager, Waste Products Utilization, Office of Industrial Programs, US Dept. of Energy, 1000 Independence Avenue SW, Washington, DC 20585

Conroy, P., GE Plastics, Pittsfield, MA

Cronin, K., California State Division of Recycling, Sacramento

Curlee, T. R., Oak Ridge National Lab, Box 2008, Building 4500-N, Mail Stop 6205, Oak Ridge, TN 37831

Curry, M., Plastics Institute of America, Hoboken, NJ

DeKadt, M., INFORM, NY, NY

Delfano, M., State University of New York, Stony Brook, NY

DeRiggi, D.P., Mayor & Supervisor, City of Glen Cove, Glen Cove, NY, 11542

DeYoung, R., School of Natural Resources, University of Michigan, 430 East University, Ann Arbor, MI 48109-1115

Dinger, P., Director of Technology, Council for Solid Waste Solutions, Washington, DC

Ege, H.D., Burn & McDonnell Engineering Co., 4800 East 63rd Street, Kansas City, Missouri 64130

Englebright, Steven, Aid: Jay Schoenfeld, 149 Main Street, East Setauket, NY 11733

Epp-DiLorenzo, J., Research Director, Senate Subcommittee on the LI Marine District/Senator Owen H. Johnson/4th District, 23-24 Argyle Square, Babylon, NY 11702

Erickson, R., University of Minnesota, St. Paul, MN

Facciola, M., Legislative Comm./Science and Technology, NYS Senate Office of Senator LaValle, 146 State Street/Rm 207, Albany, NY, 12247

Ferrand, T., Ferrand Associates, San Diego, CA

Ferretti, W., NYS Department of Economic Development, Albany, NY

Franklin, W., Franklin Associates, Prairie Village, KS

Fullmer, J. and S. Meyland, Citizens Campaign For The Environment 10 Lawrence Avenue/Suite #4, Smithtown, NY 11787

Gainer, M., Gainer Associates, Arcata, Calif.

Gamelsky, S., SCS Engineers, 2 Crosfield Avenue, Suite 422 West Nyack, NY 10994

Goertzel, A., National Forest Products Association, Washington, DC

George, D., Long Island Railroad, Long Island, NY

Hammer, F., President, Hammer's Plastic Recycling, Iowa Falls, Iowa

Hartman, F., Waste Management Inc., York, PA

Hayes-Morrison, T., BioEnergy International, Gainesville, FL

Heaton, C., Metro Portland, Portland, OR

Heil, J., Town of Brookhaven, NY

Householder, R., Sonoco Products Company, Hartsville, SC

Howland, J., Waste Management, Inc., Albany, NY

Humphrey, G.P., Green Tree Plastics Technology, Inc., Woodland Hills, California

Hunt, W., GE Plastics, Pittsfield, MA

Huntley, J.Y. c/o American Plastics Council/S.P.I., 1275 K Street, NW, Suite 400, Washington, DC 20005

Iles, K., Hammer's Plastic Recycling, Upland, California

Johnsen, J., Smithtown Municipal Services Facility, 85 Old Northport Rd., Kings Park, NY 11754

Keithley, C., Wood Heating Education and Research Foundation, Washington, DC

Kemalyan, R.S., Plastics Recycling Corporation of California
3345 Wilshire Boulevard, Suite 1105, Los Angeles, California
90010

Keoleian, G., School of Natural Resources, University of Michigan, 430 East University, Ann Arbor, MI 48109-1115

Kimmelman, J., National Resources Defense Council, NY, NY

Kemalyan, R., President, Plastic Recycling Corporation of California, Los Angeles

Kempton, W., Princeton University, Princeton, NJ

Kowalski, J., Economist, Energy, Minerals and Natural Resources Department, State of New Mexico, Santa Fe, New Mexico

Lee, J., Brookhaven National Laboratory, Upton, NY

Legler, J., National Solid Wastes Management Association, Washington, DC

LeGrand, J., Stress Panels, Inc., Pittsburg, KS

Leupold, K.J., Commissioner of Public Works, Town of Oyster Bay, Bureau of Recycling, 150 Miller Place, Syosset, NY 11791-5699

Liblit, E.R., Commissioner/Dept. of Environmental Control, Town of Babylon, 281 Phelps Lane, North Babylon, NY 11703-4006

Liesemer, R., Council for Solid Waste Solutions, Washington, DC

Loomgarden, P., Mid-Atlantic Plastic Systems, Roselle, NJ

Maczko, J., Mid-Atlantic Plastic Systems P.O. Box 507, 320 Chestnut Street Roselle, NJ 07203

Mahan, T., Herbold Granulators USA, Inc., Sutton, MA

Manning, J.E., Deputy Commissioner, Town of Hempstead/Dept. of Sanitation, 1600 Merrick Rd., Merrick, NY 11566

Matthes, G., Plastmachines Gelderland, GMBH, Munich

Mazzalupo, D., Tempek, Old Lyme, CT

McCaffrey, M., Mullen & McCaffrey, 197 Hog Creek Road, East Hampton, NY 11937

Milgrom, J., Walden Research, Inc., Worcester, MA

Morrow, D.R., Morrow Associated Enterprises, 411 B Southgate Court, Mickleton, NJ 08056

Naumann, E., Rensselaer Polytechnic Institute, Troy, NY

Newton, D., Recycling Coordinator (Suffolk County), Dept. of General Services, 395 Oser Ave., Hauppauge, NY. 11788-3631

Nordman, B., Lawrence Berkeley Laboratory, Berkeley, CA

Nosker, T., Center for Plastics Recycling Research, Rutgers University, Piscataway, NJ

Noto, A., President, Trimax Plastic Lumber, 2076 Fifth Avenue Ronkonkoma, NY 11779

Pearson, W., Executive Director, Plastic Recycling Foundation, Washington, DC

Penn, G., Council Office, Huntington Town Hall, 100 Main Street, Huntington, NY 11743-6990

Perkins, R., Council for Solid Waste Solutions, Washington, DC

Phelps, R., Menasha Corporation, Watertown, WI

Pollock, C., Consultant, Edmonton, Alberta

Potter, R., Town of Brookhaven, NY

Powell, J., Plastics Recycling Update/Resource Recycling, Portland, OR

Ramer, R.M., Florida D.O.T., 2006 NE Walso Road, P.O. Box 1029, Gainesville, FL 32602

Rathje, W., University of Arizona, Prof. William L. Rathje, Anthropology/BARA, University of Arizona, Tucson, AZ 85271 Tucson, AZ

Reichert, R., Town of Brookhaven, Deputy Commissioner of Waste Management, 3233 Route 112, Building #5, Medford, NY 11763

Ridinger, J.M., Recycling Coordinator, Dutchess County Resource Recovery Agency, Sand Dock Road, Poughkeepsie, NY 12601

Alan E. Robbins, President, The Plastic Lumber Company, Box 80075, Akrow, OH 44308-0075

Roethel, Frank J., MSRC, SUNY Stony Brook, Stony Brook, NY.

Ronan, J., Town of Hempstead, NY

Roth, P.M., Regional Solid Waste Engineer, NYS Dept. of Environmental Conservation, SUNY, Bldg. #40, Stony Brook, NY 11794

Rushing, J., Marketing Associates, Inc., Anaheim, Calif.

Ruston, J., Economist, Environmental Defense Fund, New York City

Ryan, J., Solar Energy Industries Association, Washington, DC

Sisson, E., Goodyear Tire and Rubber Co., Akron, OH

Solomon-Hess, J., Editor, Recycling Today, Cleveland, Ohio

Stauffer, R., National Appropriate Technology Assistance Center, Butte, MT

Stevens, P., Chief Purchasing Agent, Suffolk County, NY

Stipther, S., Manager, Santana Products, Laguna Hills, Calif.

Susky, V., American Trucking Association, Washington, DC

Sweger Jr., C., President, Keystone Custom Recycling Inc., P.O. Box 11642, Federal Square Station, Harrisburg, Pennsylvania 17104-1642

Swenson, E., Superintendent of Environmental Control, Oyster Bay, NY, 11771

Tomaszek, T., North American Plastics, Glen Falls, NY

Vandenberg, N., Markets for Recycled Products, c/o CENYC (Council on the Environment NYC), 51 Chambers Street, Room 228, New York, New York 10007

Visalli, J., NYS Energy Research and Development Authority, Albany, NY

Weed, H., Official, Brightwaters, NY

Weis, R., DuPont Polymer Products Department, Wilmington, DE

Wolke, Andrew, Smithtown Sanitation Chief, 85 Old Northport Road, Kings Park, NY 11754

Wolpert, V., Hunters, Coleman's Hatch, East Sussex, England

Wolsky, A., Argonne National Laboratory, Argonne, IL

Zerbe, USDA Forest Products Laboratory, Madison, WI

Respondents contacted specifically for the surveys are not listed. The surveys were conducted on the basis of an assurance of anonymity, to protect proprietary and other information of potential competitive value. There were some other persons contacted for this report who also requested their names not be provided. Some of the persons contacted were from the following organizations:

Babylon Office of Environmental Control, 281 Phelps Lane, North Babylon, NY 11703

Brightwaters Town Hall, Brightwaters, NY

Brookhaven Waste Management Department, 3233 Route 112/Bldg. #5, Medford, NY 11763

Burn & McDonnell Engineering Co., 4800 East 63rd Street, Kansas City, Mo. 64130

Center for Plastics Recycling Research, Rutgers, The State University of New Jersey, Piscataway, New Jersey 08855

Christiansen Associates, P.O. Box 7364, Toledo, Ohio 43615

Citizens Campaign For The Environment, 10 Lawrence Avenue, Suite #4, Smithtown, NY 11787

City of Glen Cove, Glen Cove, NY 11542

Cornell Waste Management Institute, Cornell University, 468 Hollister Hall, Ithaca, NY 14853-3501

Dutchess County Resource Recovery Agency, Poughkeepsie, NY

Dynamite Tool Co., 221 Selden Plaza, Selden, NY 11784

Environmental Control, Oyster Bay, NY

Friendly Carting and USA Recycling, 110 Old Northport Rd, Kings Park, NY 11754

General Electric, 12 Sheridan Avenue, Albany, NY 12207

Huntington Town Hall, Council Office, Huntington, NY

Insurance Risk Management Firm

Keystone Custom Recycling Inc., Harrisburg, PA

Legislative Committee, Science and Technology, NYS Senate, Office of Senator LaValle, 146 State Street, Rm 207, Albany, NY 12247

Markets for Recycled Products, c/o CENYC (Council on the Environment NYC), New York, NY

Mullen & McCaffrey, East Hampton, NY

National Waste Technologies, Inc., Ronkonkoma Recycling Facility, 934 Easton Street, Ronkonkoma, NY 11779

NYS Dept. of Environmental Conservation, Stony Brook, NY

Office of the Babylon Commissioner of Environmental Control, North Babylon, NY 11703

Office of Smithtown Town Supervisor, Town Hall, 99 W. Main Street, Smithtown, NY 11787

Pallet Sales Corporation, 132 Dupont Street, Plainview, NY 11803

Phoenix Recycling Corp., 2019 County Rd-C2, Roseville, Minnesota, 55113

Reporter, Concerned Citizen, East Setauket, NY

Senate Subcommittee on the LI Marine District, Senator Owen H. Johnson, 4th District, 23-24 Argyle Square, Babylon, NY 11702

Smithtown Dept. of Environment & Waterways, Donald A. Devine Bldg., 124 West Main Street, P. O. Box 575, Smithtown, NY 11787

Smithtown Municipal Services Facility, 85 Old Northport Rd., Kings Park, NY 11754

Smithtown Sanitation, Kings Park, NY

Suffolk County Office of Economic Development, H. Lee Dennison Bldg., 11th Floor, Veterans Memorial Highway, Hauppauge, NY 11788

Suffolk County Department of General Services, Recycling, NY

Town of Babylon, Dept. of Environmental Control, NY

Town of Brookhaven, Waste Management Department, Medford, NY

Town of Hempstead, Solid Waste Management Authority, 220 Plandome Rd., Manhasset, NY 11030

Town of Hempstead, Department of Sanitation, Merrick, NY

Town of Oyster Bay, Bureau of Recycling, NY

Trimax Plastic Lumber, Ronkonkoma, NY

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