MARKET DEVELOPMENT FOR RECYCLED HIGH DENSITY POLYETHYLENE (HDPE)

by

Esther Siskind

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ABSTRACT

Plastics are one of the most controversial issues in solid waste management. Each year the number of plastic containers, bottles, wrappers and bags that fill our trash grows. As the solid waste crisis worsens, plastics are becoming a growing concern of the public, environmental groups, legislators and solid waste management officials. The sources of this concern are many: the service life of a plastic cup is a few minutes, but once thrown "away" it can continue to live for hundreds of years in as landfill; when incinerated, toxic air emissions may be produced; toxic by-products are released during plastics production; petroleum and natural gas resources are depleted to make plastic; and tens of thousands of sea birds and a hundred thousand marine animals die each year by ingesting or becoming entangled with plastic debris.

More and more, communities are exploring plastics recycling as an alternative to landfilling and incineration. However, there may not be enough end markets to absorb these materials. Plastic food containers and packaging, unlike glass bottles or aluminum cans, cannot be recycled for use in food applications because they have the tendency to absorb contaminants. Other markets must therefore be found for recycled plastic. This thesis examines one type of plastic, high density polyethylene (HDPE) -- the plastic used in milk jugs, laundry detergent bottles and base cups for soda bottles -- to determine whether adequate end markets exist.

A market development study was conducted, analyzing the sources of post-consumer HDPE and HDPE end markets. The study concludes that HDPE end markets may not be able to absorb more than a fraction of the residential disposable HDPE produced each year and, to increase plastics recycling levels above those estimated in this analysis, recycled plastics would have to replace wood and metal in certain applications. The thesis also suggests a market development strategy, for cases in which the public sector determines that plastics recycling should be promoted.

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This thesis grew out of a research internship I had last summer with the Environmental Defense Fund (EDF). It is therefore appropriate that I begin by thanking John Ruston who exposed me to the world of recycling, gave me my first plastics recycling project, offered much thoughtful and perceptive advice throughout the proposal and thesis writing process and who, in effect, I considered a de facto member of my thesis committee. His commitment to environmental work has always inspired me. The internship that I had with EDF helped me to become more analytical, taught me not to be intimidated by scientific information, and most of all, helped me develop a stronger understanding of the economic complexities of solid waste management.

I would like to thank my committee members, who brought unique backgrounds and perspectives to the review of my thesis: Pat Hynes, my advisor, who was always approachable, asked thought-provoking questions and who -- when I was bogged down in melt indexes and environmental stress crack resistances -- put my thesis in the broader perspective of the role of plastics recycling in solid waste management; Richard Tabors who helped me organize numerous charts and graphs and gave me a deeper understanding of the economics; and Gretchen Brewer, who took time out of her busy schedule to review this thesis and give the type of detailed and thoughtful comments that only an expert in the field could give. The supportive comments of all my committee members gave me much encouragement.

This thesis could not have been written without the help of the many plastics recyclers, plastics manufacturers and other plastics experts who took the time to answer all my questions and explain the intricacies of plastics and plastics recycling. None of this information could have come from a book. In particular I would like to thank Eric Christiansen, Bob Davidson, Gary Fish, Thomas Miller, William Sacks, Michael Schedler, Ian Smith, Tom Tomazak, Michael Twomey and Steve Van Asdale.

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CONTENTS

INTRODUCTION

"I just want to say one word. Just one word, `PLASTICS.´ There´s a great future in plastics."

-The Graduate (1968)

"A word of advice, Benjamin: Stay out of plastics."

- Business Week (PIA 1989a)

Plastics: The Problem

The movie, *The Graduate*, prophesied correctly. The use of plastics in packaging was almost non-existent 20 years ago. Today plastics wrap nearly every type of product we buy. Plastics made possible and then rode the wave of our disposable lifestyle. Disposable plastics both nourished and fed on the growth of fast food stores and the extensive use of packaging and disposable products spurred by an increased emphasis on marketing and advertising to influence consumers´ preferences.

Each year, plastics increasingly invade our lives. And each year, the number of plastic containers, bottles, wrappers, and bags that fill our trash grows. As the solid waste crisis worsens, plastics are becoming a growing concern of the public, environmental groups, legislators and solid waste management officials. In the past two years, various types of plastics have been banned in fifteen to twenty communities in the U.S. Legislation to ban or limit the use of plastics is pending in approximately fifty to sixty more (Ruston 1990).

Why have plastics, more than any other packaging material, become the target of public attention?

The answer lies in the properties of plastics themselves. While many plastics are produced for disposable applications, they are highly durable. The service life of a plastic cup is a few minutes. Once thrown "away," it can continue to live for centuries in a landfill. If burned in an incinerator, toxic air emissions may be produced. Heavy metals, particularly cadmium, used as stabilizers and pigments in plastic products are found in incinerator ash. Toxic byproducts are also released during plastics production and product manufacturing. Tens of thousands of sea birds and a hundred thousand marine mammals die each year by ingesting or becoming entangled with plastic debris (GAO 1988). Petroleum and natural gas resources are being depleted to produce plastics.

These problems will be exacerbated by the fact that plastics, particularly disposable plastics used in packaging, are the fastest growing fraction of the waste stream, replacing wood, paper, glass and aluminum in many applications (Franklin Associates 1988). Although plastics represent only 7% of the waste stream by weight (the statistic most often quoted by the plastics industry), they make up about 18% of the waste stream by volume and volume is what governs collection costs and landfill life. A new study is expected to reveal that plastics may account for as much as 27% of the waste stream by volume (*Modern Plastics* 1989d).

Plastics Recycling: A solution?

In the face of growing regulation and fearful that for certain applications plastics will be banned into "a thing of the past," the plastics industry has proffered recycling as a solution to problems of plastics disposal claiming that plastics are one of the most recyclable materials (PIA/Aronhalt 1989a).

Communities and states are beginning to explore plastics recycling as an option for reducing the amount of plastics that end up in incinerators and landfills. As mandatory recycling legislation is being passed around the country, communities and states are considering adding plastics, particularly polyethylene terephthalate (PET) and high density polyethylene (HDPE)[1], to the list of materials collected for recycling.

To date, few have taken this step. Less than 1% of all plastics are currently being recycled (Brewer 1988 and Bennett 1989a). In 1988, 23% of PET soda bottles were recycled, so far the only substantial plastics recycling effort. Only 93 million lbs. of HDPE was recycled, while about 3.5 billion lbs. was produced for use in disposable packaging applications (Bennett 1990 and *Modern Plastics* 1990b). The recycling of other post-consumer plastics is negligible.

The extent to which "there's a great future" in plastics recycling is debatable. The amount of the plastics waste stream that can potentially be recycled is unknown. There are many economic, technological and attitudinal constraints that currently stand in the way of achieving a rate of plastics recycling that would substantially reduce the

[1]PET and HDPE are plastic resins. The primary packaging application for PET is beverage bottles (i.e. soda bottles). Packaging applications for HDPE, the focus of this paper, include milk jugs, laundry detergent bottles and plastic bags.

problems of plastics production and disposal. However, there is certainly much more room for penetration into this relatively new and underdeveloped industry, particularly since an insignificant percentage of plastics is currently being recycled.

Market Development and a Plastics Recycling Infrastructure
Ultimately, the viability of large-scale plastics recycling will depend on the development of a substantial and reliable plastics recycling infrastructure -- a system for collecting, processing and manufacture using recovered resins. The collection and processing components of this infrastructure must guarantee a large, steady and usable supply while the manufacturing segment must support stable markets for recovered materials.

While the development of each segment of this infrastructure is critical to the overall viability of plastics recycling, this analysis will focus on market development. The importance of markets to successful recycling has been made self-evident by the recent decline in old newsprint prices in the Northeast which has cast uncertainty on the economics of local collection programs. In a few short-term cases, secondary newsprint markets have dried up completely. It is now clear that public and private concerns should have thought through market development more carefully as they implemented and devoted resources to recycling collection programs.

The development of markets for recycled plastics faces a set of special economic and technological factors which could limit the availability of markets.

First, due to their high volume, plastics face very high collection costs compared to other recyclable materials. Separation and processing costs are also higher because of the diversity of different plastic compounds, which generally must be segregated to maximize their commodity value. In order to partially offset these higher costs, it is important that recycled resins retain a high intrinsic value. If end markets for recycled plastics are only comprised of low value applications, they may not be able to bear the price of recycled resins.

Second, for all but the most recyclable plastics (i.e. soda bottles and milk jugs), plastics recycling is suffering from what Gretchen Brewer calls the "chicken and egg" phenomenon. Collection will not happen without the existence of adequate markets. At the same time, markets won't be developed without large steady supplies (Brewer 1990a). Since this thesis seeks to evaluate the market potential for a wide range of plastic goods -- not just the first easy targets --

the technical and economic potential of underdeveloped markets is very important.

Third, this thesis is concerned with the potential for plastics recycling to reduce the production of virgin plastics, and along with it, the associated environmental problems related to toxics production, resource depletion and energy consumption. The interaction between virgin and recycled plastics markets is therefore of fundamental importance. The potential for recycled plastics to displace virgin materials is threatened by the large capacity expansions that are being planned and are coming on line in the virgin resin industry which will glut the market with virgin materials and reduce their prices. The construction of a large number of virgin newsprint mills has had a similar effect on the recycled newsprint market (Ruston 1990).

Fourth, recent volatility of virgin plastics prices has threatened the economic viability of small-scale recyclers. When virgin plastics prices fall, the use of recycled plastics in many end-uses becomes unattractive.

Fifth, developing markets for recycled plastics is more complex than for other materials such as aluminum and glass. Recycled plastics have undergone an additional heat history, causing them to lose some of their properties. This factor often limits the markets for recycled plastics to low value added end uses. Plastic food containers and packaging, unlike aluminum cans and glass bottles, cannot be recycled for use in food applications because plastic cannot be melted at high enough temperatures to destroy contaminants (doing so would destroy the properties of the plastic). Other markets must therefore be found for recycled plastic.

The Implications of Markets for Recycled Plastics for Solid Waste Planners and the Plastics Industry

From the public standpoint, it is not essential that market prices generate a profit for recycling, since the point of recycling is to avoid skyrocketing landfill and incineration costs.[2] However, the <u>reliability</u> of any waste management option is of paramount concern to solid waste professionals. For recycling, this translates into the need for viable and stable end markets to absorb the material. Solid waste planners play a critical role in market development because they determine what will be collected and how it will be initially processed and because they have the ability to

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[2] From the public sector perspective, in order for recycling to be economically viable, collection and processing costs minus the market revenues generated for the recycled material should be less than or equal to the costs associated with disposing of the material through incineration or landfilling.

offer incentives to industry to stimulate markets for recycled materials.

Plastics recycling cannot develop from a small-scale to a large-scale industry without the cooperation and support of the plastics industry. Such an effort would require large investments for which only the private sector has the resources. If plastics recycling can be shown to be profitable, industry would have an incentive to develop the plastics recycling industry on its own. Profitability requires stable markets.

High Density Polyethylene (HDPE)

Recycled high density polyethylene (HDPE) will be the focus of this market development analysis. The scope will be limited to post-consumer residential disposable HDPE which largely consists of packaging applications. Industrial scrap and commercial waste will not be examined. These materials are already being recycled to a large extent, and are much easier to recycle because they are cleaner and are segregated (OTA 1989). It is the mixed, contaminated, post-consumer residential waste that presents the most difficult recycling challenge.

The analysis will address the following questions:

* What constraints do end markets -- manufacturing products and processes -- pose on post-consumer HDPE recycling?
* How should end markets for recycled HDPE be developed to improve the economic and practical viability of HDPE recycling?

<u>What is HDPE?</u>

Over 8 billion pounds of high density polyethylene was sold in the U.S. in 1989, making it the second largest type of plastic, or "resin," produced[3] (*Modern Plastics* 1990b). Almost half of the HDPE produced finds its way into disposable applications (Figure 1). The most easily identifiable product made of HDPE is milk bottles. Other easily recognizable applications include base cups for PET beverage

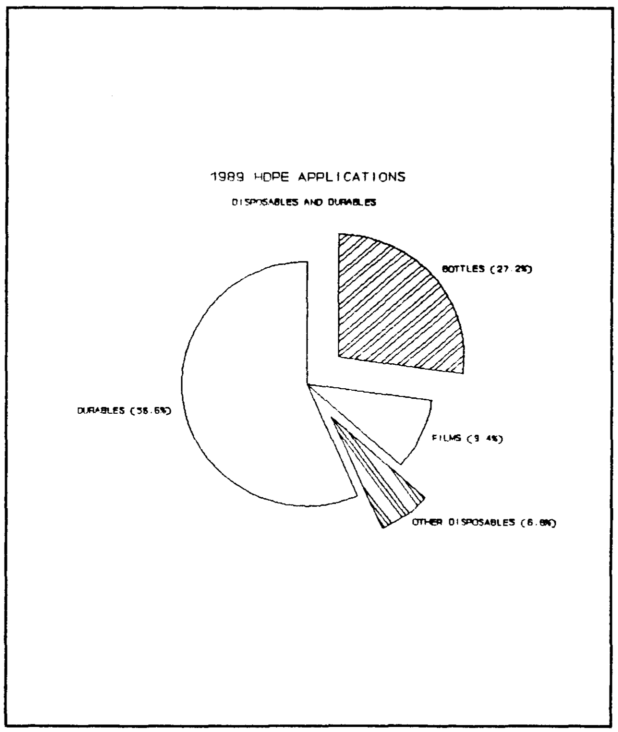

Figure 1

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[3] Low density polyethylene is the largest, with over 10 billion lbs. in sales in 1989 (Modern Plastics 1990b).

bottles and laundry detergent, bleach and automotive oil bottles. HDPE is also used in pipe, drums, gas tanks, toys, furniture, garbage cans, pails, crates and wire and cable insulation. Extruded as a film, HDPE is used to manufacture garbage bags, grocery sacks and sheet. HDPE is characterized by its opaqueness, light weight, rigidity, tensile strength, resistance to chemicals and electrical insulating properties (*Modern Plastics Encyclopedia '89* 1988).

Why focus on HDPE?

I have chosen HDPE for several reasons. HDPE is being considered for collection by many communities and states and industry is also gearing up for HDPE recycling. It is being targeted because at this point in time it has the greatest recycling potential. Many of its applications are easily identifiable (i.e. milk jugs and laundry detergent bottles) which facilitates collection and sorting; it is highly amenable to reprocessing and reheating; and it is the second most widely used resin in the U.S. Currently, markets for post-consumer recycled HDPE are considered to be fairly large. However, very little is being recycled. If large-scale HDPE recycling programs were to be established, it is uncertain whether end markets would be large enough to absorb the HDPE collected. Finally, HDPE offers a baseline for plastics recycling in general. In other words, if HDPE recycling does not succeed, it is unlikely that other resins such as low density polyethylene, polystyrene, polypropylene and polyvinyl chloride, can be recycled because the problems associated with recycling these resins are more complex.

Although the scope of this market development study is limited to HDPE, the analysis should provide a useful methodology for evaluating markets for other large-volume resins.

Objectives and Scope

This analysis has several objectives. First, to provide a useful framework for solid waste planners and market development analysts which will enable them to judge the feasibility of HDPE and other types of plastics recycling and to more effectively design their plastics recycling programs. Based on market development analysis, decisions can be made on which materials should be collected and how they should be processed. Planners also can use this analysis to determine how they should most effectively direct their resources. For example, technical and financial assistance can be offered to industry to spur new markets and encourage the growth of recycling industries.

Second, to assist industry in making decisions on how they should target their investments in recycling, design their plastics recycling operations, and develop strategies over the long-term.

Third, to accurately assess the feasibility of plastics recycling. The role of plastics in the "garbage crisis" is one of the most controversial topics in solid waste management. The plastics industry including companies such as Dow Chemical, Amoco, Mobil and Chevron have poured millions of dollars into advertising and public relations geared to convincing the public and policy makers that plastics are very recyclable. The budget of the Council on Solid Waste Solutions (CSWS), an arm of the Society of the Plastics Industry, alone is over 13 million dollars (Leaversuch 1989b and Rogers 1990b).

The plastics industry claims that viable markets for recycled plastics are in place (CSWS 1989d). While it is true that viable markets currently exist for some types of HDPE, less than 1% of all HDPE produced is currently being recycled. What this thesis seeks to examine is whether assertions regarding the viability of markets will be true over the long-term. It is the long-term stability of markets that solid waste planners must consider in implementing recycling programs. The only way to cut through the rhetoric and accurately assess the environmental and economic costs and benefits of plastics recycling is to conduct a detailed examination of what is actually being done and what might be possible.

Several underlying assumptions are made in this thesis. Only HDPE end markets will be examined. Replacement of wood and metal by recycled plastics does not reduce the amount of virgin plastics produced. Rather, closed loop recycling systems must be designed.

It is beyond the scope of the analysis to discuss the pros and cons of plastics use and whether or not plastics should be banned. This paper also will not address alternatives to plastics recycling such as waste reduction, incineration and landfilling. Nor will it discuss the benefits that waste reduction, minimization and reuse have over plastics recycling. It is assumed that reducing waste should be the first option to which solid waste planners direct their resources. However, despite the most concerted efforts at waste minimization and reuse (or unless there is an outright ban on all disposable plastics in the U.S.), disposable plastics will be entering our waste stream. For environmental as well as economic reasons, recycling is a better alternative than incineration and landfilling.

Overview

This paper is divided into three Parts.

Part 1, Building Blocks, provides the background needed to perform a market analysis. Chapter 1, Overview of Plastics Recycling, reviews plastic resins and manufacturing processes, the history of plastics recycling and the HDPE recycling process and infrastructure. Chapter 2, Market Development Issues, discusses recycled resin quality, prices, product standards, and manufacturers' perceptions - factors which impact the size of end markets for recycled HDPE.

Part 2 is the Market Analysis. Chapter 3 examines each Source of Supply, while Chapter 4, examines all potential HDPE End Markets (demand). Based on this exploration, in Chapter 5, Market Assessment, I will assess the ability for end markets to absorb potential supplies of post-consumer HDPE taking into consideration economic, technological and institutional constraints.

Part 3, Implications of the Market Analysis, consists of two chapters. Chapter 6, Market Development Strategy, will discuss the public sector's role in market development and will suggest a strategy for improving the viability of end markets for recycled HDPE. Chapter 7, Conclusions, will examine HDPE recycling from a broader perspective: the implications of the market development analysis for the plastics industry and the public sector.

Terminology

Recycling terminology is used throughout this paper. Terminology associated with recycling has often been a source of confusion in both studies and in market situations. For example, post-consumer HDPE and recycled HDPE have different meanings; post-consumer HDPE refers to commercial and residential applications which are used and discarded; recycled HDPE includes industrial scrap which has never been used. While I have tried to remain as consistent as possible in the use of terminology throughout this paper, it is to be assumed, unless otherwise stated, that all allusions to post-consumer HDPE are to post-consumer residential disposable HDPE. For reference, I have included a Glossary of recycling-related terminology (See Appendix 1).

PART 1

BUILDING BLOCKS

Part 1 is aimed at developing the basic building blocks needed to assess the viability of end markets for recycled HDPE. These building blocks are: a basic understanding of plastics, the HDPE recycling process and factors which impact the recyclability of HDPE.

Part 1 consists of two Chapters:

Chapter 1, Overview of Plastics Recycling, highlights plastics materials and processes, the history of plastics recycling and the HDPE recycling process and infrastructure.

Chapter 2, Market Development Issues, delves deeper into issues which impact the recyclability of HDPE. These issues are: recycled resin quality, price, design and performance standards, and manufacturers' willingness to use recycled HDPE.

CHAPTER 1

OVERVIEW OF PLASTICS RECYCLING

1.0 INTRODUCTION

Plastics are everywhere -- in your car, on your desk, in your refrigerator, in your closet and in your garbage. They wrap your food, encase the ink of your pen, your disposable razor and your clock, hold your laundry detergent and carry your garbage. Their primary characteristic is versatility and it is versatility which allows them to be used in everything from throw-away bottles and films to durable computer housings, records, auto parts, refuse containers and even clothing.

This versatility has fundamental implications for recycling. All glass and aluminum is essentially alike, making recycling rather simple. However, because there are many different types of plastics, recycling programs must be adapted to meet the more complex needs of plastics. This chapter will discuss the different types of plastics and the recycling infrastructure which is unique to plastics.

2.0 THE NATURE OF PLASTICS

2.1 PLASTIC RESINS

Plastic comes in many different forms, or "resins," each with its own unique properties that make it more or less suitable for use in specific products. The plastics of most concern in the face of the growing solid waste crisis are thermoplastics, the large volume throw-away plastics used in packaging. The primary thermoplastic resins are[1]:

2.1.1 Low Density Polyethylene (LDPE)

LDPE is the largest volume resin used for packaging. Its flexible and transparent qualities make it ideal for film and sheet applications. As a film, LDPE is made into trash bags, grocery bags, clothes packaging, food wrap and diapers. Other applications include: coating for milk containers, pipe, wire and cable, milk caps, glue bottles, lids and containers. Linear low density polyethylene (LLDPE), more recently introduced, is used in similar applications.

LDPE Sales 1989 (including LLDPE): 10,636 million lbs.

2.1.2 High Density Polyethylene (HDPE)

The most easily identifiable products made of HDPE are milk jugs, base cups for PET beverage bottles and laundry detergent bottles. HDPE is also used in automobile oil bottles, pipe, drums, gas tanks, toys,

[1]Unless otherwise noted, the source for all resin descriptions is Modern Plastics Encyclopedia '89. All sales data is from Modern Plastics 1990b.

furniture, garbage cans, pails and crates, and wire and cable insulation. Extruded as a film, it is used in garbage bags and grocery sacks. HDPE is characterized by its opaqueness, light weight, rigidity, tensile strength, resistance to chemicals and electrical insulating properties.

HDPE Sales 1989: 8,115 million lbs.

2.1.3 Polyethylene Terephthalate (PET)

The most easily identifiable product made from PET resin is the carbonated beverage bottle (returnable under deposit legislation in several states). PET has captured this market because it is lighter than glass, shatterproof, and provides a good barrier to gas and water transmission. Other applications include toiletry, vegetable oil and syrup bottles, microwave trays, photograph and x-ray film and magnetic recording tape.

PET Sales 1989: 1905 million lbs.

2.1.4 Polypropylene (PP)

PP is used in numerous food packaging applications including yogurt and margarine tubs, deli containers, snack food wrappers and straws. Other applications include: medicine and shampoo bottles, diaper lining, syringes, bottle caps, ski jackets, and filaments for carpet yarns and backing. It is injection molded to produce automotive parts, appliances, furniture and office equipment.

PP Sales 1989: 7,246 million lbs.

2.1.5 Polystyrene (PS)

PS comes in several forms. Expanded bead PS, marketed by Dow Chemical under the tradename, "styrofoam," is used in cups, thermal insulation applications and as cushioned packaging. Impact PS is used in cutlery, disposable razors and light fixtures. Crystal PS is a foamed version used in fast food packaging as well as egg cartons and meat and poultry trays. Oriented PS is used in clear clam shell take out containers from salad bars.

PS Sales 1989: 5,184 million lbs.

2.1.6 Polyvinyl Chloride (PVC)

Most PVC is used in building construction applications such as pipe, house siding, window profiles and flooring. Garden hose, gloves, bottles and the vinyl of upholstery, luggage and clothing are other applications made of PVC. Due to possible carcinogenic effects, it is used in only a limited number of food and packaging applications such as meat wrap and vegetable oil bottles (Wirka 1988). PVC is highly versatile because of its blendability with plasticizers, stabilizers and other additives. Because it is often mixed with lead and cadmium additives, recycling is difficult and incineration can have adverse health effects.

PVC Sales 1989: 8,307 million lbs.

Additives are used in the production of plastics to modify and upgrade the properties of plastics, thus enabling them to be used in a wider range of applications. Examples of additives are: eat stabilizers which prevent degradation; ultraviolet (UV) stabilizers which prevent discoloration, embrittlement and cracking; plasticizers which soften and give flexibility; and foaming agents which give foamed plastics their cellular structure (Smoluk 1988).

2.2 PLASTICS MANUFACTURING PROCESSES

Plastics products are produced in numerous processes. The most important for the manufacture of products made with HDPE are: (For additional information on these processes, see Appendix 2.)

2.2.1 Extrusion

Extrusion is used to make continuous products of constant cross section such as film and sheet, profiles, and pipe and tubing.
The process is also used to compound and pelletize resins and to coat wire and cable (Wilder 1988) The extruder consists of one or two screws which rotate inside a long heated barrel or cylinder. Resin, in the form of powder, granules, pellets or beads, is poured into a hopper and is picked up by the rotating screw which mixes, melts and pumps the resin through the barrel. At the far end of the cylinder, the melt is pumped through a die which gives the product its shape. Before leaving the die, the melt passes through a screen pack, or filter, located between the screw and the die, which removes any unmolten polymer and accidental contaminants which could damage the die or final product (Leidner 1981; Powell 1983; Radian Corp. 1986; Modern Plastics Encyclopedia '89 1988). Two or more resins can be co-extruded to form a

multilayer product.

2.2.2 Injection Molding

A wide range of products of varying sizes, from tiny components to pieces that are many feet long, can be produced through injection molding. Products manufactured in this process have a high degree of dimensional accuracy and can be as finely detailed as a screw. Typical products include: housewares, toys, furnishings and automotive parts (Radian Corp. 1986)

Similar to the extrusion process, the resin is pumped along and melted by a rotating screw in a heated barrel. Unlike extrusion, injection molding is a batch, rather than continuous, process. When a specified amount of resin has accumulated at the end of the barrel, a valve opens and the resin is pushed into the mold cavity. After the piece has set, the mold opens and the part is ejected from the mold. The pieces are trimmed to remove excess material (the sprues and runners) and the scrap (referred to as reclaim or rework) is usually ground and reused (Leidner 1981; Powell 1983; Radian Corp. 1986; Modern Plastics Encyclopedia '89 1988).

2.2.3 Blow Molding

Blow molding is primarily used to produce bottles such as HDPE milk jugs and the PET soda bottles. Other applications include containers used in packaging applications, drums, auto fuel tanks, dolls and flower pots (Radian Corp. 1986).

There are two basic types of blow molding processes; extrusion and injection blow molding. Both processes begin with the creation of a preform which is expanded by air pressure to fill the inside of a mold. The difference between the two processes is the way in which the preform is made (Radian Corp. 1986).

Extrusion Blow Molding:

In extrusion blow molding, a tube shaped preform is extruded downwards and positioned between the open halves of a mold. When the mold is closed, the tube is pinched together on the bottom. Pieces produced in this process can be recognized by the long scar, often found at the base of the bottle, created during the pinching step. The tube is then expanded by compressed air inside the mold cavity and conforms to the shape of the mold (Powell 1983 and Radian Corp. 1986). This process is used to manufacture HDPE plastic bottles such as milk jugs and laundry detergent bottles. PVC and PP are also produced in this process.

Injection Blow Molding:

For bottles produced in this process, a test tube shaped preform is formed by injection molding. In the blow mold, air is blown into the tube and the preform is expanded to the size and shape of the bottle or container. This process is largely used to produce PET beverage bottles (Allen 1989 and Leidner 1981).

3.0 HISTORY AND CURRENT STATUS OF POST-CONSUMER PLASTICS RECYCLING

Less than 1% of all plastic discarded is recycled (Brewer 1988 and Bennett 1989a). Post-consumer plastics recycling is, by and large, limited to PET soda bottles and HDPE. Recently, small-scale polystyrene recycling pilot programs have been established by large polystyrene resin producers in an effort to improve the image of polystyrene in light of polystyrene bans in several localities and bad publicity resulting from the past use of CFCs in polystyrene products.

PET and HDPE each have their own post-consumer recycling history. All post-consumer plastic recycling was brought into existence directly or indirectly through legislation. Future legislation, much of it pending, will largely determine whether plastics recycling will be propelled into a large scale industry, or whether plastics will be increasingly regulated or taxed.

3.1 PET

Plastics recycling was ushered into existence in 1979 with the passage of deposit, or "bottle bill," legislation at the state level. The PET soda bottle was introduced in 1978; one year later, it became the first plastic subject to recycling legislation. A PET recycling industry sprang up as large quantities of supply were made available.

In 1988, 170 million lbs. of PET, or 23% of the amount used in beverage bottles, was recycled, largely collected in the nine states with deposit laws (Bennett 1990a). About 100 million lbs. of this post-consumer PET is recycled by Wellman Inc., which buys, cleans and processes the bottles, from which it manufactures fiberfill for use in pillows, sleeping bags and ski jackets. Recycled PET is also used in carpet backing and strapping and is glass reinforced for use in automobile fenders, head lamp covers and panels (Bennett 1989a). It can also be converted by hydrolysis, a chemical process, whereby it is broken down into its chemical constituents. These chemicals can then be converted back into PET and used to manufacture film or other products. In 1989, a 100% recycled PET bottle made through this process was introduced by Procter and Gamble for its product, Spic 'n Span. Food contact bottles made through this process are currently being tested (Mt. Auburn Associates 1989). If successful, a closed loop recycling system could be developed for PET, whereby soda bottles would be converted back into soda bottles.

3.2 HDPE

The roots of post-consumer HDPE recycling can be traced to the recycling of PET. Attached to the bottom of the PET bottle is the HDPE base cup (its purpose is to support the bottle). During the PET bottle recycling process, the base cup is removed. A large supply of base cups spurred an HDPE recycling industry through which these base cups were recycled back into base cups.

The recycling of post-consumer HDPE bottles -- milk jugs and laundry detergent bottles -- had different origins. An HDPE recycling industry sprang up to recover industrial scrap from the manufacture of blow molded bottles. During the bottle labelling process, known as in-mold labelling, paper labels are fused with the HDPE bottle. Rejects, contaminated with paper, were largely discarded until companies, such as Eaglebrook Plastics and Midwest Plastics (a pipe manufacturer) saw the potential for a profitable enterprise in the cleaning and recycling of this material. Once the cleaning process had been developed, post-consumer bottles were the next logical step (Leaversuch 1988a).

With the exception of base cup recycling, post-consumer HDPE recycling has been largely market driven, unlike PET and PS recycling which largely grew out of legislation. HDPE recycling took root during a period (mid to late 1980s) of virgin HDPE scarcity and high prices. Recycled HDPE's price advantage over virgin resin made it attractive to manufacturers of low quality end products.[2]

According to industry estimates, approximately 93 million lbs. of HDPE were recycled in 1988 (Bennett 1990a). The primary post-consumer feedstock is base cups, milk jugs and laundry detergent bottles which are recycled into base cups, drainage pipe, flower pots, trash cans, plastic lumber, auto mudflaps, kitchen drainboards, crates and pallets and plastic lumber (boards made of mixed plastic) (Bennett 1989a). Recently, recycled HDPE is being used in laundry detergent and oil bottles. There has also been some small scale activity in the recycling of HDPE film. (See Table 1.1 for post-consumer supply and demand data for 1987, the latest year for which this information is available.)

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[2]Swings in virgin prices over the past year, however, have affected the demand for recycled HDPE. See Chapter 2.

TABLE 1.1: RECYCLING OF POST-CONSUMER HDPE DISPOSABLES 1987
(million lbs.)

APPLICATION	VIRGIN SALES 1989	1987 RECYCLING OF POST-CONSUMER DISPOSABLES DEMAND	SUPPLY
BLOW MOLDING			
Bottles			
Milk Jugs**	720		20
Other Food Bottles	320		0
Household Chemical Bottles	732		13
-Oil Bottles	224		2
Pharmaceutical/cosmetics Bottles	208		2
Total Packaging Applications	2204		37
Drums (15 gal. & larger)	154		
Fuel Tanks (all types)	96		
Tight-head pails	90	10	
Toys	70		
Housewares	51		
Total Non-Packaging Applications	461	10	
Other Blow Molding	270		
TOTAL BLOW MOLDING	2935	10	37
EXTRUSION			
Film			
Merchandise Bags	182		
Tee shirt sacks	215		
Trash Bags Institutional	124		
Trash Bags Consumer	15		
Food packaging/deli	110		
Multiwall sack liners	50		
Other Film	70		
Total Film (< 12 mil)	766		
Pipe and Tubing			
Corrugated	103	30	
Water	59		
Oil & Gas Production	70		
Industrial/Mining	61		
Gas	112		
Irrigation	40		
Other	46		
Total Pipe and Tubing	491	30	
Sheet (> 12 mil)	305		
Wire & Cable	146		
Coating	51		
Other Extrusion	36		
TOTAL EXTRUSION	1795	30	0
INJECTION MOLDING			
Food Contact Packaging			
Milk Bottle Caps	25		
Dairy Tubs	136		
Ice Cream Containers	85		
Other Food Containers	46		
Non-Food Contact Packaging			
Other Caps	56		
Beverage Bottle Bases***	122	10	26
Paint Cans	31		
Total Packaging Applications	501	10	26
Dairy Crates	56	5	
Other Crates, Cases, Pallets	120	10	
Pails	380		
Housewares	190		
Toys	78		
Other Injection	218		
TOTAL INJECTION MOLDING	1543	25	26
OTHER			
Rotomolding	122		
Export	830		
Other	890		
TOTAL OTHER	1842		
GRAND TOTAL	8115	65	63

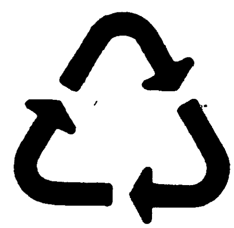
SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs

Despite the fact that HDPE recycling has steadily grown in recent years -- from 59 million lbs. in 1986 (Bennett 1990a) -- the amount of HDPE recycled dims when compared to the amount of HDPE discarded each year. The 93 million lbs. recycled in 1988 represents a mere 1% of all HDPE produced and 2% of the HDPE used in packaging. While technically more recyclable than PET, increased HDPE recycling has primarily suffered from the lack of a coordinated infrastructure.

4.0 THE HDPE RECYCLING INFRASTRUCTURE

The three arrows of the recycling symbol (see diagram) represent the three segments of a recycling infrastructure: collection, processing and end markets.



An HDPE recycling infrastructure is emerging: more communities are adding HDPE milk jugs and laundry detergent bottles to the list of recyclables they are collecting; large resin producers --such as the Du Pont Company, Dow Chemical and Union Carbide -- eager to show that HDPE is recyclable, have announced that they plan to enter the HDPE recycling industry; and new uses for HDPE are quickly being found as plastics manufacturers seek to reap the benefits of the rise in "environmental marketing."

However, the plastics recycling infrastructure remains highly underdeveloped. Large-scale processing facilities are yet to be built.

Adequate collection mechanisms must be devised, processing must be further automated and recycled plastics must gain the acceptance of plastics manufacturers. This section gives an overview of each segment and discusses some of the constraints on plastics recycling posed by each. (See Figure 1.1 for a diagram of the HDPE recycling infrastructure.)

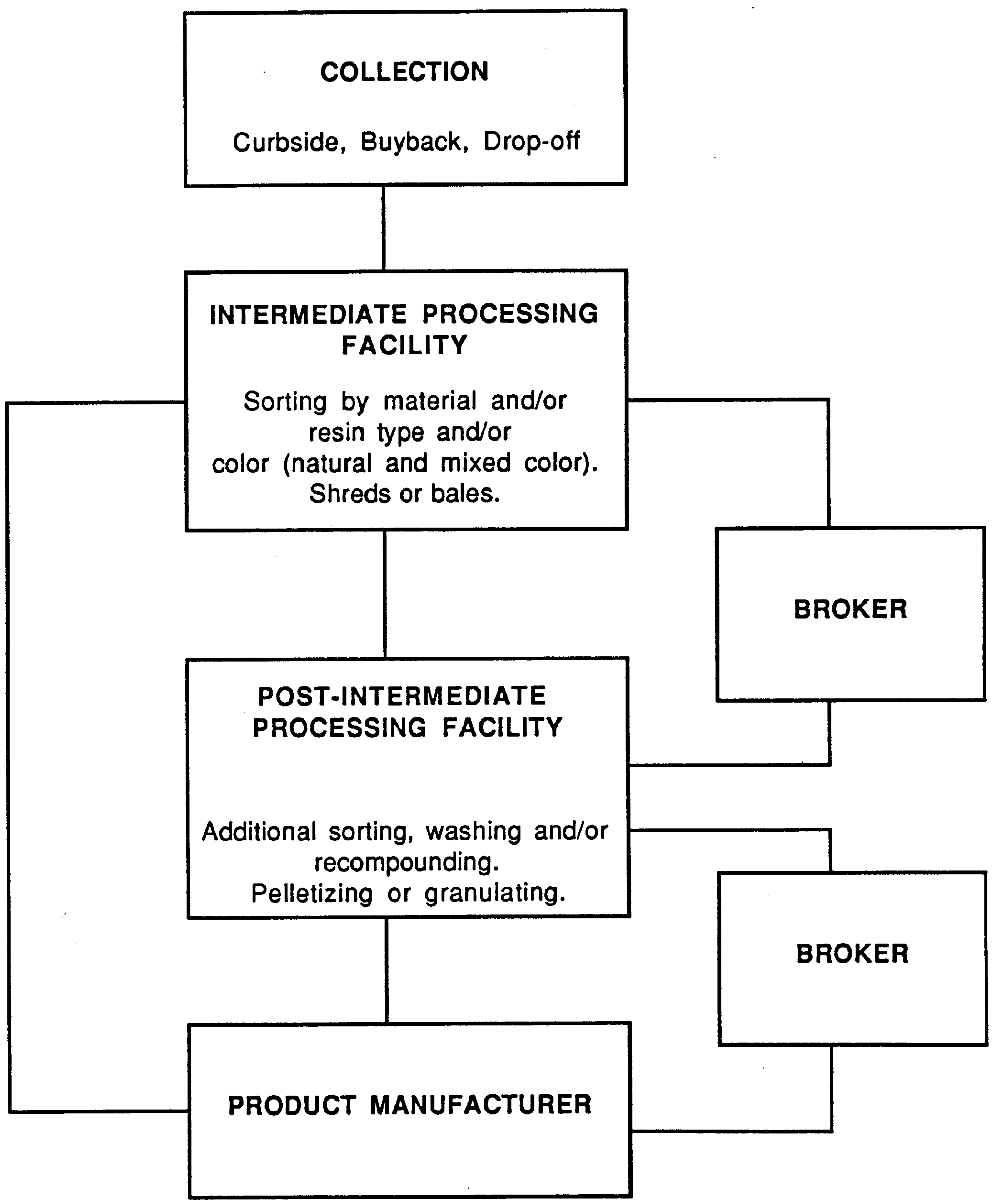
4.1 COLLECTION AND PROCESSING

While "end markets" is the infrastructure segment on which this paper focusses, they must be examined within the context of collection and processing. What material is collected and how it is processed determines in which end markets it can be used. An overview of these two infrastructure segments is therefore necessary.

Both collection and processing pose major impediments to plastics recycling. The source of difficulty stems from the high volume to weight ratio of plastic.

The volume to weight conversion ratio for disposable plastics is 2.5:1; plastics are 7.3% of the solid waste stream by weight, yielding a volume of 18%. (If a margin of error is considered, volume falls between 14% and 22%). A new study is expected to reveal that plastics currently account for 9% of the solid waste stream by weight. (With a margin of error, by volume they could account for as much as 27% of the waste stream.) (Modern Plastics 1989d) Rhode Island, the first state to

FIGURE 1.1
THE HDPE RECYCLING INFRASTRUCTURE



mandate curbside collection which includes plastics, has found that HDPE, although accounting for only 1.6% by weight of all recyclables they collect, accounts for 17.7% by volume (CSWS/Gold 1989a).

The high volume to weight ratio makes plastics collection and processing costs higher than for other materials. Because plastics take up so much volume in collection trucks, they are the costliest recyclable material to collect. Processing costs are high because plastics are so light that many pieces have to be sorted through before a significant bulk is acquired. And, due to these high costs, a study conducted by the State of Rhode Island found, "despite the relatively high market price for plastics on a weight basis, they contribute little to the overall...revenue stream" (CSWS/Gold 1989a).

Lastly, high volume increases the amount of space the consumer must set aside to collect the material. However, as Trish Ferrand points out, complaints of "I just don't have the space to handle all that material," must be overcome. She goes on to say, "Our kitchens are full of gadgets and appliances that we never knew we needed 10 or 20 years ago, when our kitchens were built bigger: We have specialty holders for slicing bagels and we have popcorn poppers, Cuisinarts, vegetable juicers, spinning colanders, pizza stones, expresso makers, electric crockpots and woks, ice cream makers, knife sharpeners, and now microwaves" (Ferrand 1988). However, despite this perceptive comment, the fact that increased inconvenience to the consumer reduces recovery rates, is a real concern.

4.1.1 Collection

4.1.1.1 Overview

Unlike PET which is collected through a legislated deposit mechanism, there is no legislated collection mechanism for HDPE (other than base cups). Post-consumer HDPE is currently being collected in one of three ways: curbside collection programs, buyback centers and drop-off centers.

Curbside collection is usually instituted through mandatory recycling legislation passed at the local level. Few communities -- about 300 -- are recycling one or more types of plastic through curbside collection programs (Brewer 1990b). It is estimated that 1.7 million households presently are provided with curbside plastics service of at least one type (Plastics Recycling Update 1990b). However it can be expected that in the near future, curbside collection of HDPE will increase. Many communities are in the process of establishing mandatory programs and large waste hauling companies are beginning to offer recycling as an alternative to incineration and landfilling. Potential revenues from the sale of plastics has induced both communities and these companies to consider collecting HDPE.

Buyback centers, which take many forms, pay individuals and businesses for recyclables. Some centers, such as R2B2 in the South Bronx (NY) and National Temple Recycling in Philadelphia (PA) operate as community economic development enterprises, collecting and processing substantial tonnages of a wide variety of materials. Others are run by aluminum and glass manufacturing corporations to provide a source of supply. Many community groups, sometimes supported by municipal government, operate small neighborhood centers that do not process materials to any great extent (Ruston 1990).

Drop-off centers, provide a collection site at which people can deliver their recyclables without payment. Drop-off centers can be community run, or sited at a local landfill or supermarket.

Curbside programs are the most effective method for ensuring the collection of large quantities of materials. The easier it is for the consumer, the higher the participation rate (Mannis 1989). (See Table 1.2.)

TABLE 1.2

Average Participation Rates for All Recyclables

Method of collection	Participation rate
Drop-off	10%
Buyback	15%-20%
Curbside	70%-90%

Source: PRF, Plastics Recycling: From Vision to Reality

4.1.1.2 Impediments to Curbside Collection

In adding plastics to a curbside collection program, there are several factors a community must consider: the types of plastic to be collected, collection techniques and frequency, collection equipment, the mechanics of separation, and marketing (PRF 198?a).

The problems associated with plastics collection are twofold. First, their large volume imposes significant collection costs. Second, because there are so many different types of plastic, deciding what to collect must be carefully considered because such decisions affect down stream processing costs and market availability.

Collection Costs:

Designing a vehicle to collect plastics for recycling, has confounded all who have tried. The difficulty stems from the fact that plastics take up a large volume in collection trucks, filling up the truck so quickly that additional trips or vehicles are required.

Densification is the key to reducing collection costs. Several different collection systems and trucks have been experimented with but each poses its own set of problems. For trucks with on-board compaction equipment hauling times are increased due to cycle times of the compactor and the need to sort at the curb. In addition, compacted plastics are more difficult to sort at the processing center. Lighter density compaction is therefore being investigated. On board granulators are even slower than on-board compaction and make separation at the processing center more difficult (CSWS 1989a). Another option, requiring that households crush their garbage, increases the inconvenience of recycling and therefore reduces participation, hence recovery rates.

Deciding What to Collect:

All plastic is not alike and all HDPE is not alike. As discussed above, HDPE is only one of many different resin types. In addition, there are many different grades of HDPE each with its own properties. Except for use in low quality applications such as plastic lumber, different types and grades of plastic cannot be blended together to form a product.

What is collected affects processing costs and potential revenue. If several different types of plastic are collected, they must be separated downstream. Even if only HDPE were to be collected, separation into HDPE grades is necessary. Separation of plastics is not easy because different resins and grades are difficult to tell apart. Communities, interested in maximizing revenue and minimizing processing costs, may decide to collect only one high revenue producing plastic such as milk jugs, thereby also reducing the amount of plastics destined for recycling.

4.1.2 Processing

4.1.2.1 Overview

Processing is the link between collection of materials and their use in manufacturing. Plastics normally undergo two distinct processing steps: first, separation from other materials and plastics; and second, cleaning and at times, additional separation and processing to meet certain end market specifications. Additional processing, while increasing costs, increases the value of the material and the size of potential end markets.

Depending on the collection method and end market specifications, a variety of different processing configurations can take place. Plastics collected through curbside collection programs are usually sorted from other materials at Intermediate Processing Centers (IPCs), also known as Materials Recovery Facilities, or MRFs ("merfs"). MRFs are either publicly or privately owned. Twenty seven MRFs currently process HDPE bottles, and another 58 are planning to do so (Salimando 1990).

MRFs sort recyclables by material type (glass, newsprint, aluminum, plastics, etc.). If more than one type of plastic is collected, they are usually separated according to resin type; for example PET is separated from milk jugs and laundry detergent bottles. HDPE may be further separated according to color; for example milk jugs can be separated from laundry detergent bottles and other colored HDPE (Egosi 1989 and PRF 198?a and 198?b).

Plastics are then baled or shredded and sent to Post-Intermediate Processing Centers (post-IPCs) for additional processing. Depending on the condition of the material received and the specifications of the end market, the material can be cleaned, separated by resin type and color, granulated or pelletized and upgraded. Post-IPC processing facilities are small privately owned companies -- such as Eaglebrook Plastics (IL) and Partek Corp. (WA).

Brokers sometimes act as intermediaries between IPCs and post-IPCs, and between post-IPCs and end product manufacturers.

Semi-integrated manufacturers are another important part of the processing infrastructure. Semi-integrated manufacturers buy plastics scrap, process it and make an end product with it. In the case of PET, Wellman, Inc. is the most noteworthy company of this type. HDPE semi-integrated manufacturers -- such as Mid-West Plastics and United Resource Recovery -- are pipe manufacturers (Mt. Auburn Associates 1989).

Large resin producers are new entrants to the recycling infrastructure. Responding to pressure from increased regulation of plastics, resin producers have formed joint ventures with large waste haulers; the waste haulers will collect the plastic, while the resin producers will process and sell it. The Du Pont Company/ Waste Management Inc. and Dow/wTe offer two examples of such joint ventures. Since most of these recycling efforts are in the planning stages, the impact they will have on HDPE markets is unknown. These integrated ventures could pave the way to the creation of a formidable collection and processing infrastructure through which large quantities of post-consumer plastic will be recycled. Through the use of proprietary upgrading technology, they could offer higher quality recycled resins, thereby opening new markets. These have been well-publicized but large-scale collection efforts are yet to be seen. Announcements of joint ventures do not guarantee long and productive business partnerships. For example, a highly publicized plastics recycling joint venture between Dow Chemical and Domtar, after two years of announcements and planning, recently dissolved. And, a project announced in January 1990 by Waste Management Inc. and the Jefferson Smurfit Corp., the largest buyer of secondary paper in the United States, had fallen apart by April (Recycling Times 1990; Brewer 1990b; and Ruston 1990).

4.1.2.2 Types of Processing

Separation by Material Type

At MRFs, materials are usually hand sorted according to material categories. Some MRFs also use mechanical separation equipment. Metals, for example, may be magnetically separated; eddy currents remove aluminum cans; plastics are separated from glass by density separation methods.

Because plastics are so light, the number of pieces that must be sorted through to attain significant bulk is larger than for any other material. This factor slows processing rates and increases processing costs (CSWS/Gold 1989a). For this reason, communities are particularly reluctant to collect plastic film, which has the least bulk density of all plastics.

Separation by Resin Type

If more than one type of plastic is collected, plastics must be separated by resin type (unless they are to be used in low quality mixed plastics applications).

While some plastics are easily recognizable by look or feel -- such as the PET soda bottle and the milk jug -- many plastics are very difficult to tell apart. For certain applications, HDPE and polypropylene look and feel very similar (PIA/Sutherland 1989a). Finesse bottles its shampoo in almost identical looking plastic bottles; one is made of PVC, the other HDPE. Tropicana's orange juice bottle looks like an HDPE bottle but is made of multi-resin material (Holeman 1990). Some programs choose only to collect PET soda bottles and HDPE milk jugs to avoid the complication of sorting hard to identify plastics.

To facilitate the manual sorting of plastics by resin type, the Society of the Plastics Industry (SPI), a trade organization, has developed a coding system. The code, a triangle formed by three arrows around a number identifying each resin type, is to be stamped on the bottom of packaging items such as bottles, containers and bags (see Figure 1.2 for a diagram of the codes). About 16 states have adopted this coding

FIGURE 1.2

SPI CODING SYSTEM

CODE	MATERIAL	% OF TOTAL BOTTLES
1 PETE	Poly-Ethylene Terephthalate (PET)*	20-30%
2 HDPE	High Density Polyethylene	50-60%
3 V	Vinyl / Polyvinyl Chloride (PVC)*	5-10%
4 LDPE	Low Density Polyethylene	5-10%
5 PP	Polypropylene	5-10%
6 PS	Polystyrene	5-10%
7 OTHER	All Other Resins and Layered Multi-Material	5-10%

**Stand alone bottle code is different from standard industry identification to avoid confusion with registered trademarks.*

SOURCE: SPI 1989a

system or coding systems of their own (SPI 1989a and CSWS 1989c). The SPI codes have caused some controversy in that the three arrow triangle, a symbol of recycling, gives consumers the impression that plastics are being recycled when in fact few are.

In addition to hand sorting, mechanical methods can be used which separate plastic resins on the basis of their densities or electrical properties. Float-sink methods take advantage of the fact that because resins have different densities, some float and others sink in water; HDPE, LDPE and PP with densities less than that of water are floaters, while PVC, PS and PET are sinkers. The floaters can be further separated by mixing water and alcohol in different concentrations (Holman 1972).

Other separation methods include air classification, centrifugal separation (using a hydroclone) and electrostatic separation (PIA 1989b). Ideally resins could be identified by an optical reader. Such technology has not yet been developed at a commercial scale.

Once separated by resin type, each resin can be separated by grade. For example, milk jugs and base cups are two different grades of HDPE. Separation by grade is done manually; no mechanical method exists.

Finally, resins can be separated by color. Clear milk jugs are often separated from mixed color HDPE which has a lower value. This separation is also done manually.

Additional Processing

The amount of additional processing required depends on the specifications of the end market. Plastics can be cleaned, granulated, pelletized and/or upgraded. Cleaning involves washing as well as the removal of labels and metal contaminants. Labels are removed by washing or by electrostatic processes while metals are removed with the use of magnets (Holman 1972; Grubbs and Ivey 1972; and PIA 1989b).

In order to be fed back into a manufacturing process -- an extruder or molder -- plastics must be granulated or pelletized. Pellets are of a standard and uniform size, which allow them to flow more uniformly than granulated resin, or "flake."

Recompounding, the art of changing or upgrading a resin's properties through the use of additives, often allows it to be used in more demanding applications.

Tertiary recycling, the breakdown of resins into their chemical components (such as what is done for PET) is technologically feasible but in the case of HDPE, too costly (Sacks 1990).

4.2 END MARKETS

Because end markets will be discussed at length in this analysis, only a brief description is required at this point.

4.2.1 Product Manufacturers

Plastics manufacturing is the process in which resins are converted into an end-product through the use of extruders, injection molders, blow molders and other equipment. The plastics manufacturing industry is highly decentralized with an estimated 18,061 plastics manufacturing facilities in 1986. This decentralization is due to the fact that there are few barriers to entry; plastics manufacturing is not a highly technical process and doesn't require the purchase of expensive manufacturing equipment. Thousands of plants have been set up to produce everything from cocktail swizzle sticks to automotive parts. Some of these plants process plastic products for captive use. For example, many dairy companies own their own blow molding equipment to manufacture milk jugs (Rauch Associates 1987).

Because this industry is highly decentralized (in contrast to, for example, aluminum can manufacturing), increasing the use of recycled resins, to any large degree, means gaining the acceptance of thousands of manufacturers. An eventual plastics recycling goal may be the development of off-the-shelf recycling systems for plastics manufacturers. Granulators, pelletizers, extruders, conveyers and screen changers bought by end product manufacturers are being modified to handle post-consumer scrap (Toensmeier 1989).

4.2.2 Export Markets

Exporting is an alternative for low quality recycled resins which cannot be sold in domestic markets. Post-consumer plastic film, for which there is little demand in the U.S., has largely been exported. Recycled plastic is sold to plastics manufacturers in developing countries who cannot compete on world markets for virgin resin. The older, more tolerant equipment used by these manufacturers and the less demanding end products manufactured can more readily handle recycled materials (Brewer 1988). Until recently, China had been purchasing large amounts of recycled HDPE from the US. As a result of currency shortages and recent political turmoil, this market has dried up, at least temporarily.

Plastics recycling programs have been highly dependent on the availability of export markets. Seattle stopped collecting most types of plastics when an export agreement with Thailand fell through (Smith 1989). The development of a robust infrastructure capable of processing high quality recycled resins will diminish reliance on foreign markets.

5.0 CONCLUSION

This general overview of resins, manufacturing processes and the HDPE recycling infrastructure has laid the groundwork for a deeper exploration of issues that affect the development of end markets for HDPE.

CHAPTER 2

MARKET DEVELOPMENT ISSUES FOR RECYCLED HDPE

1.0 INTRODUCTION

Markets for post-consumer recycled HDPE exist. Pipe, flower pot, base cup and plastic lumber manufacturers have been relying on post-consumer recycled HDPE as their basic feedstock for some time. These markets, however, are not large enough to absorb a substantial portion of the approximately 3.5 billion lbs. of HDPE packaging discarded each year.

To expand markets for recycled HDPE:

1. A high quality recycled resin supply must be guaranteed that can be economically competitive with virgin resins,

2. Product standards which limit the use of recycled HDPE for reasons other than performance specifications must be removed, and

3. Manufacturers and their customers must become more willing to use recycled resins in their products.

2.0 THE QUALITY OF RECYCLED HDPE

Getting beyond low quality, or what Michael Twomey of MA Industries refers to as "dead end," markets is key to expanding HDPE recycling. The more readily recycled resins can be substituted for virgin resins, the more valuable they become and the larger are the number of end uses in which they can be absorbed.

Four factors which affect the quality of recycled HDPE are:

* All HDPE is not alike
* Contamination
* Color
* Additional heat history

2.1 ALL HDPE IS NOT ALIKE

Delve into the phenomenon "plastic" and you find an array of different materials: the smooth, crystal clear PET bottle; the translucent HDPE milk jug; the fibrous polypropylene of a ski jacket; and the hard durable ABS telephone.

Delve into the phenomenon "HDPE" and you find the light, rigid milk jug; the flexible, firm laundry detergent bottle; the crinkly film of a grocery sack; the hard but brittle base cup; and the solid, sturdy milk crate.

The properties of a plastic determine whether it will suit a particular application; how it will behave under various conditions (i.e. impact and exposure to heat, cold and chemicals) and its physical appearance (i.e. stiffness, hardness and opacity). One characteristic particularly unique to plastic is that its properties can be easily modified by combining different resins and by using additives such as fillers and plasticizers. HDPE is often copolymerized with other monomers to increase, strength, flexibility or environmental stress crack resistance (ESCR)-- a measure of resistance to environmental factors, particularly chemicals. Laundry detergent bottles, for example, are made of a copolymer material which gives them added ESCR (Sacks 1990).

A manufacturer, in determining the type of resin appropriate for a particular application, takes into account the (unfortunately pre-disposal only) life cycle of the application. A trash can that is likely to be used to lift heavy trash must have tensile strength. An auto fuel tank must be resistant to impact, chemicals and high temperatures. A bleach container should be rigid, resistant to chemicals and should not break if dropped. A tray would be useless if it sagged; it needs good tensile strength. To attain certain properties, trade-offs are required; for example, using a plastic with high impact strength often means sacrificing stiffness (Bentley 1990; Sacks 1990; and Twomey 1990).

Polyethylene plastics are identified primarily on the basis of two properties, namely density and melt index (also known as flow rate) (ASTM 1989a). If the density and melt index of HDPE is known, other properties such as tensile and impact strength, environmental stress crack resistance and rigidity can be determined. ASTM´s specification for polyethylene materials (ASTM Specification D1248-84) -- widely adhered to by manufacturers of polyethylene resins and products -- categorizes HDPE according to Types, or densities, and Categories, or melt indexes (see Table 2.1).

TABLE 2.1

DENSITY TYPES:

Type	Nominal Density g/cm3	Application
I	.91 to .925	
II	.926 to .94	
III	.941 to .959	detergent bottles
IV	.960 and higher	milk jugs

Types III and IV are high density polyethylene. Most HDPE bottle resin has density of .955-.965 (Technomics Consultants 1981).

MELT INDEX CATEGORIES:

Category	Nominal Flow Rate g/10 min. (a.k.a. Melt Index)	Process	Application
1	>25	IM	Base cups
2	>10-25	IM	
3	>1 to 10	IM	Crates
4	>.4 to 1	BM/EXT	Milk jugs
5	.4 max	BM/EXT	Detergent bottles

Source: ASTM Specification D1248-84

2.1.1 **Density**

Density, or specific gravity, is defined as weight per unit volume. Increasing the density of HDPE increases its tensile strength, stiffness and hardness and decreases impact strength. Changes in density also affect chemical resistance, opacity, and permeability. (*Modern Plastics Encyclopedia '89* 1988 and Technomic Consultants 1981).

As discussed in Chapter 1, density plays an important role in the separation of recycled resins. Water has a density of 1 g/cc. PE and PP with densities less than 1 will float on water,

PS, ABS, PVC and PET are denser than water and will sink.

A simple quality control check for manufacturers purchasing recycled HDPE flakes is to toss a few handfuls into water.

Sinking flakes indicate potential contamination with other types of plastic. While small amounts of LDPE and PP (floaters) can often be tolerated, small amounts of PVC (a sinker) can render an entire batch of HDPE useless (Christiansen Associates 1990c).

2.1.2 **Melt Index**

While melt index is a relatively unimportant phenomenon for processors of plastics such as nylon, HDPE manufacturers "live and die by melt index" (Smith 1990). The melt index is a measure of the flow rate of a polymer in the melt form. It describes how viscous a material is -- a high melt index correlates to a low value of viscosity, -- how it will fill the mold and how quickly it will harden. It is related to average molecular weight, toughness and environmental stress crack resistance (ESCR). A low melt index resin has a high ESCR, making it suitable for applications such as drums or bottles which hold chemicals or applications exposed to the elements such as pipe (Ray 1987; *Modern Plastics Encyclopedia '89* 1988; Sacks 1989; and Sacks 1990).

Most importantly, melt index is the property which determines how HDPE can be processed, whether by blow molding, extrusion or injection molding. Blow molding requires a viscous material that will become stiff immediately and hold together so that it can be blown. Extrusion requires a similar material which will hold its shape immediately upon exiting the die. A "fractional melt" (a melt index of less than 1), which melts at a low temperature, and therefore sets quickly, is required for these processes. Injection molding, on the other hand, requires a runny high melt index (2-100) resin which will quickly fill a mold and spread to intricate parts and crevices. Fractional melt HDPE could not be used for injection molding because it would harden before it could fill a mold and would not relax enough; thereby causing stress cracks to form. In addition, cycle times for injection molding would increase, thereby reducing economic efficiency (Schedler 1989; Curry 1990; Tomazak 1990).

Within each grade -- blow, molding, extrusion and injection molding -- there are a range of melt indexes. While milk jugs have a melt index of .75, laundry detergent bottles have a melt index of .35 and drums, .1-.3 (see Table 2.2 for a comparison of Properties of Blow Molded Applications). For high production rate injection molded applications such as base cups and margarine tubs, a high melt index of about 30 is required. For thick-walled items, such as milk crates, an 8-10 melt index is necessary (*Modern Plastics Encyclopedia '89* 1988; Sacks 1989; and Schedler 1989).

TABLE 2.2
Properties of HDPE Blow Molded Applications

APPLICATION	drums	detergent bottles	milk jugs
ASTM Type/Cat	II, 5	III, 5	IV, 4
MELT INDEX	<0.1	.35	.75
VISCOSITY	low	med	high
STIFFNESS	low	med	high
ESCR	high 800	medium 45	low 15-20
MOL WT.	high	med	low
DENSITY	.94	.95	.964

Sources: Sacks 1989 and Modern Plastics Encyclopedia ´89 1988

Identification of markets for recycled HDPE depends in large part on its melt index. Blow molded bottles can most readily be used in either blow molded or extruded applications. Base cups which are injection molded can only be used in injection molded applications.

Combining different melt index HDPE grades produces a compromise melt index according to a logarithmic formula. Different melt indexes can be attained by combining different grades of recycled HDPE or by combining recycled

HDPE with virgin. Although some post-consumer blow molded HDPE, for example milk jugs, can be combined with a virgin or recycled injection molding HDPE to produce an injection molding grade (particularly for thick-walled injection molded items), doing so would be economically inefficient Blow molding and extrusion grades are even more restrictive; they cannot be contaminated with more than small amounts of injection molding resin, closing off large markets to injection molded post-consumer HDPE (Technomics 1981; Sacks 1990; Tomazak 1990).

Combining different grades in this ad hoc way produces "wide-spec" resins with unknown properties. Higher quality control can be guaranteed by sorting items according to melt index. Because all milk jugs, for example, have uniform properties, recycled milk jugs will have consistent, uniform, tight (rather than wide) spec properties. These sorted, tight spec recycled resins, will be closer to virgin in their properties and will be a known quantity, enabling them to be targeted for specific applications as a replacement for virgin resins (Sacks 1990 and Schedler 1989). For example, laundry detergent bottles (with a melt index of .35), rather than milk jugs (with a melt index of .75), should be used in corrugated pipe (with a melt index of .45). If milk jugs were to be used, they would have to be combined with other, lower melt index resins -- either recycled drums or virgin material -- to attain a suitable melt index (Fish 1990a).

Several companies, known as custom compounders, blend different resins and different resin grades to meet customer specifications and production needs. These custom compounders use compatibilizers to prevent the mixture of resins from "unzipping." (Different types of plastics, like oil and water, tend not to mix.) This technology could become more important for plastics recycling in the future (*Plastics Technology* 1989).

2.2 CONTAMINATION

In the context of plastic recycling, contamination means much more than dirt. In addition to becoming soiled through normal use and when mixed with other solid waste, contact with numerous other contaminants affects a plastic product's recyclability.

Plastic tends to absorb materials with which it comes into contact. Rancid milk and soap residues in bottles are very difficult to remove and very unpleasant to work with (Selke 1989a). Removing automotive oil from oil bottles requires a special cleaning process. Because many bottles are used to package toxic substances -- or through their life cycle can come into contact with and absorb these substances -- the Food and Drug Administration (FDA) requirements essentially preclude the use of recycled resin in food and drug contact applications.[1] For this reason, toy manufacturers may be reluctant to use recycled resins. Care must also be taken to protect recyclers from handling containers that contained hazardous substances (PIA/Sutherland 1989a).

Contamination of recycled resin with foreign materials -- particularly metals -- can damage processing and manufacturing equipment (Buekens 1977). Contamination with paper labels can clog screens and filters, significantly slowing processing rates.
Contamination with foreign materials such as paper, ink and other types of plastic diminishes the functional and aesthetic quality of the final product. Reliable separation methods are therefore critical to any recycling process. If plans to introduce a PE film, rather than paper, in-mold label are implemented, paper contamination problems will be reduced. PE labels will also allow industrial scrap to be more easily recycled (PIA/Leaversuch 1989a). Bottle caps -- often made of LDPE and PP -- can only be tolerated in very

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[1]Soudronic AG of Switzerland claims that it is developing a machine which could determine everything that has been in the bottle prior to washing. If successful, reusable PET bottles could become a possibility (Larson 1987).

small quantities. Even caps made of HDPE are problematic because they are injection, rather than blow molded. Finally, the presence of degradable packaging in sufficient quantities, can produce a product which will fall apart. In addition, corn starch used in biodegradable plastic becomes scorched during reprocessing.

Pelletization, a 450 degree fahrenheit heating process, can destroy bacterial contaminants (Cofield 1990). However, not all recycled plastic is pelletized.

The amount of contamination that can be tolerated varies for each end product. Thick-walled or low quality products such as flower pots can handle larger amounts than can thin films which show every impurity (Buekens 1977 and Bennett 1988).

The benefits of obtaining an additional unit of purity must be weighed against its costs. A contaminant-free post-consumer resin, even if technologically feasible, would not be economically practicable.

2.3 COLOR

Mixing together the spectrum of brilliantly colored plastics, produces a color that is described as "drab olive," "khaki," or "muddy brown." Mixed color recycled resins can, therefore, only be used in applications for which color is not an important factor. Since many plastics applications are brightly colored, the use of mixed color resins is often limited to applications such as pipe, pallets, base cups, flower pots, internal parts and more recently, the center layer of bottles.

More markets are open to natural, unpigmented milk jug resin which sells for several cents a pound more than mixed color resin. The recycled natural resin is somewhat dingier than the virgin resin, but can be used in beige, grey, brown and even blue and green products. Reds, yellows and whites are difficult or impossible to achieve (Brewer 1990b).

To maximize the value of the resin, milk jugs and mixed color HDPE bottles must be hand sorted, an expensive undertaking. Municipalities, therefore, often choose to collect milk jugs only because they are easily identified and because of higher revenues received for them.

2.4 ADDITIONAL HEAT HISTORY

During recycling processing, plastics undergo exposure to heat. While for most plastics this additional heat history could cause a significant loss of properties, HDPE is highly amenable to reprocessing as long as care is taken to ensure that temperatures do not exceed certain limits (Fish 1990a). Tests comparing virgin and recycled resins show no effect on properties such as melt index and tensile strength, although impact strength and elongation at break (the extent to which plastics can be stretched without breaking) are affected somewhat (Pattanankul, et al. 1988). HDPE's ability to maintain its properties during additional processing is the primary reason that it is (along with other polyethylenes) the most recyclable resin, allowing it to be recycled over and over again (estimates range from 8 to 35 times). After a certain point, however, significant degradation does occur resulting in a loss of mechanical properties (Buekens 1977).

Recompounding can prevent degradation and even upgrade a resin's properties allowing it to be used in more demanding applications. Recompounding technologies for HDPE are expensive and for the most part, not economically viable. Du Pont, Dow and Union Carbide, however, have announced that they plan to recompound HDPE. Whether recompounded recycled HDPE will open up new markets or will be able to maintain a price advantage over virgin HDPE remains to be seen (Christiansen 1990a and Sacks 1990).

2.5 GETTING BEYOND LOW QUALITY APPLICATIONS: ENHANCING THE QUALITY OF RECYCLED RESINS

The quality of post-consumer HDPE can be enhanced through:

1. Substantial washing.
2. Sorting HDPE from other resins such as LDPE, PVC and PS.
3. Separating different grades of HDPE according to tightly defined properties, in particular, narrow melt index ranges.
4. Separating HDPE by color into natural and mixed color resins.
5. Recompounding through the use of additives.

For each level of quality achieved, the cost of getting there increases. Broader markets are open to higher quality resins, however, the costs of achieving higher quality may be prohibitive. The trade-off between cost and quality will be examined in the next section.

3.0 VIRGIN PRICE INSTABILITY AND RECYCLED HDPE MARKETS

In 1988, HDPE recyclers had no trouble finding end markets; their main challenge was ensuring a stable supply. By early 1989, the situation had reversed; recyclers were gloomy about the future of HDPE recycling -- markets dried up as many manufacturers no longer expressed interest in buying recycled HDPE. By the end of 1989, manufacturers were "knocking down the doors" of HDPE recyclers, scrambling to get contracts for the delivery of recycled resins. It is likely that in the near future, demand will fall once again. What causes the volatility of recycled HDPE markets?

In recent years, large shifts in virgin resin capacity have caused constantly fluctuating virgin resin prices. Recycled resin sales are extremely sensitive to virgin resin prices. When virgin prices drop below a certain level, it is no longer beneficial for a manufacturer to buy lower quality resins and he will switch to virgin resins. When virgin prices rise, demand for recycled HDPE can skyrocket. It is generally believed that recycled resin must be 33% to 50% less expensive than virgin resin before it will be considered an economically viable alternative by manufacturers (OTA 1989). The precise figure is probably not known, would be based on the quality of the recycled resin and would vary from end-market to end-market depending on the contribution of resin cost to total operating costs.

3.1 PRICE VOLATILITY OF VIRGIN RESINS

HDPE recycling was born in the period -- mid 1980s to 1988 -- of extremely tight virgin resin supplies. During this period, prices for virgin resins increased dramatically. Ethylene, the monomeric constituent of HDPE, was also in tight supply. Plants were operating at 97% capacity, an extremely high rate for the industry (*Modern Plastics* 1989c). (It is speculated that dangerous conditions resulting from high operating rates were the major cause of several recent plant explosions. See below.) It takes several years to add new capacity. In the meantime, an HDPE recycling industry was established which was able to compete on an economic basis with virgin resins, particularly in low quality end markets.

In early 1989, however, significant capacity expansions (of both HDPE and ethylene) began to come on-line resulting in falling virgin prices and reduced demand for recycled resins. Capacity utilization rates fell to 85%. Within a period of several months, virgin prices for large volume orders dropped 10%-20% from over $.50/lb. to $.43-$.47/lb., their lowest level in two years (Greek 1988; Leaversuch 1988b and 1989a; Agoos 1989 and *Modern Plastics* 1990a). Recyclers were predicting hard times for recycled HDPE which could no longer maintain a significant price advantage over low virgin prices.

In addition to increased supplies, diminishing virgin prices were also the result of reduced demand. Rising prices had caused some manufacturers to switch from HDPE to other resins such as polypropylene (Agoos 1989). In 1989, in the face of falling resin prices, manufacturers began eating into the large inventories built up during the period of rising prices (Agoos 1989). Lastly, export markets, particularly the Chinese market, tightened. China, which had been buying about 1 billion lbs. of virgin PE a year (and at a rate of 2.2 billion lbs. a year in the first half of 1988) at prices well above U.S. levels, largely pulled out of the market because of currency shortages and recent political turmoil (Kiesche 1989; *Modern Plastics* 1989e; and Wood 1989).

Then, in October 1989, an explosion occurred at a Phillips 66 Company HDPE plant in Texas, killing 23 workers and eliminating the source of almost 20% of virgin HDPE supplies. Price increases of \$.03-\$.05/lb. were announced in November. Adding to the impact of the explosion at

Phillips were other smaller PE explosions at Quantum and Mobil (*Modern Plastics* 1989c). It is estimated that the HDPE producing industry would have to run at 108% capacity to maintain pre-explosion production levels (Meade 1989).

Blow molders, rotomolders and pipe extruders -- the major markets supplied by Phillips -- will most likely feel the effects through higher prices and tight supplies. While supplies to major markets such as milk and household and industrial chemical (HIC) bottles is assured (albeit with higher prices), small manufacturers of such items as housewares and toys will likely be hurt by the supply crunch (*Modern Plastics* 1989c and 1990a). The result has been unprecedented demand for recycled HDPE. Manufacturers have been scrambling to get whatever recycled HDPE they can get their hands on.

In the future, virgin resin prices could be expected to fall once again. Phillips expects its plant to come back on line in mid-1990 and further capacity expansions are expected through the early 1990s. These expansions could increase polyethylene capacity (including LDPE) by up to 4.4 billion lbs., a 22% increase over 1989 levels (*Modern Plastics* 1990b and Wood 1989). The recycled HDPE resin market could once again be adversely impacted. However, the effects may be less serious because the HDPE recycling industry will likely be more established and therefore less sensitive to falling virgin prices.

In addition to changes in capacity and demand, virgin prices are sensitive to gas and oil prices which are likely to increase in the future (Toensmeier 1988).

3.2 RECYCLED RESINS PRICES

Recycled resins prices float in a general relationship to virgin resin prices. The level at which they float varies depending on the cost of virgin resins. When virgin prices drop, the level increases because recycled resins can't drop below the cost of processing.) In February 1990, HDPE reprocessed pellets floated at 60%-70% of virgin prices and post-consumer milk jug flake at about 50% of virgin prices ($.05/lb. less for mixed color). With virgin priced at almost $.50/lb., reprocessed pellets have recently been selling for $.32/lb., cleaned natural flake for $.25/lb., and cleaned mixed color flake for $.20/lb (Christiansen Associates 1990e). (See Table 2.3 and Figure 2.1 for recent price history.)

FIGURE 2.1

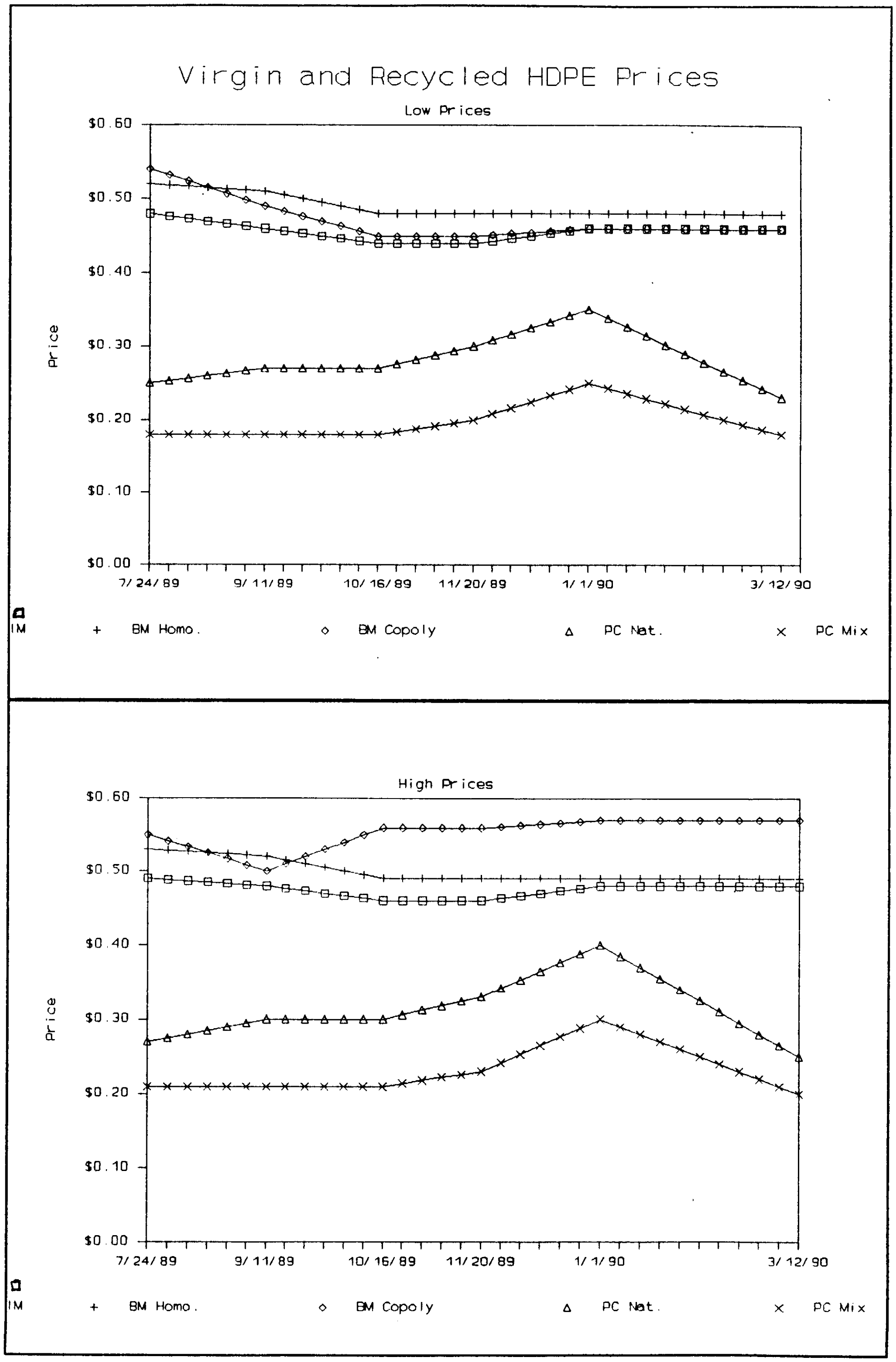
Virgin and Recycled HDPE Prices
Low Prices
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
Price
7/24/89
9/11/89
10/16/89
11/20/89
1/1/90
3/12/90
+ BM Homo.
◇ BM Copoly
△ PC Nat.
× PC Mix
High Prices
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
Price
7/24/89
9/11/89
10/16/89
11/20/89
1/1/90
3/12/90
+ BM Homo.
◇ BM Copoly
△ PC Nat.
× PC Mix

TABLE 2.3: RECENT VIRGIN AND RECYCLED HDPE PRICES

		7/24/89	9/11/89	10/16/89	11/20/89	1/1/90	3/12/90
VIRGIN							
Injection Molding Grade	Low	$0.48	$0.46	$0.44	$0.44	$0.46	$0.46
	High	$0.49	$0.48	$0.46	$0.46	$0.48	$0.48
Blow Molding Grade							
Homopolymer (Milk)	Low	$0.52	$0.51	$0.48	$0.48	$0.48	$0.48
	High	$0.53	$0.52	$0.49	$0.49	$0.49	$0.49
Copolymer (HIC)	Low	$0.54	$0.49	$0.45	$0.45	$0.46	$0.46
	High	$0.55	$0.50	$0.56	0.56	$0.57	$0.57
RECYCLED							
Natural Post Consumer	Low	$0.25	$0.27	$0.27	$0.30	$0.35	$0.23
	High	$0.27	$0.30	$0.30	$0.33	$0.40	$0.25
Mixed Color Post Consumer	Low	$0.18	$0.18	$0.18	$0.20	$0.25	$0.18
	High	$0.21	$0.21	$0.21	$0.23	$0.30	$0.20

SOURCE: PLASTICS NEWS

Recycled resins are particularly sensitive to off-spec virgin resin prices which directly compete for the same low quality end markets (Off-spec resins are defective resins having anywhere from slight to rather large property variations from those of standard virgin resins.) Off-spec resin prices are also closely tied to those of virgin prices. In early 1989, as virgin resin prices began to fall, large quantities of off-spec HDPE were dumped onto the market by virgin resin producers, which contributed to the drying up of recycled HDPE markets (Schedler 1989).

Prices for recycled resins vary according to the type of the resin (natural or colored) and the quality of the resin, or the amount of processing it has undergone. Moving up the scale of quality from dirty bales to clean pelletized increases both the processing cost and the price received for the resin.

Table 2.4
Costs and Value Added for Processing Steps

	cost/lb.	value added price/lb.
Sorting	$.02-.03	$.03-.04
Baling :	$.03-.04	
Grinding:	$.03-.04	$.04-.08
Cleaning 1989 (Flake input/output)	$.10-.15	$.12-.20
Cleaning Proj. 1994	$.05-.07	$.06-.10
Pelletizing	$.05-.07	$.06-.10

Source: Christiansen Associates 1990e

Estimates on recompounding costs range from \$.06/lb. to \$.30/lb. (Christiansen 1990a; Scarola 1990; Twomey 1990). Recompounded recycled resin may therefore not be able to compete with virgin resin (Christiansen 1990a and Sacks 1990).

The establishment of a plastics recycling infrastructure will likely have an effect on recycled resin prices. While the costs of grinding and pelletizing should remain constant over the next few years, it is expected that improvements in cleaning processes plus competitive pressures will cut current cleaning costs by half within 5 years (Christiansen 1990e).

Other factors -- all relating to the quality issues discussed in the previous section -- affect the price of recycled resins. Capless bottles command a higher price than bottles with caps. Oil bottles, because they are more difficult to clean, are less valuable than laundry detergent bottles. Colored laundry detergent bottles are less valuable than natural milk jugs. Depending on how markets develop, laundry bottles may become more valuable than milk jugs because their high environmental stress crack resistance allows them to be more readily used in certain markets. As can be seen in Table 2.3, virgin copolymer prices are often more expensive than homopolymer.

The more perfectly virgin and recycled materials substitute for one another, the more important is a small change in their relative prices in affecting the amount of recycling. Very small price differences can be strongly felt by manufacturers who buy large quantities of the resin (Page 1981).

While clean recycled HDPE flake has recently been selling for about 50% of virgin, the price doesn't take into account the cost of collecting and separating the plastic waste, a service municipalities provide (Sherman 1989). This factor takes on less importance in light of the fact that municipalities are interested in the most economical disposal method. As long as collection, separation and other processing costs incurred minus the revenues from the sale of the recycled material is less than alternative disposal methods, recycling will be the most economical option. The decision to recycle should, however, also be based on criteria other than economics such as environmental quality issues. (For additional information on comparing the costs and benefits of waste disposal alternatives, see EDF 1985; ORDEQ 1986; Kordik 1987; CDM 1987; Seattle Solid Waste Utility 1988; Ruston and Kirshner 1988).

One factor that affects the plastics recycling industry in particular is that recycled plastic must compete with low priced virgin and even less expensive off-grade resins. Recycled aluminum, for example, does not face this problem. The negligible cost differential between virgin and recycled resins is one reason why plastics recyclers are trying to penetrate some metal and wood markets rather than compete with virgin resins in plastics markets (Selke 1988b and RIS 198?).

3.3 MARKET FAILURES AND OTHER FACTORS FAVORING VIRGIN RESIN

Several market failures and other factors give virgin resins a competitive advantage over recycled resins (Page 1981; Stavins 1990; and Tietenberg 1988). These factors include:

1. Recycled processing is more labor intensive than virgin production. High wage rates in this country make it difficult for any labor intensive industry to compete.
2. The price of virgin resin doesn't reflect environmental externalities. These externalities include the toxicity of the virgin resin production process (recycled resin processing can be toxic albeit much less so), the depletion of valuable resources such as oil and natural gas, oil spills and the cost of disposal. The cost of depleting scarce resources for use in plastic falls, to a

large extent, on future generations.

3. Large virgin producers have the financial resources to invest in technological improvements. These technological improvements tend to lower their costs.
4. Tax incentives in the form of depletion allowances are given to extractive industries which include the oil and gas industry.
5. Resin producing companies are oligopolies and can, to a certain extent, control the market and the price of resins. They do this by building up inventories during periods of low prices. On the other hand, the plastics recycling industry is characterized by many small companies that are not powerful enough to control the market and that are very susceptible to price fluctuations. The virgin resin industry has the power to manipulate prices and supplies to the detriment of the recycling industry. It can cut virgin prices to the point at which recycled resins cannot compete, or it can dump large quantities of off-spec material on the market, a situation that occurred in early 1989.
6. Due to their high bulk density, transportation costs are a higher percentage of recycled resins costs.

One factor favoring the recycled resin industry is that the virgin resin industry is much more energy intensive and energy prices are likely to climb in the near future.

The numerous factors favoring virgin resins are evidence of the fact that in order for recycling to succeed, government intervention will likely be needed. Government can correct many of these biases (some which they themselves have created) by removing depletion allowances; ensuring that environmental externalities are included in the price of virgin materials through such mechanisms as packaging and disposal taxes; taking biases against recycling (i.e. hidden subsidies to incineration and landfilling) into account when assessing disposal alternatives; supporting R&D in the recycling industry; and offering other types of financial assistance.

4.0 PRODUCT STANDARDS

Product performance and design standards often preclude or limit the use of recycled resins in various applications. These standards are set by federal, state and local governments and by trade organizations such as the American Society of Testing and Materials (ASTM). In addition, private companies, such as Procter and Gamble, and industries, such as the auto industry, set their own standards.

Whereas, for some applications, standards requiring the use of virgin resin are necessary for health and safety reasons, in other instances, there is no technical or performance reason for the requirement (Selke 1988b). Many of these standards were developed during a period when plastics were first being introduced for use in specific applications. For example, strict standards requiring the use of virgin resins in PVC pipe were made at a time when PVC pipe manufacturers were trying to penetrate the pipe market which was largely dominated by copper and the performance of plastic pipe was unproven. Such standards have not been re-evaluated and remain intact to this day.

4.1 GOVERNMENT STANDARDS

Government regulates the use of recycled materials in applications where their use could present a risk to health and safety or establishes the acceptability of recycled content in procurement guidelines. The most obvious example of the first type of restriction is the U.S. Food and Drug Administration (FDA) regulation which, although not specifically precluding recycled plastic from food and drug contact applications, requires that manufacturers guarantee that the materials they use are contaminant-free (Brewer 1990b). Because plastics easily absorb contaminants, manufacturers do not use recycled resins in food and drug contact applications which in effect, cuts off a large market segment to recycled resins and eliminates the possibility for developing a closed loop recycling system whereby, for example, milk jugs would be recycled back into milk jugs in much the same way that aluminum cans are recycled back into aluminum cans. New markets must therefore be found for recycled resins made from plastic food packaging.

Government procurement specifications often require the use of virgin materials, cutting off large potential markets for recycled materials. These specifications fly in the face of stated policies which are aimed at encouraging the use of recycled materials. Many of these standards are not based on performance criteria. Take, for example, corrugated drain pipe, a low quality pipe which is successfully made using 100% recycled HDPE. State departments of transportation follow American Association of State Highway and Transportation Officials (AASHTO) specifications which require the use of virgin resin in corrugated pipe. AASHTO shows no willingness to change its specifications to include the use of recycled resins (Christiansen 1990a).

While at least 23 states have enacted laws requiring state and local agencies to procure items made from recycled materials, and to review their procurement guidelines to eliminate existing specifications that unduly discriminate against recycled materials, most modifications have been for recycled paper (Kovacs 1988). Several years ago, however, the U.S. Soil Conservation Service (SCS) collaborated with a pipe manufacturer to modify its procurement specification for corrugated HDPE pipe to include the use of recycled resins (Christiansen 1990a). In another example, Du Pont and the Illinois Department of Transportation are cooperating in an effort to develop products from recycled HDPE which could meet procurement performance specifications (CSWS 1989b).

4.2 ASTM STANDARDS

The standards which potentially have the greatest impact on the use of recycled resins, other than FDA standards, are ASTM standards. ASTM, a large membership organization made up of manufacturers and industry representatives, sets standards and performance tests for materials and products. Although ASTM standards have no legal authority, they are widely adhered to by both plastics manufacturers and their customers as the performance criteria by which materials and products are evaluated. In ordering products from plastics manufacturers, clients often specify that the product meet certain ASTM standards. Government and other standards are often based on ASTM standards (Christiansen 1990a and

VandenBerg 1989).

ASTM standards have greatly limited the use of recycled resins. Despite the fact that post-consumer recycled resins could meet performance criteria for use in many products, ASTM standards -- such as those for corrugated pipe -- generally require that only virgin or rework (industrial scrap used within the original operation) be used. Most ASTM standards for polyethylene, however, are not application-based. ASTM specification D1248-84 which defines polyethylene grades (see Quality above) is used by manufacturers and their clients to specify the type of resin acceptable in a particular application. This standard does not mention the use of recycled resins and implies the acceptability of only virgin resin (ASTM 1989a).

The overly restrictive requirements for the use of virgin resin are largely ignored by manufacturers of pipe. However, in cases where ASTM or other standards requiring virgin are specified by a customer, manufacturers ignore the requirement at the risk of being sued by the customer. In addition, manufacturers that falsely claim adherence to ASTM and other standards requiring virgin resin, risk being sued by those manufacturers that abide by them.

To address the need for greater plastics recycling and in recognition of the fact that recycled plastics can meet performance criteria, ASTM has been working to broaden its standards to include the use of recycled plastics. Since 1987, ASTM has been in the process of developing a guidance for the use of recycled plastics. The draft guidance is being developed by a committee of resin producers, plastic product manufacturers, government officials and non-profit organizations (ASTM 1989b and VandenBerg 1989).

The guidance provides for the development of standards relating to the proper use of recycled plastics; clarifies recycling terminology; and addresses quality control including contamination, separation by classes and labeling. The guidance emphasizes the development of performance, rather than design, standards for the use of recycled materials. In other words, rather than requiring that a product be made from a specific material, the standard would specify the criteria (for example, density, melt index, etc.) the end product must meet (ASTM 1989b).

The draft guidance states that:

1. "Unless a specification or other standard specifically restricts the use of recycled plastic[2], and justifies the

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[2]Recycled material is defined in the guidance as post-consumer material and/or recovered material (those materials recovered or diverted from the waste stream, rather than those commonly reused within the manufacturing process).

restriction based on performance standards, then recycled plastic can be used as feedstock. It is not necessary to specifically mention in a specification or standard that recycled plastic can be used.

2. A specification or standard that currently restricts the use of recycled plastic , or implies the restriction by specifically mentioning the acceptability of reworked plastic (or other similar materials), should be promptly revised by the subcommittee which has the jurisdiction for the specification or standard. If the restriction is valid for known performance reasons, the justification should be stated. If the restriction cannot be justified by test data, it should be removed (ASTM 1989b)."

The draft guidance has been approved by several ASTM committees and has gone through a full vote of all ASTM members. Several opposition votes were cast and parts of the guidance will have to be revised. It is expected that these difference will be resolved in the near future and that the guidance will be passed in July 1990. Once approved, all plastics committees will review their specifications to determine the acceptability of recycled resins (Shaz 1990 and Smith 1990).

It is unclear the extent to which ASTM standards will be changed or what impact changes would have on increasing the use of recycled resins. However, the move to revise standards could influence manufacturers and their customers to consider using recycled resins and encourage agencies, organizations and industries to reassess their own standards.

5.0 MANUFACTURERS´ PERCEPTIONS

A major obstacle to expanding markets is that plastics manufacturers are reluctant to use recycled resins. Inconsistent quality and unpredictable supply of recycled resins have been the primary reasons for their hesitancy. In addition, most manufacturers are unfamiliar with recycled resins and are ignorant about the extent to which they can be used in certain applications. Many manufacturers are not given the flexibility to use recycled resins by their customers. Finally, manufacturers that do use recycled resins don´t admit it because even in applications where they can readily substitute for virgin resins, they are perceived as being inferior by customers and consumers (Bennett 1988; Selke 1988b; Mt. Auburn Associates 1989; Abt 1989; and Christiansen 1990a).

High quality and steady supply at low cost are necessary conditions for increased acceptance of recycled resins by manufacturers. Despite the fact that recycled resins are less expensive than virgin resins, many manufacturers do not feel that the lower price compensates them for the potential problems that the use of these resins could cause. Contaminants in recycled resins could clog machinery, slow production and cause defects in their products for which they would be held liable. In addition, unless they can be guaranteed a steady supply, manufacturers will not invest in adapting their processes for the use of recycled resins by purchasing equipment such as automatic screen changers, granulators and augers. These concerns are beginning to be addressed; supplies of recycled resins are growing due to mandatory recycling legislation and efforts are being made to improve quality.

While for many manufacturers concerns over quality are valid, for others, skepticism stems from ignorance. In general, manufacturers are unaware of new recycling technologies that can produce high-quality recycled resins and the extent to which properties of recycled and virgin resins are similar, at least for HDPE (Bennett 1988). Manufacturers think of recycled plastic as garbage and do not want to pay for it. Other manufacturers say recycling is just a phase which comes and goes (Twomey 1990). These attitudes are evidence that educating manufacturers is a crucial step in gaining acceptance for recycled resins.

A recent survey of over 125 plastics manufacturers in the state of Connecticut found that an overwhelming majority of manufacturers claim that they are not willing to use recycled resins. Some were manufacturers of military equipment, food packaging and cosmetic packaging, applications which for health and safety reasons, preclude the use of recycled materials. However, manufacturers of low quality applications also expressed the same reluctance. Their main reason for not being able to use recycled resins was that they did not meet performance and customer specifications. Perceptions that products made with recycled plastic are inferior in quality and a lack of supply were other reasons given (Mt. Auburn Associates 1989).

Despite claims of not being able to use recycled resins, when a subset of these same manufacturers were asked whether they would be willing to be contacted by recyclers selling recycled resins, 50% responded that they would. One possible conclusion that can be drawn from these seemingly inconsistent responses is that manufacturers do not know a lot about recycled resins but are open, even eager, to learn more about them. The use of recycled resins would offer these manufacturers a cost advantage in a very competitive industry.

Manufacturers, particularly custom molders, are largely constrained by their customer's specifications. If a customer specifies the use of virgin resins, an ASTM or other standard which requires the use of virgin, or a color such as red, yellow or white, a manufacturer has little leeway. Therefore, customers can make a large impact by requesting that recycled material be used in the products they order from manufacturers (Brewer 1988 and Brewer 1990b). Once Procter and Gamble made the decision to convert to bottles made of recycled plastic, bottle manufacturers quickly responded. At the same time, manufacturers can play a significant role by educating their customers on recycled resins and offering them recycled resins as an alternative to virgin. Sonoco Graham, a large bottle manufacturer, will be offering all their customers the option of bottles produced with recycled content.

Historically, manufacturers that do use recycled materials have been reluctant to publicize this to their customers for fear that their products may be perceived as inferior. One flower pot manufacturing company, riding the wave of recent environmental consumerism, recently advertised that it had been using recycled resin for 20 years, angering their customers who thought they were receiving a product made of virgin resins.

However, with growing environmental awareness, the use of the term "recycled" is becoming increasingly attractive (Abt 1989). In fact, the main reason why many large companies are using recycled resins is not for economic reasons but rather because they want to be able to claim that they are environmentally conscious (Rankin 1990). These claims are at times misleading. Some manufacturers who claim they are using recycled resins are using only small amounts or are using their own regrind which they had been using all along (Twomey 1990). As the number of abuses of environmental marketing grows, backlash from environmentalists, the media and government agencies is increasing (Holusha 1990).

PART 2

MARKET ANALYSIS

Now that the basic building blocks for an understanding of HDPE recycling have been established, we turn to an analysis of markets.

To determine whether HDPE recycling is viable, it is necessary to ascertain whether end markets exist for the material. Recycling is like a puzzle; each piece of post-consumer packaging collected must fit neatly into an end market. An understanding of the properties of each supply source and end use as well as the infrastructural, attitudinal and institutional constraints of each end use is necessary in order to match supplies with feasible end markets. Once the supplies and end markets are matched, the capacity for the end market to absorb the amount of post-consumer material generated can be assessed.

Part 2 consists of three Chapters:

Chapter 3, Sources of Supply, reviews each HDPE packaging application -- bottles, film, base cups, etc. -- to assess its recyclability. For each application, estimates are given for potential recovery rates through recycling.

Chapter 4, End Markets, reviews current and potential HDPE end markets -- bottles, pipe, base cups, plastic lumber, etc. -- which can absorb the post-consumer material discussed in Chapter 3. For each end market, estimates are given for potential demand for post-consumer HDPE.

Chapter 5, Market Assessment, pairs the potential recovery rates given in Chapter 3 with the potential demand given in Chapter 4 to determine whether sufficient markets are available to absorb the post-consumer HDPE that could be collected by 1993. Sensitivities, uncertainties and assumptions of the analysis are explained.

It is important to reiterate that this market analysis addresses the supply of and potential end markets for POST-CONSUMER RESIDENTIAL APPLICATIONS ONLY. Industrial scrap and post-consumer commercial scrap are dealt with only to the extent that they impact on the recycling of post-consumer packaging.

CHAPTER 3

SOURCES OF SUPPLY

1.0 INTRODUCTION

In 1988, 93 million pounds of post-consumer HDPE -- primarily bottles and base cups -- were recycled (Bennett 1990a). Other sources of post-consumer supply are film, ice cream containers, caps and other food containers, all of which have limited recycling potential.

This Chapter will describe each of these sources -- the quantities consumed and recycled; their properties; the end uses in which they can be absorbed; and any issues that impact their recyclability. Understanding the properties of each of these supply sources is critical in determining potential end markets.

For each source of supply, estimates for the amount of HDPE likely to be collected for recycling in 1993 will be given. These estimates are based on a recent study which claims that by 1991, 20% of all U.S. households will have curbside recycling programs (Modern Plastics 1989b). Since plastics will not be collected by most programs for several years after program start-up, estimates for plastics recovery rates are for 1993.[1]

Assuming a capture rate (a function of participation and set-out rates) of 75%, curbside recovery rates of all recyclable materials will be 15%. Since drop-off and buyback centers will provide other means of collecting post-consumer residential waste, I estimate that 25% of Americans will be recycling some types of materials (this figure does not include those recycling through deposit-refund systems, which, except for base cups, do not apply to HDPE).

The HDPE supply estimates begin with 713 million lbs. of potential supply. This figure represents the residential disposable HDPE consumed by the 25% of the population that will be recycling. It does not include non-collectable disposables such as trash bags and paint cans. Table 3.1 gives the amount of each collectable residential disposable HDPE supply source that is consumed by the recycling population.

Due to technical, end market and other constraints, less than 25% of the population will be recycling post-consumer residential HDPE. Many collection programs will not offer plastics collection; certain types of HDPE packaging (i.e. shampoo bottles and yogurt containers) are difficult to collect because they cannot be readily identified by the consumer as being made of HDPE; other types of HDPE (i.e. film) will not be collected in large quantities because their low volume to weight

[1] While recovery rates may rise above 25% between 1991 and 1993, the impact on plastics is not likely to be great.

TABLE 3.1: 1993 SUPPLY OF POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	POST-CONSUMER DISPOSABLES COLLECTED 1987	TOTAL RESIDENTIAL DISPOSABLES	NON-COLLECTABLE RESIDENTIAL DISPOSABLES	COLLECTABLE RESIDENTIAL DISPOSABLES	% POP THAT WILL RECYCLE****	COLLECTABLES CONSUMED BY RECYCLING POPULATION
BLOW MOLDING	0.1	0.8							
Bottles									
Milk Jugs**	0.75	0.75	720	20	720		720	25%	180
Other Food Bottles			320		320		320	25%	80
Household Chemical Bottles	0.3	0.5	732	13	732		732	25%	183
-Oil Bottles	0.3	0.5	224	2	224		224	25%	56
Pharmaceutical/cosmetics Bot	0.3	0.5	208	2	208		208	25%	52
Total Packaging Applications			2204	37	2204		2204		551
Drums (15 gal. & larger)	<0.1	0.3	154						
Fuel Tanks (all types)			96						
Tight-head pails			90						
Toys			70						
Housewares			51						
Total Non-Packaging Applications			461		0		0		0
Other Blow Molding			270						
TOTAL BLOW MOLDING			2935	37	2204	0	2204		551
EXTRUSION	<0.1	0.8							
Film	0.1	0.45							
Merchandise Bags			182		182		182	25%	46
Tee shirt sacks			215		215	215			
Trash Bags Institutional			124						
Trash Bags Consumer			15		15	15			
Food packaging/deli			110		110	110			
Multiwall sack liners			50						
Other Film			70						
Total Film (< 12 mil)			766		522	340	182		46
Pipe and Tubing									
Corrugated	0.45	0.45	103						
Water			59						
Oil & Gas Production			70						
Industrial/Mining			61						
Gas			112						
Irrigation			40						
Other			46						
Total Pipe and Tubing			491		0	0	0		0
Sheet (> 12 mil)			305						
Wire & Cable			146						
Coating	10	12.5	51		51	51			
Other Extrusion			36						
TOTAL EXTRUSION			1795		573	391	182		46
INJECTION MOLDING	2	100							
Food Contact Packaging									
Milk Bottle Caps			25		25		25	25%	6
Dairy Tubs			136		136		136	25%	34
Ice Cream Containers	25	30	85		85		85	25%	21
Other Food Containers	25	40	46		46		46	25%	12
Non-Food Contact Packaging									
Other Caps			56		56		56	25%	14
Beverage Bottle Bases***	30	30	122	26	122		122		29
Paint Cans			31		31	31			
Total Packaging Applications			501	26	501	31	470		116
Dairy Crates	6	20	56						
Other Crates, Cases, Pallets	6	20	120						
Pails	8	23	380						
Housewares			190						
Toys			78						
Other Injection			218						
TOTAL INJECTION MOLDING			1543	26	501	31	470		116
OTHER									
Rotomolding	5	20	122						
Export			830						
Other			890 *						
TOTAL OTHER			1842		0	0	0		0
GRAND TOTAL			8115	63	3278	422	2856		713

SOURCE MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 105 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
*** 1993 base cup supply and demand figures account for a 20% decline in base cup use
**** does not include deposit-refund programs

ratio makes collection and processing prohibitively expensive; while still others will not be collected due to a lack of demand by end-manufacturers.

Estimating the collection potential of each supply source begins with the amount of each supply source consumed by the recycling population (25% of the total U.S. population) presented in the last column of Table 3.1. This amount is multiplied by a collection probability to give the amount of the item that could be collected by 1993. (Refer to Table 3.2.)

To illustrate: milk jugs is the item most likely to be collected because they are in the greatest demand and are easily recognizable; I estimate that by 1993, 60%-80% of the recycling population will be part of collection programs that will be recycling milk jugs. Therefore, of the 180 million lbs. of milk jugs consumed by this population, 108 million to 144 million lbs. will be recycled. However, since 720 million lbs. of milk jugs are produced each year, 15% - 20% of all milk jugs will be collected for recycling. A smaller percentage of all other sources of supply will be collected for recycling.

TABLE 3.2: 1993 SUPPLY ESTIMATES FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	COLLECTABLES CONSUMED BY RECYCLING POPULATION	1993 SUPPLY OF POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE: LOW Collection Probability	LOW Amount	LOW as % of virgin sales	HIGH Collection Probability	HIGH Amount	HIGH as % of virgin sales
BLOW MOLDING	0.1	0.8								
Bottles										
Milk Jugs**	0.75	0.75	720	180	60%	108	15%	80%	144	20%
Other Food			320	80	5%	4	1%	20%	16	5%
Household Chemical	0.3	0.5	732	183	40%	73	10%	60%	110	15%
-Oil	0.3	0.5	224	56	10%	6	3%	33%	18	8%
Pharmaceutical/cosmetics	0.3	0.5	208	52	5%	3	1%	20%	10	5%
Total Packaging Applications			2204	551		193			299	
Drums (15 gal. & larger)	<0.1	0.3	154							
Fuel Tanks (all types)			96							
Tight-head pails			90							
Toys			70							
Housewares			51							
Total Non-Packaging Applications			461	0		0			0	
Other Blow Molding			270							
TOTAL BLOW MOLDING			2935	551		193			299	
EXTRUSION	<0.1	0.8								
Film	0.1	0.45								
Merchandise Bags			182	46	5%	2	1%	10%	5	3%
Tee shirt sacks			215							
Trash Bags Institutional			124							
Trash Bags Consumer			15							
Food packaging/deli			110							
Multiwall sack liners			50							
Other Film			70							
Total Film (< 12 mil)			766	46		2			5	
Pipe and Tubing										
Corrugated	0.45	0.45	103							
Water			59							
Oil & Gas Production			70							
Industrial/Mining			61							
Gas			112							
Irrigation			40							
Other			46							
Total Pipe and Tubing			491	0		0			0	
Sheet (> 12 mil)			305							
Wire & Cable			146							
Coating	10	12.5	51							
Other Extrusion			36							
TOTAL EXTRUSION			1795	46		2			5	
INJECTION MOLDING	2	100								
Food Contact Packaging										
Milk Bottle Caps			25	6	0%	0	0%	0%	0	0%
Dairy Tubs			136	34	0%	0	0%	0%	0	0%
Ice Cream Containers	25	30	85	21	0%	0	0%	10%	2	3%
Other Food Containers	25	40	46	12	0%	0	0%	10%	1	3%
Non-Food Contact Packaging										
Other Caps			56	14						
Beverage Bottle Bases***	30	30	122	29		29			29	
Paint Cans			31							
Total Packaging Applications			501	116		29			32	
Dairy Crates	6	20	56							
Other Crates, Cases, Pallet	6	20	120							
Pails	8	23	380							
Housewares			190							
Toys			78							
Other Injection			218							
TOTAL INJECTION MOLDING			1543	116		29			32	
OTHER										
Rotomolding	3	20	122							
Export			830							
Other			890							
TOTAL OTHER			1842	0		0			0	
GRAND TOTAL				715		225			336	

SOURCES:
MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
*** 1993 base cup supply and demand figures account for a 20% decline in base cup use
**** does not include deposit-refund programs

In summary:

Virgin resin used to produce milk jugs (million lbs.)	720
% recycling population	x25%
milk jugs consumed by recycling population	180

collection probability:	60% - 80%
collected by 1993:	108 million - 144 million lbs.
collection as % of all milk jugs:	15%-20%

****

Base cups are the only exception to this methodology; they are estimated to have a higher than 25% recovery rate because, for the most part, they are collected through deposit legislation and not curbside and drop-off collection programs.

This chapter describes the factors affecting the recyclability of each residential disposable source of supply that went into the estimates presented in Tables 3.1 and 3.2.

2.0 BLOW MOLDED DISPOSABLES

2.1 BOTTLES

Each year, over 2 billion pounds of virgin HDPE makes its way into bottles, making them the single largest supply source of post-consumer HDPE. Milk jugs and household and industrial chemical (HIC) bottles make up 33% and 43% respectively of the blow molded bottle market. The remaining 24% are other food bottles and pharmaceutical and cosmetic bottles (Modern Plastics 1990b).

2.1.1 Properties

Because the properties and other issues which affect the recyclability of these bottles were extensively covered in Chapter 2, only a brief overview is presently required.

The physical properties of milk jugs and HIC bottles are different. First, milk jugs are clear allowing them to be absorbed in a large number of end markets. HIC bottles, on the other hand, can only be used in applications in which color is not an important factor.

Second, milk jugs are made of pure or homopolymer HDPE, while HIC bottles are made of a copolymer resin (HDPE mixed with small amounts of other resins to enhance its physical properties). Milk jugs have a melt index (MI) of .75 and an environmental stress crack resistance (ESCR) of 15-20; HIC bottles has an MI of .35 and an ESCR of 45. What this means in layperson's terms is that the higher melt index material of milk jugs is more rigid and can be made into thin walled products; therefore it is less expensive to use. However, the plastic of HIC bottles have a higher ESCR which allows it to be more readily recycled into applications such as packaging for chemical products, pipe and drums (Sacks 1989 and 1990).[2]

A final difference is their smell. While post-consumer milk jugs have the odor of rancid milk, laundry detergent bottles smell like scented soap. Ironically, the rancid smell of milk jugs is easier to remove than the soap smell of laundry detergent bottles which often lingers even after processing (Twomey 1990).

Pharmaceutical and cosmetic HDPE bottles, such as shampoo bottles, have similar properties to those of laundry detergent bottles.

2.1.2 Recyclability

Milk jugs are the largest single type of container produced in the U.S. (Selke 1988a). Fortunately, of all HDPE applications, they are the most recyclable. They are easily identifiable by consumers and therefore can be easily collected. Because they are unpigmented and their properties are uniform, they are in the greatest demand by manufacturers and

---

[2]Companies such as Quantum will shortly release new "lightweighting" resins which can be used for thinner bottles without sacrificing ESCR. This is an important issue for source reduction. HIC bottles have always been heavier than necessary in order to maintain their firm feel. Eventually, thickness may be reduced by 15-20% (Rogers 1990a).

command the highest price. Currently there is far more demand for these bottles than there is supply. Approximately 20 million pounds, or 2.7%, of milk jugs were recovered in 1987 (Leaversuch 1988a). Of the 180 million lbs. consumed by the recycling population, I estimate that 60% to 80%, or 108 million to 144 million lbs., will be collected annually by 1993. This represents 15-20% of the 720 million lbs. of milk jugs produced. (Refer to Table 3.3 for blow molded supply estimates.)

Most HIC bottles -- particularly laundry detergent bottles and oil bottles -- are readily identifiable. Oil bottles are in less demand than laundry detergent bottles because they are harder to clean. Approximately 15 million lbs., or 1.6%, of HIC bottles were recovered in 1987 (Leaversuch 1988a). By 1993, since a smaller percentage of HIC bottles will be recovered than milk jugs, I estimate that of the 183 million lbs. of non-oil HIC bottles consumed by the recycling population, 40% - 60%, or 73 million to 110 million lbs. will be collected. This represents approximately 10%-15% of the 732 million lbs. of HIC bottles produced. The percent of oil bottles collected, will be somewhat less.

It is unlikely that significant quantities of pharmaceutical, cosmetic and other food bottles will be collected. These HDPE bottles are difficult to distinguish from bottles made of other plastic resins and are difficult to sort, thereby discouraging their collection by many communities.

TABLE 3.3: 1993 SUPPLY OF BLOW MOLDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX		VIRGIN	COLLECTABLES CONSUMED BY	1993 SUPPLY OF POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE					
					LOW			HIGH		
	LOW	HIGH	SALES 1989	RECYCLING POPULATION	Collection Probability	Amount	as % of virgin sales	Collection Probability	Amount	as % of virgin sales
BLOW MOLDING	0.1	0.8								
Bottles										
Milk Jugs**	0.75	0.75	720	180	60%	108	15%	80%	144	20%
Other Food			320	80	5%	4	1%	20%	16	5%
Household Chemical	0.3	0.5	732	183	40%	73	10%	60%	110	15%
-Oil	0.3	0.5	224	56	10%	6	3%	33%	18	8%
Pharmaceutical/cosmetics	0.3	0.5	208	52	5%	3	1%	20%	10	5%
Total Packaging Applications			2204	551		193			299	
Drums (15 gal. & larger)	<0.1	0.3	154							
Fuel Tanks (all types)			96							
Tight-head pails			90							
Toys			70							
Housewares			51							
Total Non-Packaging Applications			461	0		0			0	
Other Blow Molding			270							
TOTAL BLOW MOLDING			2935	551		193			299	

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

** includes milk, water, and juice jugs

2.1.3 End Markets

Milk jugs can be absorbed in all the blow molded and extruded end uses to be discussed in Chapter 4 except for film. These end uses include: HIC and toiletry bottles; corrugated pipe; blow molded pails, flower pots, trash cans, and toys; and plastic lumber. Whether they can be used in low or high quality end uses depends on whether they are sorted from other plastics and HDPE.

End uses for HIC bottles are similar to those of milk jugs. However, the amounts of HIC bottles and milk jugs that can be used in each of these applications differs due to the difference in their properties, particularly melt index, ESCR and color. (See Figure 3.1 for a diagram of end markets for milk jugs and HIC bottles.)

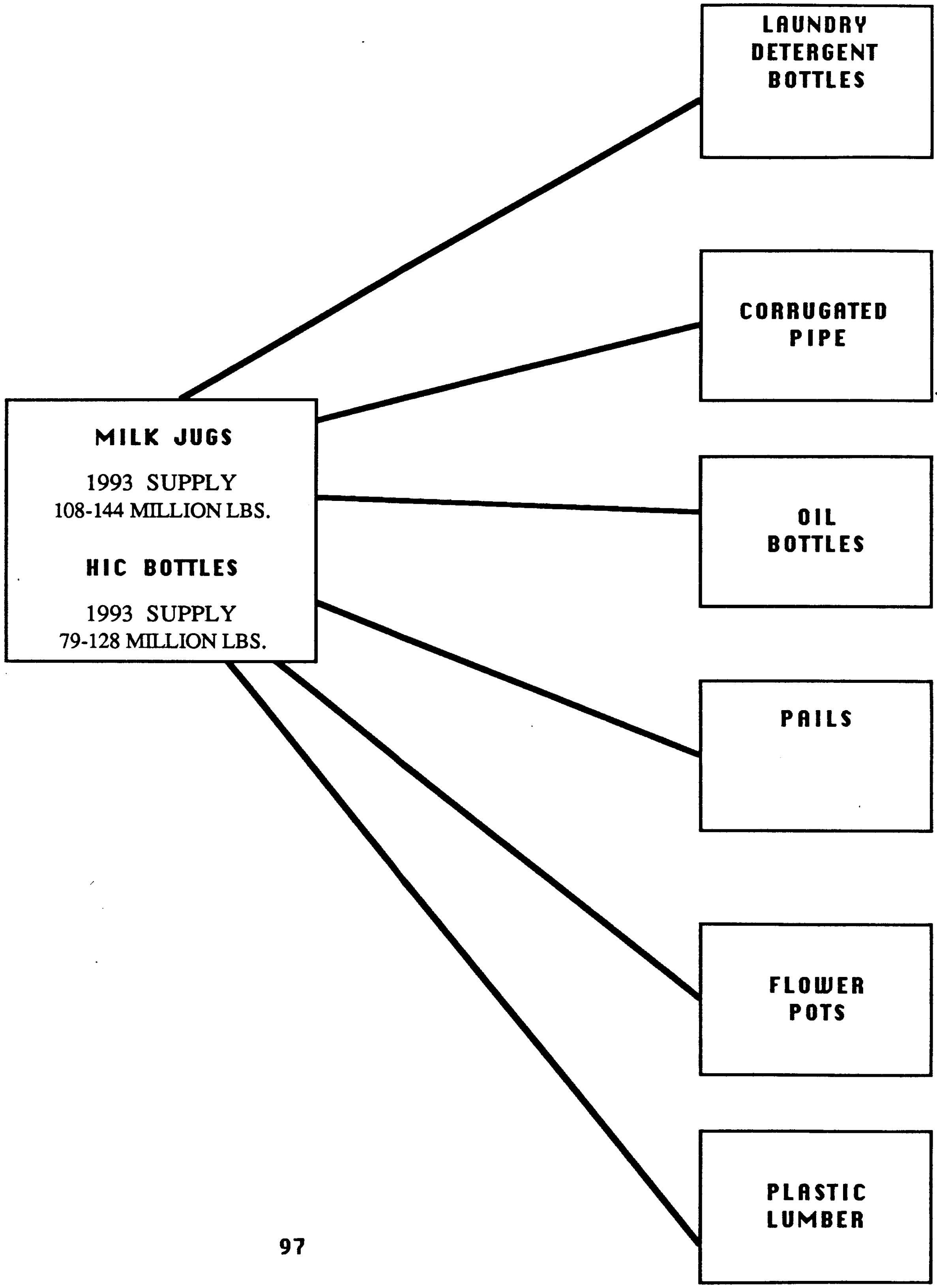
3.0 EXTRUDED DISPOSABLES

3.1 FILM

The overwhelming majority of film is made of low density or linear low density polyethylene, rather than HDPE. In 1989, over 8 billion lbs. (an amount equivalent to all HDPE resin produced) of low density resin went into the production of film, whereas only 766 million lbs. of film was made of HDPE (Modern Plastics 1990b). It is therefore likely that efforts to recycle film will be focussed on low density film.

FIGURE 3.1

END MARKETS FOR POST-CONSUMER MILK JUGS AND HIC BOTTLES



There may, however, be one niche for HDPE film recycling. While 70% of all bags are made of low density films, 65% - 75% of all grocery bags are made of HDPE (Miller 1990 and Van Asdale 1990). They are easily distinguished from low density bags by their crinkly, rather than smooth, feel.

In addition to grocery sacks, other HDPE film packaging applications include merchandise sacks, trash bags, tee shirt sacks and food packaging films. Many of these films are not likely to be recycled. Trash bags (other than those collected through recycling programs) are destined for disposal. Food packaging film is often made with more than one resin or material. Food packaging film and tee shirt sacks are not easily distinguished from those made with LDPE.

Thus far, little post-consumer film has been collected for recycling. End markets for post-consumer films are virtually non-existent. The negligible amount of post-consumer film collected in this country is either used in low quality, mixed plastics applications or is exported to Southeast Asia. There, labor costs are so low that hand washing and separating is economically feasible. Bags are reused or are used as feedstock for low quality end products.

Just a few months ago, recycling post-consumer film for use in domestic markets was almost unthinkable. Recently, however, some movement in this direction has begun to take place.

Post-consumer grocery sacks have recently begun to be collected from drop-off collection bins placed at supermarkets. Two bag manufacturers, Vanguard Plastics (St. Louis) -- a manufacturer of HDPE bags, and PCL Eastern (Canada) -- a manufacturer of LDPE bags, collect plastic bags through such an arrangement. PCL Eastern also collects used stretch film from supermarkets and recycles post-consumer bags collected through Canadian blue box programs.[3] PCL Eastern used about 1 million lbs. of post-consumer plastic bags and stretch film to make its plastic bags (Miller 1990). Vanguard Plastics which began its recycling program at the end of 1989, has been collecting 500 lbs./week (a rate of 26,000 lbs./year) (Van Asdale 1990). Both companies will expand collection in the coming months. Other companies such as Mobil Chemical have agreements with supermarkets for similar programs (Brison 1990 and Cofield 1990). Most programs, however, are for LDPE bags.

In addition, Union Carbide has announced that it will be recycling post-consumer films in its new plastics recycling plant in New Jersey (Meade 1990). These announcements may be premature in light of the fact that the company plans to initially recycle only industrial scrap film and will not be gearing up for post-consumer film recycling any time in the near future (Scarola 1990).

[3] Recycling programs are often referred to as "blue box" programs because the recyclable materials are collected by households in blue trash cans provided by the municipality in order that recyclables may be distinguished from other discards.

3.1.1 Recyclability

Technically, film is recyclable. In Europe, a substantial amount is being recycled. However, there are certain factors particular to film which make it more difficult to recycle than, for example, bottles.

Separating HDPE from LDPE

For most end uses, HDPE and LDPE films must be separated from one another. Because of their different properties end uses which can absorb one, cannot absorb the other.

The grocery sack market is such that HDPE, LDPE and LLDPE grocery sacks are distributed geographically. In other words, there are many geographic pockets throughout the U.S. that use only HDPE bags and a few that use only LDPE. In St. Louis, for example, most grocery sacks are of HDPE. In Maine and Canada, 75% and 90% respectively, are made of LDPE (Miller 1990). In large U.S. cities, grocery sack composition is more varied. In light of this fact, separation has not been a major problem for companies collecting grocery sacks from supermarkets. PCL Eastern knows that most of the grocery sacks it collects from Maine and Canada will be made of LDPE. In a typical collection box (placed in front of a store they supply), 80% of the post-consumer bags collected will be LDPE bags from the store. Vanguard Plastics has found that 90% of the bags it collects from supermarket collection boxes will be HDPE bags (Miller 1990 and Van Asdale 1990).

PCL Eastern manually separates the HDPE bags (4%-5%) from the LDPE bags it collects. This is the most expensive part of the process; because bags are so lightweight, thousands of bags must be sifted through in order to acquire a significant bulk. It estimates that investing in mechanical separation equipment will be justified once they collect 1.5-2 million lbs. a year, a target they expect to reach in 1990. Its planned separation technique will be a centrifuge, whereby materials of different densities are flung out at different distances (Miller 1990).

Separating LDPE and HDPE films collected through a municipal recycling program would be difficult. Canada has succeeded in collecting bags through its programs largely because almost all bags (grocery and merchandise) are made of LDPE. Separation by hand, even with proper labelling, would be too costly.

Most other film being recycled is industrial scrap. This scrap is largely homogeneous and therefore does not pose separation problems (Davidson 1990).

Contamination

Contamination is largely dependent on the method of collection. Collection through supermarkets programs has assured a relatively clean supply of film. Very few bags are contaminated to the point that they cannot be used. Vanguard Plastics claims that the bags it is collecting from supermarkets are in the same relative condition as plant scrap

(Miller 1990 and Van Asdale 1990).

Opinion is divided as to whether plastic bags can be collected through MRF systems. While PCL Eastern claims that the bags they collect through blue box programs in Canada are cleaner than those they collect in supermarkets, several U.S. bag manufacturers were skeptical about the possibility of using bags collected through MRFs (Davidson 1990; Martinson 1990; and Van Asdale 1990). (The level of contamination of materials processed through MRFs is highly dependent on the method of collection and separation.)

Many contaminants are destroyed during the 450 degree pelletization process (Cofield 1990). Therefore, washing is often not required. For highly soiled bags, a washing system could be set up. While adding cost to the process, it is much less costly than separation (Davidson 1990).

Several contaminants pose particular problems. First, receipts and coupons left in the bags clog filters and screens on the extruders. This paper must be removed from the bags manually. Second, bags with string, rigid or paper handles cannot be recycled at this time. Ironically bags made for "blue bag" recycling programs by Union Carbide (through its Glad Bag division) are string bags and are not recyclable. Third, ink from printing on bags lowers the properties of the end product. This is not as problematic with grocery sacks as it is with other merchandise bags (Claes 1990; Davidson 1990; Miller 1990; and Van

Asdale 1990).

Degradable bags did not seem to be a concern for several bag recyclers. However, their lack of concern is due to the fact that they are avoiding areas with high concentrations of these bags and because degradable bags are often marked "degradable" even though they are no different from regular plastic bags. The use of degradable bags could severely curtail plastic bag recycling; at least one recycler stopped collecting bags because degradable bags were finding their way into his supply (Ruston 1990).

Densification

Densification has been a major obstacle to effectively recycling films (Miller 1990 and Davidson 1990). Film flake is extremely light and fluffy; one cubic foot of bag flake weighs 3-4 lbs., while one cubic foot of virgin resin weighs 39 lbs. Bags must be densified to ensure that they can be fed into an extruder at a good rate. In addition, unless densified, the material would reside in the extruder too long and would be scorched. PCL, after one year of experimentation, asserts that it has figured out a simple (proprietary) method which does not add cost to the process (Miller 1990).

In conclusion, the lack of a clean supply of post-consumer film is the major constraint to increased post-consumer film recycling (Van Asdale 1990, Davidson 1990, Miller 1990 and Fish 1990b). However, it is not likely that large amounts of film will be collected until the constraints facing film recycling are overcome and large scale film processing facilities are built. Communities are not interested in collecting post-consumer films until they first deal with higher bulk items such as rigid containers (Osterchrist 1990). Until this time, small scale, supermarket collection programs and buyback centers will likely remain the only collection vehicles for post-consumer film. Possibly 5% - 10% of the recycling population will be recycling HDPE merchandise sacks by 1993. This amounts to 2 million to 5 million lbs., or 1% to 3% of the 182 million lbs. of HDPE merchandise bags produced. Most other types of post-consumer film, for reasons discussed earlier will not be collected (Refer to Table 3.4 for supply estimates for post-consumer film).

3.1.2 End Markets

As an extruded product, HDPE films have a melt index of .1-.45. They can technically be used in any application with similar properties (i.e. melt index) (Fish 1990b). End markets include other HDPE films such as grocery bags, trash bags and multisack liners; corrugated pipe; bottles; and low quality applications such as blow molded flower pots and plastic lumber. The ability for these end uses to utilize recycled HDPE film depends on the extent to which it has been cleaned and separated. (See Figure 3.2 for a diagram of end markets for film.)

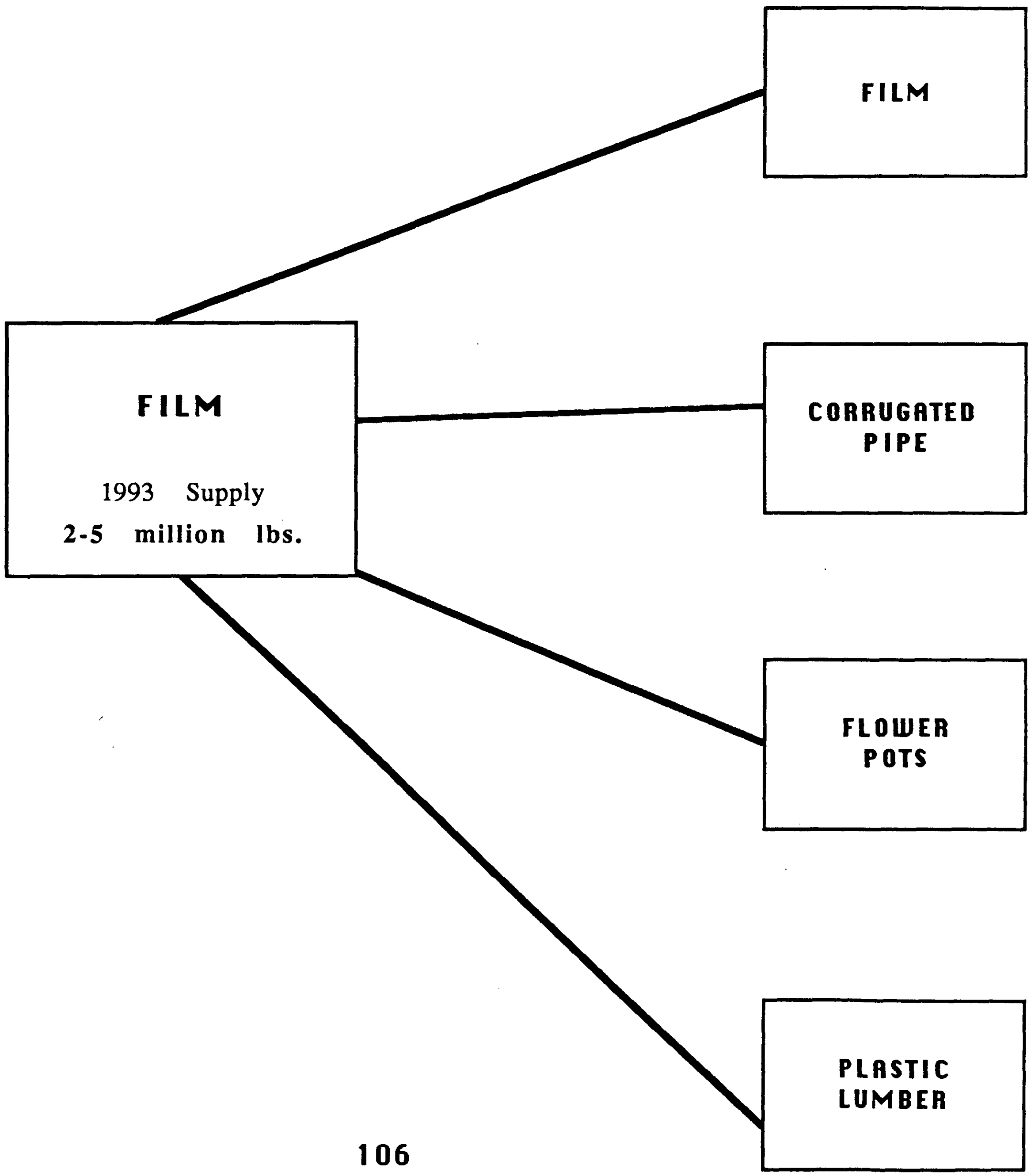
TABLE 3.4: 1993 SUPPLY OF EXTRUDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	COLLECTABLES CONSUMED BY RECYCLING POPULATION	1993 SUPPLY OF POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE — LOW: Collection Probability	LOW: Amount	LOW: as % of virgin sales	HIGH: Collection Probability	HIGH: Amount	HIGH: as % of virgin sales
EXTRUSION	<0.1	0.8								
Film	0.1	0.45								
Merchandise Bags			182	46	5%	2	1%	10%	5	3%
Tee shirt sacks			215							
Trash Bags Institutional			124							
Trash Bags Consumer			15							
Food packaging/deli			110							
Multiwall sack liners			50							
Other Film			70							
Total Film (< 12 mil)			766	46		2			5	
Pipe and Tubing										
Corrugated	0.45	0.45	103							
Water			59							
Oil & Gas Production			70							
Industrial/Mining			61							
Gas			112							
Irrigation			40							
Other			46							
Total Pipe and Tubing			491	0		0			0	
Sheet (> 12 mil)			305							
Wire & Cable			146							
Coating	10	12.5	51							
Other Extrusion			36							
TOTAL EXTRUSION			1795	46		2			5	

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

FIGURE 3.2

END MARKETS FOR POST-CONSUMER FILM



4.0 INJECTION MOLDED DISPOSABLES

4.1 BASE CUPS

Base cups are a sore point with recyclers. Triggered by PET recycling, the base cup was the first post-consumer HDPE application to be recycled. Base cup recycling was highly successful; approximately 20%, or 24 million lbs., of all base cups were being recycled.[4] Because it was a closed loop system -- injection molded base cups from PET beverage bottles were recycled back into black base cups -- new markets did not have to be found for the material.

Base cup recycling is now in jeopardy. Recently, Johnson Controls released a blow molded base cup onto the market. While small amounts of the blow molded base cups can be tolerated (estimates on this amount vary from 5% to 20%), large amounts mixed in with injection molded grade would substantially lower the melt index, making it impossible for the material to be recycled back into base cups (Reall 1990; Tomazak 1990; Twomey 1990).

The two base cups cannot be easily separated. Although there is obviously a difference in melt index (the injection molded is a 30 MI resin, the blow molded, a .6 MI resin) and a slight difference in appearance (the blow molded has a scaly surface, the injection molded, a shiny one), they cannot be separated by mechanical separation methods

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[4] Based on the fact that 20% of all PET bottles are being recycled (Bennett 1989a).

and manual separation is too costly (Twomey 1989).

Most recyclers have stopped buying the material. It is estimated that 10 million lbs. of post-consumer base cups is currently being warehoused (Schedler 1990). The situation is particularly problematic in those geographical areas (such as Michigan) which are supplied with a higher percentage of the blow molded version (Reall 1990).

Johnson Controls, which manufactures the blow molded base cups, has agreed to take them off the market. Until they have been substantially purged from the system, the warehoused base cups will likely be used in flower pots and other low end applications (Schedler 1990).

Two factors will affect future supplies of HDPE base cups; a likely increase in the number of PET bottles collected in the coming years and the fact that beverage companies will switch to "big foot" PET bottles that do not require base cups (Rankin 1990). Assuming that PET bottles collection will increase from 23% in 1988 to 30% by 1993, HDPE base cups will follow suit at 30%. (Table 3.5, which gives recycling supply estimates for post-consumer injection molded HDPE, assumes a 20% decline in the use of base cups by 1993.)

4.1.1 <u>End Markets</u>

In addition to base cups and injection molded flower pots, base cups can be used in low quality injection molded applications and in plastic lumber.

TABLE 3.5: 1993 SUPPLY OF INJECTION MOLDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	COLLECTABLES CONSUMED BY RECYCLING POPULATION	1993 SUPPLY OF POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE: LOW Collection Probability	LOW Amount	LOW as % of virgin sales	HIGH Collection Probability	HIGH Amount	HIGH as % of virgin sales
INJECTION MOLDING	2	100								
Food Contact Packaging										
Milk Bottle Caps			25	6	0%	0	0%	0%	0	0%
Dairy Tubs			136	34	0%	0	0%	0%	0	0%
Ice Cream Containers	25	30	85	21	0%	0	0%	10%	2	3%
Other Food Containers	25	40	46	12	0%	0	0%	10%	1	3%
Non-Food Contact Packaging										
Other Caps			56	14						
Beverage Bottle Bases***	30	30	122	29		29			29	
Paint Cans			31							
Total Packaging Applications			501	116		29			32	
Dairy Crates	6	20	56							
Other Crates, Cases, Pallet	6	20	120							
Pails	8	23	380							
Housewares			190							
Toys			78							
Other Injection			218							
TOTAL INJECTION MOLDING			1543	116		29			32	

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

*** 1993 base cup supply and demand figures account for a 20% decline in base cup use

4.2 OTHER INJECTION MOLDED APPLICATIONS

4.2.1 Caps and Closures

Many caps and closures are de facto recycled because they are mixed right in with the bottles that are being recycled. Despite the fact that these caps are injection molded HDPE, LDPE or PP, they are not significantly harming the properties of the recycled bottle resin because they account for a very small proportion by weight. However, if blow molded bottles were to become lighter in the future (which is the general trend), caps could present a problem (Tomazak 1990).

There are no end markets for caps; they would be difficult to collect, are of such a small quantity that they are not worth collecting, and it would not be feasible to sort out one resin type from another (Tomazak 1990).

4.2.2 Dairy Tubs and Other Food Containers

Food containers (i.e. ice cream containers, yogurt containers and margarine tubs, etc.) are made of HDPE, polypropylene and other resins. Because these different containers are indistinguishable, it is not likely that they will be collected in significant quantities. If collected, they will likely be used in plastic lumber and other low quality end uses.

5.0 CONCLUSION

Bottles, particularly milk jugs will be, by far, the major supply source of recycled HDPE. Total sources of packaging recovered for recycling in 1993 will range from 225 million pounds to 336 million pounds. This represents only 6.9% - 10.3% of the 3278 million lbs. of HDPE used in disposable residential applications produced (See Tables 3.1 and 3.6).

Several factors account for this low percentage. Approximately 422 million pounds will not be collected because they are used in applications (i.e. trash bags and paint cans) which are not amenable to recycling. Of the remaining 2856 million pounds, at least 75% will not be collected due to a lack of recycling collection programs (see the introduction to this chapter), leaving 714 million pounds[5] that could be collected. Because much of this is film, unidentifiable container and other objects -- which will not likely be collected due to the technical, end market, and other constraints discussed in this chapter -- it is estimated that only 225 million to 336 million pounds will ultimately be collected. (See Tables 3.2-3.6)

The only disposable HDPE that will be collected in substantial proportions are: base cups (30%), milk jugs (15%-20%) and HIC bottles (10%-15%, not including oil bottles). These three sources of supply

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[5] Table 3.1 gives 713 million lbs. as the amount of collectable HDPE. This is the actual estimate, due to the fact that base cups are collected through deposit refund systems and their collection was therefore estimated through a different methodology.

account for 210 million to 283 million pounds, or 84% - 93% of the 225 million to 336 million pounds of post-consumer residential HDPE likely to be collected.

TABLE 3.6
ESTIMATING POST-CONSUMER RESIDENTIAL HDPE
TO BE COLLECTED FOR RECYCLING BY 1993
(millions of pounds)

VIRGIN HDPE PRODUCED (1989)	8115
VIRGIN HDPE USED IN RESIDENTIAL DISPOSABLES	3278
NON-COLLECTABLE RESIDENTIAL DISPOSABLES (i.e. trash bags, coating, caps)	- 422
COLLECTABLE RESIDENTIAL DISPOSABLES	2856
% POPULATION THAT WILL RECYCLE ALL MATERIALS (includes capture rate)	x 25%
COLLECTABLE RESIDENTIAL DISPOSABLES BOUGHT BY POPULATION THAT IS RECYCLING	714

ESTIMATED POST-CONSUMER RESIDENTIAL DISPOSABLES COLLECTABLE BY 1993:

225 MILLION POUNDS - 336 MILLION POUNDS

CHAPTER 4

END MARKETS

1.0 INTRODUCTION

Markets exist for recycled HDPE because they offer a price advantage over virgin resins particularly for use in low value end markets. It is not clear, however, whether markets are large enough to absorb a large proportion of the HDPE packaging discarded each year. Post-consumer recycled HDPE is currently being used in base cups, drain pipe, animal pens, boat piers, curb stops, toys, flower pots, garden furniture, drums, pails, milk crates, pallets, trash cans and plastic lumber (Bennett 1989b). Bottles made from recycled HDPE have recently been introduced and could potentially absorb large quantities of recycled HDPE. Film is a potential, but limited, market.

This Chapter will describe current and potential end markets for HDPE. Factors affecting the demand for recycled HDPE in these end markets include:

* market size;
* the properties of the end use;
* sources of supply;
* technological feasibility;
* planned recycling capacity (or planned conversion to the use of

recycled materials);

* current saturation of the market with post-consumer, industrial scrap and off-spec resin; and
* attitudinal and institutional constraints.

Based on factors unique to each application, market potential for absorbing post-consumer recycled HDPE will be estimated. Although markets for virgin HDPE total 8115 million lbs., recycled HDPE is precluded from many of these markets - 1840 million lbs. - for health and safety reasons. (Refer to Table 4.1 for estimated demand for recycled post-consumer HDPE.)

TABLE 4.1: 1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	POST-CONSUMER DISPOSABLES DEMANDED 1987	HEALTH & SAFETY APPLICATIONS WHICH PRECLUDE RECYCLED HDPE	APPLICATIONS WHICH COULD ABSORB RECYCLED HDPE	1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE LOW %****	LOW Amount	HIGH %****	HIGH Amount
BLOW MOLDING	0.1	0.8								
Bottles										
Milk Jugs**	0.75	0.75	720		720					
Other Food			320		320					
Household Chemical	0.3	0.5	732			732	10%	73	15%	110
-Oil	0.3	0.5	224			224	10%	22	15%	34
Pharmaceutical/cosmetics	0.3	0.5	208			208	0%	0	5%	10
Total Packaging Applications			2204		1040	1164		96		154
Drums (15 gal. & larger)	<0.1	0.3	154			154	0%	0	5%	8
Fuel Tanks (all types)			96		96					
Tight-head pails			90	10		90	10%	10	20%	20
Toys			70			70	1%	1	3%	2
Housewares			51			51	0%	0	5%	3
Total Non-Packaging Applications			461		96	365		11		32
Other Blow Molding			270			270	1%	3	10%	27
TOTAL BLOW MOLDING			2935	10	1136	1799		109		213
EXTRUSION	<0.1	0.8								
Film	0.1	0.45								
Merchandise Bags			182			182	1%	2	2%	4
Tee shirt sacks			215			215	0%	0	0%	0
Trash Bags Institutional			124			124	0%	0	5%	6
Trash Bags Consumer			15			15	0%	0	5%	1
Food packaging/deli			110		110					
Multiwall sack liners			50			50	0%	0	5%	3
Other Film			70			70	0%	0	1%	1
Total Film (<< 12 mil)			766		110	656		2		14
Pipe and Tubing										
Corrugated	0.45	0.45	103	30		103	20%	27	30%	40
Water			59		59					
Oil & Gas Production			70		70					
Industrial/Mining			61		61					
Gas			112		112					
Irrigation			40			40	25%	10	50%	20
Other			46			46	10%	5	25%	12
Total Pipe and Tubing			491	30	302	189		41		71
Sheet (> 12 mil)			305			305	5%	15	10%	31
Wire & Cable			146			146	0%	0	0%	0
Coating	10	12.5	51			51	0%	0	0%	0
Other Extrusion			36			36	0%	0	10%	4
TOTAL EXTRUSION			1795	30	412	1383		58		119
INJECTION MOLDING	2	100								
Food Contact Packaging										
Milk Bottle Caps			25		25					
Dairy Tubs			136		136					
Ice Cream Containers	25	30	85		85					
Other Food Containers	25	40	46		46					
Non-Food Contact Packaging										
Other Caps			56			56	0%	0	5%	3
Beverage Bottle Bases***	30	30	122	10		122	25%	26	25%	26
Paint Cans			31			31	2%	1	5%	2
Total Packaging Applications			501	10	292	209		27		31
Dairy Crates	6	20	56	5		56	5%	3	10%	6
Other Crates, Cases, Pallets	6	20	120	10		120	15%	20	25%	33
Pails	8	23	380			380	5%	19	10%	38
Housewares			190			190	0%	0	5%	10
Toys			78			78	0%	0	1%	1
Other Injection			218			218	0%	0	10%	22
TOTAL INJECTION MOLDING			1543	25	292	1251		69		139
OTHER										
Rotomolding	3	20	122			122	0%	0	5%	6
Export			830			830	NA	0	NA	0
Other			890 *			890	5%	45	10%	89
TOTAL OTHER			1842		0	1842		45		95
GRAND TOTAL			8115	65	1840	6275		280		567

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
*** 1993 base cup supply and demand figures account for a 20% decline in base cup use
**** percentage of 1987 recycled demand and 1989 virgin demand

2.0 BLOW MOLDED APPLICATIONS

2.1 BOTTLES

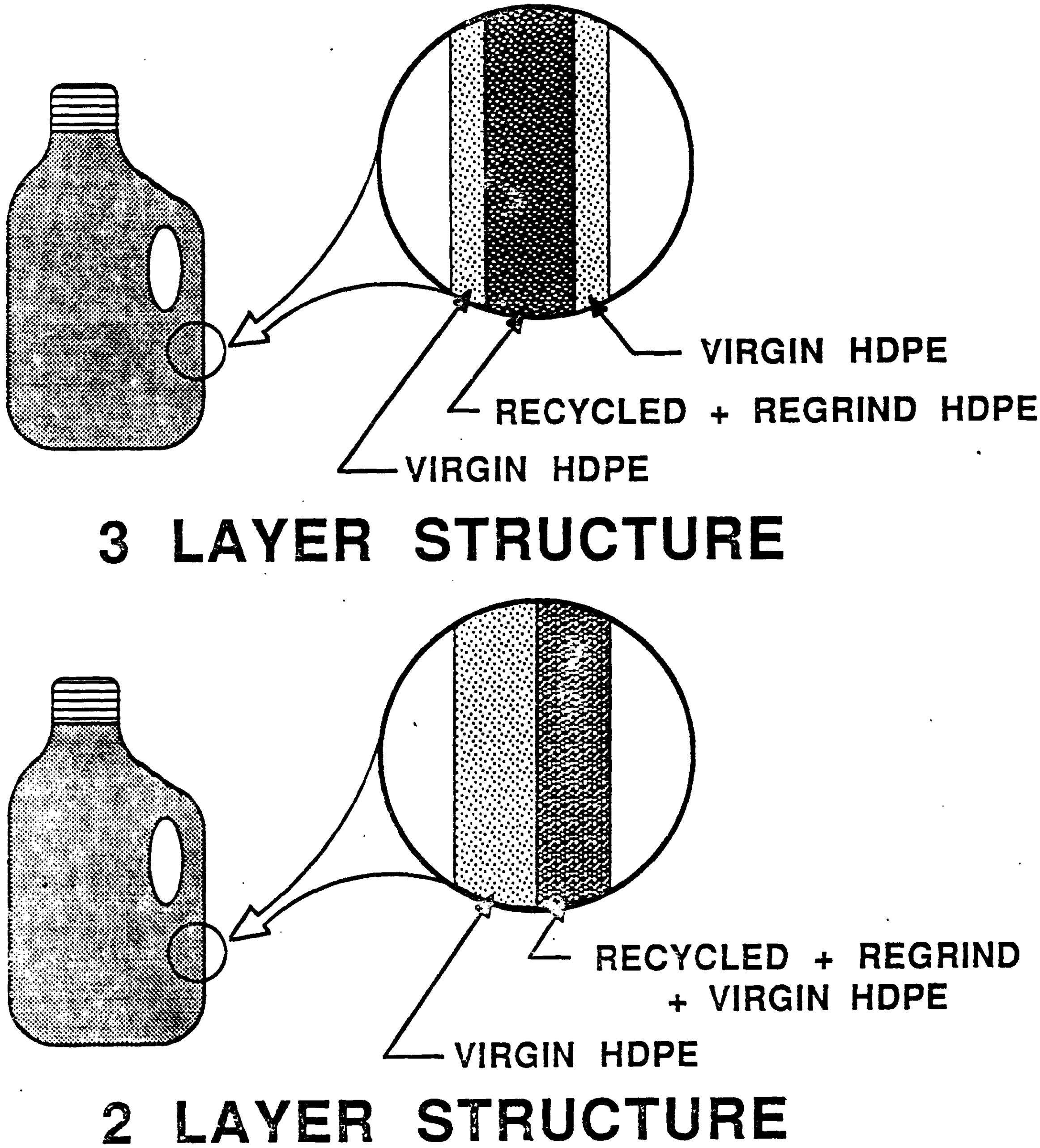
2.1.1 HIC Bottles

Household and industrial chemical (HIC) bottles -- for laundry detergent, motor oil, and a host of other household and industrial chemicals such as cleansers, pesticides and anti-freeze -- is potentially the largest market for recycled HDPE. Currently, the bottles are absorbing 956 million lbs., or 12%, of virgin HDPE annually (Modern Plastics 1990b).

Procter and Gamble (P&G) is largely responsible for opening this market to recycled HDPE. The company along with several bottle makers -- Plastipak, Sonoco Graham, Continental Can and Owens Brockway -- have been testing bottles made of recycled resins for several years. In 1989, P&G introduced the first bottle made of 100% recycled PET for Spic 'n Span. More recently, these companies have developed a multi-layer HDPE bottle containing a center layer of recycled HDPE, sandwiched between two layers of virgin resin. The virgin outer and inner layers account for 25% and 20% of the bottle respectively. The center layer, 55% of the bottle, consists of 20%-30% post-consumer HDPE bottle resin and 25%-35% trim scrap. (See Figures 4.1 and 4.2 for a diagram of the bottle and process.) The bottles are currently being test marketed for Procter and Gamble's Tide, Cheer and Downey laundry detergents (Luce 1990; Plastics Recycling Update 1988; Luce 1990; and Rogers 1990a).

FIGURE 4.1

MULTI-LAYER BOTTLE



Source: Sacks 1989

MULTILAYER BLOW MOLDING PROCESS
(3-LAYER COEXTRUSION)

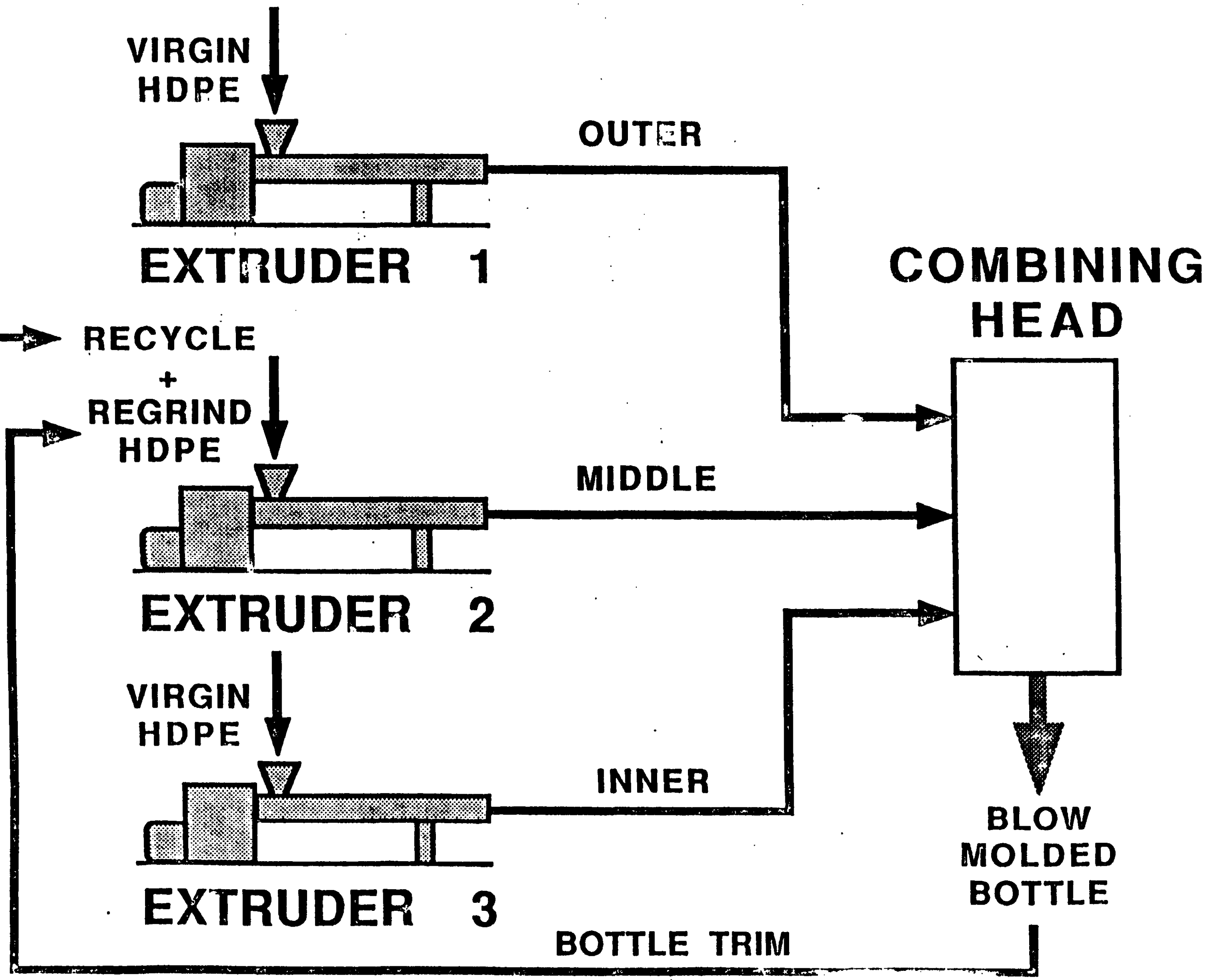


FIGURE 4.2

Source: Sacks 1989

Double layered HDPE bottles were developed several years ago in an effort to conserve expensive fluorescent pigments. (Unpigmented virgin resins are used on the inside, pigmented virgin resins on the outside.) This technology was adapted in the form of a triple layer bottle for use of recycled resins. The multi-layer construction allows manufacturers to retain the brightly colored exterior which they claim is vital for marketing purposes. (According to manufacturers, laundry detergent packaged in a 100% recycled HDPE black bottle would not sell. The bottle must reflect the way you want your clothes -- bold and bright!). Milk jug resin is the main feedstock for the center layer. Although bottle makers hope to use laundry detergent bottles in the future, the dark color of mixed resin shows through the bright outer layer in some bottles (Sacks 1990). The inner virgin layer acts as a barrier between the recycled center layer and the detergent. The odor of recycled resins is often difficult to remove and, in the absence of an inner layer, would interfere with the scent of the laundry detergent. One bottle manufacturer is experimenting with a two-layer dark blue Cheer bottle; the outer layer is made of recycled, reclaim and virgin resins (Luce 1990 and Rogers 1990a).

<u>Monolayer</u> bottles made of recycled resins, largely developed by Sonoco Graham, have been marketed since the end of 1989. One quart oil bottles are being made using 15%-25% recycled resins. Natural milk jug resins are used to make white and colored bottles; mixed color bottle resins are used in black bottles. Bottles using up to 10% HDPE recycled film are currently being tested. Within the next few years, these bottles

may be made of 50% recycled resin. Sonoco Graham (which consumes about 1/3 of 956 million lbs. of virgin resin used to produce HIC bottles) is offering monolayer and multi-layer bottles to all its customers (Claes 1990 and Rogers 1990a).

Due to color constraints, most of the recycled content of these bottles is homopolymer milk jug resin (Rogers 1990a). From a technical standpoint, however, copolymer recycled resin is the preferred feedstock because its properties match those of the bottle. In a monolayer HIC bottle, for example, 20%-25% homopolymer can be used, whereas it is technically feasible to use 100% recycled copolymer. It is unlikely however, that manufacturers will produce bottles with more than 50% recycled content because of skepticism on the part of their customers (Claes 1990).

2.1.1.1 Market Potential

Procter and Gamble which accounts for 20% (150 million of 732 million lbs.) of the non-oil bottle HIC market, is planning to use 25 million lbs. of recycled resins annually in its bottles (Rogers 1990a). Clean Tech, a division of the bottle manufacturing company, Plastipak, has recently opened a plant in Michigan which, by 1991, will be processing 12 million lbs. of recycled HDPE for use in multi-layer bottles, primarily for Procter and Gamble products (Luce 1990). Plastipak estimates that by 1992, 20% of the HDPE it consumes in HIC bottles will be recycled resin (Rogers 1990a). Sonoco Graham consumed 10 million lbs. of post-consumer HDPE last year and hopes to increase that number to 20 million lbs. in 1990 and 50 million lbs. in 1992 (Claes 1990). By 1992, these two bottle manufacturers alone may be using 62 million lbs. of post-consumer HDPE to produce HIC bottles, displacing 8% of virgin HDPE in this market. Other bottle manufacturers can be expected to follow suit.

Modern Plastics predicts that by 1992, recycled material may account for as much as 15% of the HDPE used in HIC bottles (Rogers 1990a). This estimate may be slightly optimistic since it is unlikely that by 1992, on average 50% of all HIC bottles will be made of 30% post-consumer content. Rather, assuming that one third of all bottles are made of 30% post-consumer HDPE, 10% of virgin HDPE will be displaced. (Refer to Table 4.2 for market potential estimates for blow molded applications.)

Ultimately, the extent to which recycled HDPE can penetrate this market depends on the availability of a large clean supply and sufficient number of three layer blow molding capacity (Rogers 1990a).

2.1.2 Pharmaceutical and Cosmetic Bottles

While HIC bottles are the first bottles to be experimented with, toiletry bottles could be a potential market. One manufacturer plans to market a shampoo bottle made of recycled HDPE (Luce 1990 and Schedler 1990). Recycled resins cannot be used in pharmaceutical bottles. Compared to the HIC bottle market, however, there is little movement in this market. Overall, few recycled resins will be used in

TABLE 4.2: 1993 DEMAND FOR BLOW MOLDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	POST-CONSUMER DISPOSABLES DEMANDED 1987	HEALTH & SAFETY APPLICATIONS WHICH PRECLUDE RECYCLED HDPE	APPLICATIONS WHICH COULD ABSORB RECYCLED HDPE	1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE: LOW %****	LOW Amount	HIGH %****	HIGH Amount
BLOW MOLDING	0.1	0.8								
Bottles										
Milk Jugs**	0.75	0.75	720		720					
Other Food			320		320					
Household Chemical	0.3	0.5	732			732	10%	73	15%	110
-Oil	0.3	0.5	224			224	10%	22	15%	34
Pharmaceutical/cosmetics	0.3	0.5	208			208	0%	0	5%	10
Total Packaging Applications			2204		1040	1164		96		154
Drums (15 gal. & larger)	<0.1	0.3	154			154	0%	0	5%	8
Fuel Tanks (all types)			96		96					
Tight-head pails			90	10		90	10%	10	20%	20
Toys			70			70	1%	1	3%	2
Housewares			51			51	0%	0	5%	3
Total Non-Packaging Applications			461		96	365		11		32
Other Blow Molding			270			270	1%	3	10%	27
TOTAL BLOW MOLDING			2935	10	1156	1799		109		215

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
**** percentage of 1987 recycled demand and 1989 virgin demand

pharmaceutical and cosmetic bottles. Less than 5% penetration into this market is likely by 1993.

2.2 OTHER BLOW MOLDED APPLICATIONS

(Many of these products are also injection molded. See Injection Molded Applications below.)

Recycled HDPE can be used in numerous other blow molded applications including pails, toys, trash cans and flower pots. The size of these blow molded markets is unknown. However in 1980, non-critical blow molded applications accounted for 12.5% of the blow molded HDPE market (Technomic Consultants 1981). Projecting to 1989, this represents a 367 million pound market. Based on Modern Plastics' 1989 survey, it is likely that this number is somewhat smaller (Modern Plastics 1990b). (Refer to Table 4.2 for market potential estimates for these blow molded applications.)

Drums: Because drums have an extremely low melt index (<.1-.3), post-consumer recycled HDPE is not likely to be used in this application in large quantities.

Fuel Tanks: Safety considerations would preclude the use of recycled resins in fuel tanks.

Pails: Recycled resins are currently being used in pails and will likely penetrate this market further, displacing 10%-20% of the virgin resin currently used in this market.

Toys: The use of recycled resin in toys is constrained by the fact that they are, for the most part, brightly colored (Christiansen 1990a). Milk jugs, however, could be used in some applications. In addition, due to the industry's concern about liability suits, toy manufacturers may be skeptical about using recycled resins.

Trash Cans: Blow molded trash cans, particularly those cans supplying recycling programs, can be made using large proportions of recycled resin.

Flower Pots: Plastic flower pots are a low quality application, ideal for consuming recycled resins. However, since no flower pots are currently made with virgin resin, post-consumer resins can only penetrate this market by displacing other recovered resins. (Gage 1990).

3.0 <u>EXTRUDED APPLICATIONS</u>

3.1 PIPE

Corrugated, water, oil, gas and irrigation pipe are all made from HDPE. Of these types of pipe, corrugated pipe is currently the only pipe market open to recycled HDPE (See Table 4.3). Recycled resins cannot be used in pressure pipe applications such as oil, gas and water pipe for safety reasons; small defects could prove hazardous. They are also not used in pipe carrying potable water for much the same reasons that recycled resins are precluded from use in food applications (Christiansen 1990a and Meyer 1990).

Corrugated drain pipe, or as it is sometimes called, drain tile, is an ideal application for post-consumer recycled resins; color is not a factor and it can absorb a wide range of extruded and blow molded resins. The industry began with farm drainage and expanded in the past 20 years to include septic tank leachfield, residential foundation, driveway and highway drainage pipe among other uses (Christiansen 1989).

HIC bottles are the perfect post-consumer supply source for corrugated pipe. Their density, melt index and ESCR closely match those of drainage pipe. Milk jugs can be used if blended with a reclaimed resin such as drums or films having a lower melt index and higher ESCR. Corrugated pipe can also incorporate 10% film or 5% drum material (Fish 1990b).

TABLE 4.3: 1993 DEMAND FOR EXTRUDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	POST-CONSUMER DISPOSABLES DEMANDED 1987	HEALTH & SAFETY APPLICATIONS WHICH PRECLUDE RECYCLED HDPE	APPLICATIONS WHICH COULD ABSORB RECYCLED HDPE	1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE LOW %****	LOW Amount	HIGH %****	HIGH Amount
EXTRUSION	<0.1	0.8								
Film*	0.1	0.45								
Merchandise Bags			182			182	1%	2	2%	4
Tee shirt sacks			215			215	0%	0	0%	0
Trash Bags Institutional			124			124	0%	0	5%	6
Trash Bags Consumer			15			15	0%	0	5%	1
Food packaging/deli			110		110					
Multiwall sack liners			50			50	0%	0	5%	3
Other Film			70			70	0%	0	1%	1
Total Film (< 12 mil)			766		110	656		2		14
Pipe and Tubing										
Corrugated	0.45	0.45	103	30		103	20%	27	30%	40
Water			59		59					
Oil & Gas Production			70		70					
Industrial/Mining			61		61					
Gas			112		112					
Irrigation			40			40	25%	10	50%	20
Other			46			46	10%	5	25%	12
Total Pipe and Tubing			491	30	302	189		41		71
Sheet (> 12 mil)			305			305	5%	15	10%	31
Wire & Cable			146			146	0%	0	0%	0
Coating	10	12.5	51			51	0%	0	0%	0
Other Extrusion			36			36	0%	0	10%	4
TOTAL EXTRUSION			1795	30	412	1383		58		119

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
**** percentage of 1987 recycled demand and 1989 virgin demand

Recycled and industrial scrap resins have successfully been used in drainage pipe for many years. Hancor (OH), a large pipe manufacturer, first bought a reprocessing machine at least ten years ago. Working with the U.S. Soil Conservation Service (SCS), they helped develop SCS specifications allowing for the use of recycled resin in corrugated pipe (SCS subsurface drain specification 606) (Christiansen 1990a). Hancor has since started a subsidiary company, United Resource Recovery (URR), which annually consumes 5 million lbs. of post-consumer recycled resin (Harris 1990).

Midwest Plastics (WI) has been manufacturing pipe from post-consumer resin for 6 years. It uses over 90% post-consumer HDPE in its corrugated pipe (less than 10% is reclaimed industrial scrap), amounting to 8 million lbs. annually (Fish 1990a).

Despite the success of firms like Midwest and URR, several factors limit the use of recycled resins in corrugated pipe. When asked about market potential for corrugated pipe, Eric Christiansen of Christiansen Associates, refers to an old fable, according to which, for the lack of a nail, a soldier couldn't put a horseshoe on his horse; the horse couldn't run and the battle was lost. The American Association of State Highway and Transportation Officials (AASHTO), he says, is the nail.

As discussed in Chapter 2, AASHTO requires the use of virgin resin in its corrugated pipe specification (AASHTO Specification M294-881). Pipe manufacturers meeting AASHTO specifications are required to stamp

"AASHTO" every 10 feet on the pipe. Pipe manufacturers using recycled resins, ignoring the AASHTO requirement for virgin resin, also stamp "AASHTO" on their pipe.

At first glance, AASHTO standards seem quite innocuous since under 10% of corrugated pipe is used in AASHTO applications. However, through its specification, AASHTO has the potential to control all corrugated pipe production. Pipe manufacturers market their pipe through a distributor; the ultimate buyer is unknown to them. Therefore, in order to meet AASHTO requirements, all pipe would have to be produced from virgin HDPE, on the 10% chance that it would be bought by a state department of transportation (Christiansen 1990a).

Recently state highway officials have begun to inspect corrugated pipe plants to determine whether they are using virgin resins. As a result of these investigations, some of these companies are being sued by state departments of transportation in Minnesota, Wisconsin and California (Christiansen 1990a and Brewer 1990b). This presents a quandary, particularly in states such as Minnesota which are trying to promote recycling.

In addition, pipe manufacturers that adhere to AASHTO standards by using virgin resins are beginning to sue those that do not. A company which uses virgin resin competes at a disadvantage with a company that uses recycled resin.

ASTM specifications have also been problematic. Its corrugated polyethylene pipe standards (F405 and F667) require the use of virgin or rework (industrial scrap from a manufacturers own operation) resin. Manufacturers that meet ASTM standards are also required to stamp "ASTM" on the pipe every ten feet. Recently, the word "virgin" was removed from these ASTM standards. However, the standard still specifically requires the use of rework material, implying that post-consumer HDPE is not acceptable. As discussed in Chapter 2, ASTM is currently in the process of modifying its standards to include the use of more recycled resins and it can be expected that recycled HDPE will be acceptable for use in corrugated pipe as long as it meets certain performance standards (Christiansen 1990a; Fish 1990a; and Meyer 1990).

In light of the these circumstances, companies manufacturing corrugated pipe from recycled resin are secretive about it. Both Midwest and United Resource Recycling were founded as subsidiary companies so that the reputation of their parent companies would not be harmed. Midwest, however, is now fairly open about its use of recycled resins (Fish 1990a and Christiansen 1990a). It is likely that other corrugated pipe companies use recycled resin despite claims to the contrary.

3.1.1 Market potential

It is estimated that 400 million to 500 million lbs. of HDPE is used in corrugated pipe (Christiansen 1990a). Approximately 103 million lbs. is virgin resin, over 100 lbs. is off-spec resin and approximately 30 million lbs. is post-consumer resin; the remaining 300-400 million lbs.

is industrial scrap and other recovered resin. (Christiansen 1990a, Modern Plastics 1990b and PRF 198?b).

Since the corrugated pipe market is largely saturated with recovered resins, post-consumer residential HDPE will penetrate this market only by displacing these resins. Only 103 million pounds of "on-spec" virgin resin is being consumed, in all likelihood, by companies that have decided to adhere to AASHTO and ASTM standards. Since it is unlikely that AASHTO standards will change in the near future, these companies will, for the most part, continue to use virgin resin. Perhaps some of these companies may switch to recycled HDPE as supplies become more readily available. However, potential lawsuits by state departments of transportation may have the opposite effect. Recycled HDPE will probably not displace more than 20% to 30% of virgin HDPE currently used in corrugated pipe. (Refer to Table 4.3 for market potential estimates for extrusion applications.)

HDPE is replacing PVC and metal in some pipe markets. Highway culvert pipe, once made exclusively of metal is one example. A new double walled corrugated pipe, smooth on the inside and corrugated on the outside, is expected to penetrate further into the culvert market and open up the storm sewer market to HDPE (Christiansen 1989). Recycled HDPE could potentially be absorbed by some of these markets.

Recycled HDPE may soon be used in drip irrigation pipe, a smooth walled non-pressure pipe (Bennett 1990b; Christiansen 1990a; and Fish 1990a).

Because the market has not been saturated by recycled resins, up to 50% of virgin HDPE used in this pipe could be displaced by recycled resins. Questions, however, arise as to whether contaminated recycled resins could leach into the water and soil and be uptaken by plants (Twomey 1990).

3.2 FILM

Film to film[6] recycling is technically feasible. LDPE film recycling is a big business in Europe; in Italy, one out of every three bags are made with recycled material (RIS 198?).

Film markets for recycled HDPE film resins include grocery and other merchandise sacks, trash bags and multiwall sack liners (double lined bags of paper and polyethylene used in trash compactors). No foreseeable end markets exist in food contact films such as food packaging and wrap; tee shirt sacks (merchandisers do not want their expensive shirts placed in an off-color recycled bag); and in most non-grocery sack merchandise bags[7] which require, for marketing purposes, bright colors (Davidson 1990).

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[6]To date, film is the only recycled resin used in film. However, a plastic bag made of post consumer milk jug resin was recently presented to Procter and Gamble officials (Plastic Recycling Update 1989).

[7] The fact that recycled HDPE cannot be used in non-grocery merchandise sacks is not problematic. Most of these bags are made of LDPE. HDPE accounts for a relatively small share of the market.

However, in order for post-consumer films to be used in this market, the collection, separation and cleaning constraints peculiar to films (discussed in Chapter 3) must be overcome. Bags are a fraction of a hair in thickness (.5 mils); any imperfections or contamination will show through. Even a spec of dirt could cause bubbles to form. In addition, LDPE cannot be tolerated in HDPE film (Davidson 1990).

3.2.1 Grocery Sacks

In the past year, post-consumer grocery sacks have begun to be recycled back into grocery sacks. Vanguard Plastics (St. Louis) -- the third largest plastic grocery sack manufacturer in the U.S. -- and Beresford Packaging are the only companies which, to my knowledge, are recycling post-consumer HDPE bags. Vanguard has been making some bags using up to 35%-50% recycled film -- a combination of rework and some post-consumer resins -- and hopes to make all its bags with recycled resins when post-consumer supplies become more readily available (Plastics Recycling Update 1990a and Van Asdale 1990). PCL Eastern (Canada) is currently using 8% post-consumer LDPE film resin in its grocery sacks. The company hopes to increase this percentage to 20-25%, but at this point, is constrained by a lack of supply (Miller 1990).

Bag companies can fairly easily convert to using recycled resin since they use a large proportion of rework resin in their bags. In the production of bags, the area surrounding the handles -- accounting for about 15% of the material used -- ends up as plant scrap. Unless bag companies were equipped to feed this material back into the process, bag manufacturing would not be economically viable. This rework material however, is easier to reprocess than granulated recycled film because it is denser (Van Asdale 1990).

Other merchandise bags can be made of recycled film except that color is a limiting factor. Recycled film resins produced from grocery bags are dyed grey or muddy brown (one manufacturer describes them as "tan" to potential customers) to hide the ink from the original bags.

3.2.2 Trash Bags and Other Films

It is technically possible, though no one is currently doing so, to use recycled grocery, merchandise and tee shirt sack films in trash bags, agricultural and construction films and multisack liners. These are particularly suitable applications for recycled film resins because color is not an important factor and since they are thicker than grocery sacks, can handle slightly more dirt and LDPE contamination (Buekens 1977; Martinson 1990, Osterchrist 1990 and Twomey 1990). Unfortunately, these applications represent small potential markets for HDPE; most are made primarily from LDPE or LLDPE. Trash bags used in recycling programs could provide a limited market (Davidson 1990).

3.2.3 Market Potential

Major developments in polyethylene film recycling have been predicted (Plastic Recycling Update 1990). While there is potential for inroads because little is currently being done, supply is a major hindrance.

Most film to film recycling operations using or planning to use post-consumer film resin will acquire their feedstock from supermarket collection bins, and most will be recycling LDPE only (Brison 1990 and Cofield 1990). Until large-scale processing capacity capable of recycling post-consumer HDPE film is built -- an unlikely outcome for the foreseeable future -- little activity can be expected in the film market.

It is unlikely that post-consumer recycled film will penetrate more than 2% of the merchandise sack (largely made up of grocery sacks) and 5% of the trash bag markets by 1993. (However, industrial film scrap which is cleaner than post-consumer film could make substantially larger inroads.) This is because much of the post-consumer supply is unlikely to be clean enough for use in film and film manufacturers are likely to be skeptical about using post-consumer films to manufacture their products. For merchandise sacks, color is also a constraint.

3.3 OTHER EXTRUSION APPLICATIONS

Tubing offers a potential market, although like pipe, it can be assumed that this market is saturated with industrial scrap and off-spec resin. Sheet could absorb substantially more recycled resin than could film because it is thicker and therefore less susceptible to contamination (Technomic Consultants 1981). Some recycled resin is currently being used in this market. Wire and cable casing may also be a potential market.

4.0 INJECTION MOLDED APPLICATIONS

4.1 BASE CUPS

The base cup market has, to a large extent, dried up. As discussed in Chapter 3, base cup recycling was a closed loop system until blow molded base cups were introduced onto the market. The mix of injection molded base cups with a 30 melt index and blow molded base cups with a fractional melt index has produced a large amount of 24 melt index HDPE which can no longer be used in base cups (Schedler 1990).

Until this unfortunate circumstance occurred, black base cups (colored base cups are not made of recycled HDPE) were made of up to 50% recycled HDPE. (One hundred percent is technologically feasible, but few manufacturers are willing to use 100% recycled resins in their products.) (Smith 1990). In 1987, almost 10% of the HDPE used to make base cups was recycled HDPE. This percentage probably increased over the years until the blow molded base cup were introduced in 1989.

4.1.1 Market Potential

Since Johnson Controls -- which produces the blow molded base cups -- has agreed to take them off the market, recycled base cup resin will likely regain its 10% share in the base cup end market. However, the wide spec base cups must be purged from the system, which could take some time.

There is substantial room for increased penetration in this market, particularly if PET bottle recycling increases (meaning that larger base cup supplies will be available). Twenty five percent will not likely be exceeded, however, because only black base cups are made from recycled resins.

The base cup market is expected to decline in coming years as beverage companies switch to "big foot" PET bottles that do not require base cups (Rankin 1990). (Table 4.4, which gives market estimates for injection molded applications, assumes a 20% decline in the use of base cups by 1993.)

4.2 OTHER INJECTION MOLDED APPLICATIONS

(Many of these applications are also blow molded. See discussion above under Blow Molded Applications.)

Low quality injection molding applications can absorb small quantities of blow molded resins or what little post-consumer residential injection molding material is collected.

Trash cans: Some injection molded trash cans are being made with recycled resins. To produce these cans, up to 20%-50% blow molded recycled resin is combined with a high melt index virgin or reclaimed resin (Twomey 1990 and Smiler 1990). Given the choice, an injection molded can manufacturer would not use blow molded resins (Curry 1990).

TABLE 4.4: 1993 DEMAND FOR INJECTION MOLDED POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE
(million lbs.)

APPLICATION	MELT INDEX LOW	MELT INDEX HIGH	VIRGIN SALES 1989	POST-CONSUMER DISPOSABLES DEMANDED 1987	HEALTH & SAFETY APPLICATIONS WHICH PRECLUDE RECYCLED HDPE	APPLICATIONS WHICH COULD ABSORB RECYCLED HDPE	1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE LOW %****	LOW Amount	HIGH %****	HIGH Amount
INJECTION MOLDING	2	100								
Food Contact Packaging										
Milk Bottle Caps			25		25					
Dairy Tubs			136		136					
Ice Cream Containers	25	30	85		85					
Other Food Containers	25	40	46		46					
Non-Food Contact Packaging										
Other Caps			56			56	0%	0	5%	3
Beverage Bottle Bases***	30	30	122	10		122	25%	26	25%	26
Paint Cans			31			31	2%	1	5%	2
Total Packaging Applications			501	10	292	209		27		31
Dairy Crates	6	20	56	5		56	5%	3	10%	6
Other Crates, Cases, Pallets	6	20	120	10		120	15%	20	25%	33
Pails	8	23	380			380	5%	19	10%	38
Housewares			190			190	0%	0	5%	10
Toys			78			78	0%	0	1%	1
Other Injection			218			218	0%	0	10%	22
TOTAL INJECTION MOLDING			1543	25	292	1251		69		139

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PHILLIPS' 66
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA
QUANTUM

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
*** 1993 base cup supply and demand figures account for a 20% decline in base cup use
**** percentage of 1987 recycled demand and 1989 virgin demand

Those using recycled resins do so because they are supplying trash bins for municipal recycling programs.

Pails and Flower Pots: Because of their low quality, some blow molded resins can be used in injection molded pails and flower pots; however, most made from post-consumer resin are blow molded. It is likely that these market will absorb some of the warehoused base cups.

Crates and Pallets: Again, crates and pallets can be made using base cups or small percentages of post-consumer blow molded recycled resins. Post-consumer commercial crates are being recycled back into crates. Pallets are successfully being made from mixed plastics which include high percentages of HDPE (see below). There is therefore no reason to use separated HDPE in this application. Mixed resins will likely replace many of the pallets currently being produced from virgin HDPE.

Toys: Injection molded toys are also constrained by a limit on the amount of blow molded resin they can absorb. Other limitations include color and skepticism on the part of toy manufacturers.

Paint Cans: Paint cans may be a target of Du Pont's recycling venture (Sherman 1989).

4.2.1 Market Potential

Except for base cups, recycled resins will not, to a large extent, be used in injection molded items (Technomic Consultants 1981). Not many HDPE packaging applications are injection molded and therefore a limited supply of post-consumer injection molded recycled resin is available. Injection molded packaging applications that do exist -- such as caps and food containers -- cannot be easily collected. Blow molded recycled resins, which are available in larger quantities, have limited application in injection molded products. Some low quality injection molded applications -- such as flower pots and agricultural stakes -- can use blow molded resins in limited amounts because the specifications for these products are not rigorous (Tomazak 1990). Thick-walled injection molded objects such a trash cans, crates and pallets can absorb a larger proportion of recycled blow molded resin, as they generally require a lower melt index than thin or intricate objects.

5.0 CONCLUSION

End markets for recycled HDPE are limited to non-food applications, reducing the size of potential end markets from 8115 million lbs. to 6673 million lbs. When one considers the applications -- such as pressure and potable water pipe and auto fuel tanks -- that cannot use recycled materials due to other health and safety reasons, the end markets for recycled are narrowed to 6275 million lbs. (See Table 4.5)

Due to other technical, attitudinal and institutional constraints, this analysis of end markets has shown that total demand for recycled HDPE in virgin HDPE end markets will range from 280 million to 567 million pounds. This represents 3.5% - 7% of virgin HDPE; 4.2% to 8.5% of the 6673 million pounds of virgin HDPE used in non-food applications; and 4.5% to 9% of the 6275 million pounds of virgin HDPE used in products which do not preclude the use of recycled HDPE for health and safety reasons. Of these potential end markets, non-food and non-pharmaceutical bottles and pipe will be the major end markets for post-consumer HDPE. (See Figure 4.3, Recycled HDPE Pyramid for a schematic of low to high quality end markets for recycled HDPE.)

TABLE 4.5
ESTIMATING POTENTIAL END MARKETS
FOR POST-CONSUMER RESIDENTIAL HDPE
(millions of pounds)

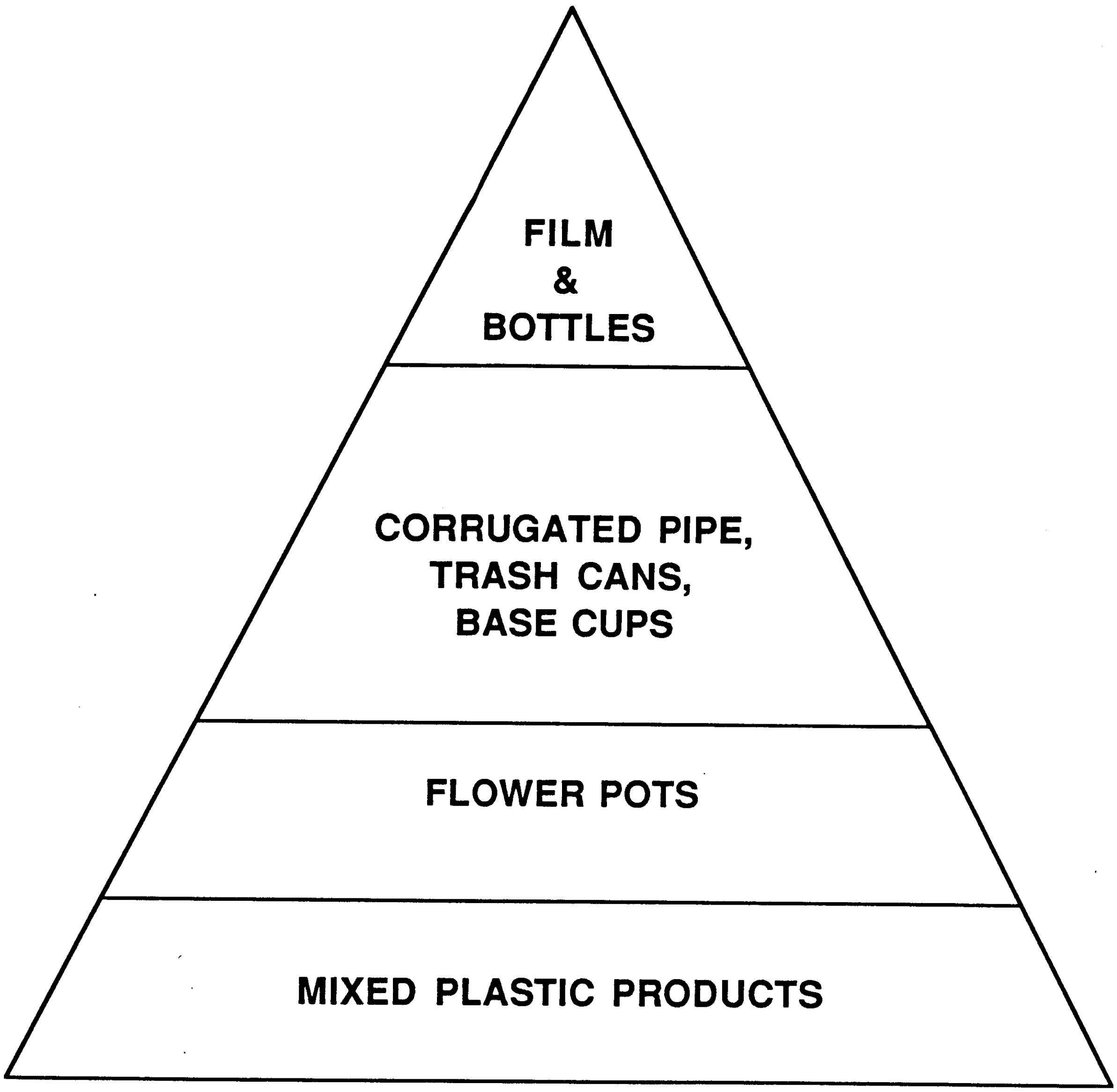
VIRGIN HDPE PRODUCED (1989)	8115
VIRGIN USED IN FOOD APPLICATIONS	- 1442
VIRGIN USED IN NON-FOOD APPLICATIONS	6673
VIRGIN USED IN OTHER APPLICATIONS WHICH POSE A RISK TO HEALTH & SAFETY	- 398
VIRGIN MARKETS WHICH COULD ABSORB POST-CONSUMER HDPE	6275

ESTIMATED DEMAND FOR POST-CONSUMER RESIDENTIAL HDPE IN THESE END MARKETS:

280 MILLION POUNDS - 567 MILLION POUNDS

FIGURE 4.3

RECYCLED HDPE PYRAMID
LOW QUALITY TO HIGH QUALITY
END USES



BASED ON PLASTICS PYRAMID BY JACK MILGROM

CHAPTER 5

MARKET ASSESSMENT

1.0 <u>INTRODUCTION</u>

In summary, what the examination of supply and demand markets in Chapters 3 and 4 have shown us is:

* <u>On the supply side</u>: Of the 8115 million pounds of HDPE produced, approximately 3278 million pounds goes into residential disposable applications. About 422 million pounds of this is not recyclable (i.e. coating, trash bags, etc.). Of the remaining 2856 million pounds that could be recycled, it is estimated that only 225 million - 336 million pounds (or 6.9%-10.3% of the 3278 million pounds of residential disposables) will be collected by 1993 due to a lack of collection programs and technical, institutional and attitudinal constraints.

* <u>On the demand side</u>: Of the 8115 million pounds of virgin HDPE produced, approximately 1840 million pounds cannot be displaced with recycled HDPE due to health and safety reasons. Of the remaining 6275

million pounds, it is estimated that only 280 million - 567 million pounds will likely be demanded in 1993.

If all types of post-consumer HDPE could be used in any application, the 280 million - 567 million pound market could absorb 9.8% -19.9% of the 2856 million pounds of collectable HDPE residential disposables discarded. However, not all HDPE is interchangeable. The use of post-consumer HDPE in most applications is constrained by its grade (blow molding, extrusion or injection molding). To determine how much of the post-consumer residential HDPE, estimated to be collected, can be absorbed in end markets, the supply of, and demand for, each grade must be compared. To help in making this assessment, I have created an integrated market development model, which pairs the supply of, and demand for, different grades of recycled HDPE.

2.0 THE MODEL -- SUPPLY AND DEMAND COMPARISON

2.1 Estimating Demand for Each Grade of Recycled HDPE

Supplies of blow molded, extruded and injection molded HDPE were estimated in Chapter 3. Chapter 4 gives the total amount of recycled HDPE that could be absorbed in each end market but does not break this amount down by resin grade. To arrive at the demand for each grade of HDPE, an additional step is required.

Demand for each grade of HDPE can come from many different end- markets and each end market can absorb several different types of post-consumer HDPE. In a sense, several types of recycled resins are competing with one another for the same markets. For example, both the blow molded bottle and extruded pipe markets can absorb blow molded recycled HDPE (estimated to be 97.5% of total demand in each of these markets), as well as small amounts of film (estimated to be 2.5% of total demand in each of these markets). In the model, the demand for each grade of post-consumer supply is estimated for each type of product and the results are added to give the total demand for each grade.

The following example illustrates how the demand for post-consumer blow molded resins (i.e. bottles) is calculated: (See Table 5.1 for all grades of post-consumer HDPE.)

1. The bottle end market: 97.5% of the demand for recycled HDPE packaging in this end market would be for blow molded bottles (the other 2.5% could come from film). Since total demand for post-consumer HDPE in this end market falls somewhere between 96 million and 154 million lbs. (estimated in Chapter 4), 93 million - 150 million lbs would come from blow molded bottles.

TABLE 5.1: 1993 DEMAND FOR POST-CONSUMER RESIDENTIAL DISPOSABLE HDPE BY GRADE
(million lbs.)

APPLICATIONS WHICH COULD ABSORB RECYCLED HDPE	VIRGIN DEMAND 1989	1993 DEMAND BY GRADE LOW TOTAL DEMAND	SUPPLY SOURCES BM %	BM AMT	EXT %	EXT AMT	IM %	IM AMT	HIGH TOTAL DEMAND	SUPPLY SOURCES BM %	BM AMT	EXT %	EXT AMT	IM %	IM AMT
BLOW MOLDING															
Bottles															
Household Chemical Bottles	732	73							110						
-Oil Bottles	224	22							34						
Pharmaceutical/cosmetics Bottles	208	0							10						
Total Packaging Applications	1164	96	97.5%	93	2.5%	2	0.0%	0	154	97.5%	150	2.5%	4	0.0%	0
Drums (15 gal. & larger)	154	0							8						
Tight-head pails	90	10							20						
Toys	70	1							2						
Housewares	51	0							3						
Total Non-Packaging Applications	365	11	100.0%	11	0.0%	0	0.0%	0	32	100.0%	32	0.0%	0	0.0%	0
Other Blow Molding	270	3	100.0%	3	0.0%	0	0.0%	0	27	100.0%	27	0.0%	0	0.0%	0
TOTAL BLOW MOLDING	1799	109		107		2		0	213		209		4		0
EXTRUSION															
Film															
Merchandise Bags	182	2							4						
Tee shirt sacks	215	0							0						
Trash Bags Institutional	124	0							6						
Trash Bags Consumer	15	0							1						
Multiwall sack liners	50	0							3						
Other Film	70	0							1						
Total Film (< 12 mil)	656	2	0.0%	0	100.0%	2	0.0%	0	14	0.0%	0	100.0%	14	0.0%	0
Pipe and Tubing															
Corrugated	103	27							40						
Irrigation	40	10							20						
Other	46	5							12						
Total Pipe and Tubing	189	41	97.5%	40	2.5%	1	0.0%	0	71	97.5%	70	2.5%	2	0.0%	0
Sheet (> 12 mil)	305	15							31						
Wire & Cable	146	0							0						
Coating	51	0							0						
Other Extrusion	36	0							4						
Total Other Extrusion	538	15	97.5%	15	2.5%	0	0.0%	0	34	97.5%	33	2.5%	1	0.0%	0
TOTAL EXTRUSION	1383	58		55		3		0	119		103		16		0
INJECTION MOLDING									0						
Non-Food Contact Packaging									0						
Other Caps	56	0							3						
Beverage Bottle Bases***	122	26							26						
Paint Cans	31	1							2						
Total Packaging Applications	209	27							31						
Dairy Crates	56	3							6						
Other Crates, Cases, Pallets	120	20							33						
Pails	380	19							38						
Housewares	190	0							10						
Toys	78	0							1						
Other Injection	218	0							22						
TOTAL INJECTION MOLDING	1251	69	20.0%	14	0.0%	0	80.0%	55	139	20.0%	28	0.0%	0	80.0%	112
OTHER															
TOTAL OTHER	1842	45	?		?		?		95	?		?		?	
GRAND TOTAL	6275	280		175		6		55	567		340		20		112

SOURCES: MODERN PLASTICS 1990
MODERN PLASTICS AUGUST 1988
PLASTICS RECYCLING FOUNDATION
PLASTICS INSTITUTE OF AMERICA

* 103 lbs. represents off-spec used to produce pipe
** includes milk, water, and juice jugs
*** 1993 base cup supply and demand figures account for a 20% decline in base cup use
**** percentage of 1987 recycled demand and 1989 virgin demand

Each blow molded end market is assessed separately and then added to give the range of total demand for bottles in all blow molding end markets: 107 million - 209 million lbs.

2. The pipe end market: 97.5% of the demand would also be for bottles; amounting to 40 million - 70 million lbs.

   Demand estimates for blow molded recycled HDPE were made for each extruded end market. These numbers were then summed to give the range of total demand for blow molded recycled HDPE in extruded applications: 55 million - 103 million lbs.

3. A similar assessment is done for each injection molding end market. The total demand for blow molded bottles in injection molding applications is estimated to be: 14 million - 28 million lbs., or 20% of all recycled HDPE demanded in injection molded applications.

4. Estimates from 1, 2 and 3 above were summed to arrive at the total demand for post-consumer blow molded resins: 171 million - 333 million lbs.

2.2 Comparison of Supply and Demand for Each Grade of Recycled HDPE

The supply of, and demand for, each grade of recycled HDPE can now be compared. (See Figure 5.1 and Table 5.2 for the results of this analysis. Notice that the demand estimates are based on Table 5.1 above.)

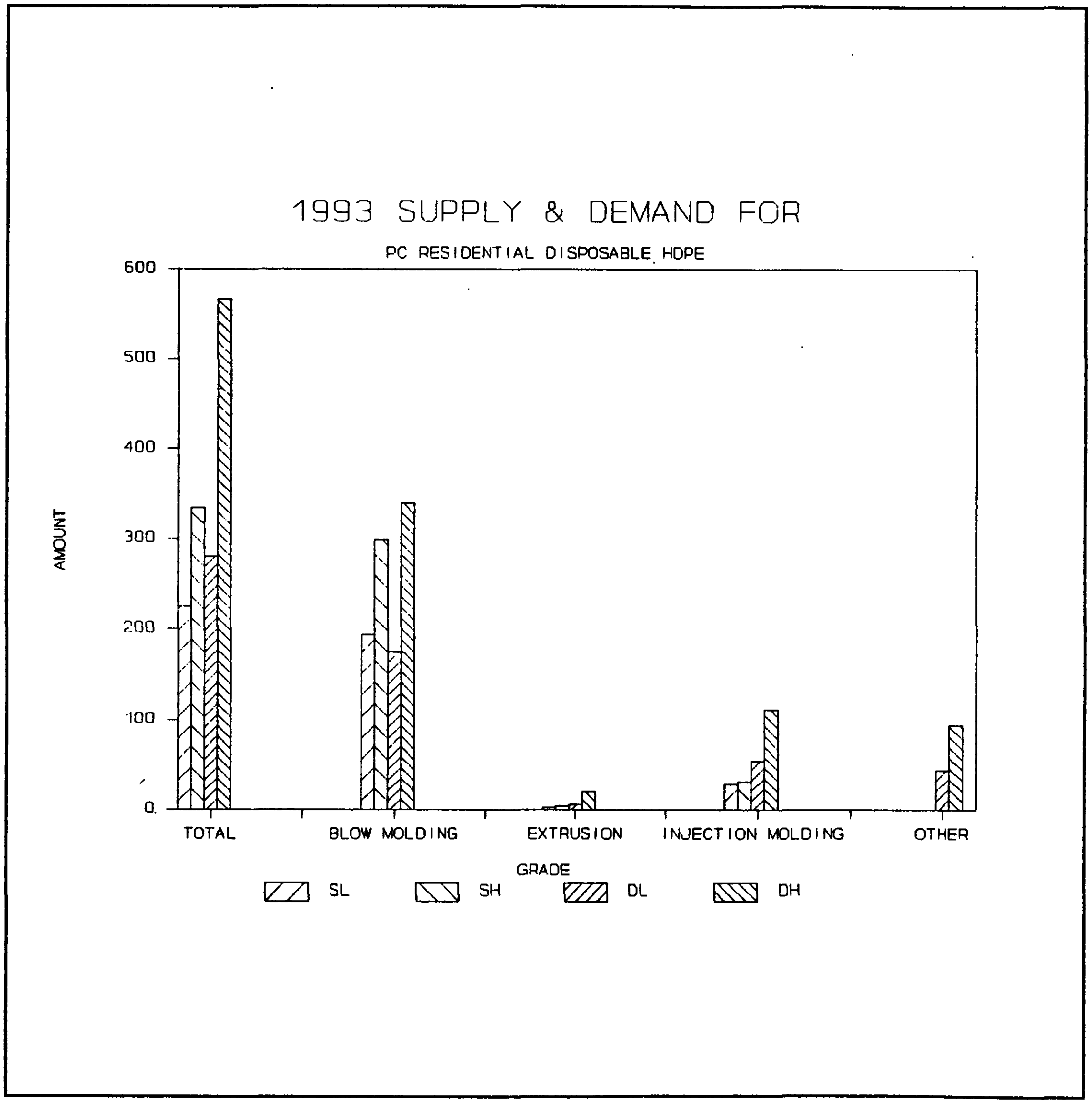


Figure 5.1

TABLE 5.2
1993 SUPPLY AND DEMAND SCENARIOS BY RESIN GRADE

SCENARIOS	TOTAL	BM	EXT	IM	OTHER
1 SL	225	193	2	29	
DL	280	175	6	55	45
SUPPLY AS % OF DEMAND	80%	110%	40%	53%	
2 SH	336	299	5	32	
DL	280	175	6	55	45
SUPPLY AS % OF DEMAND	120%	170%	81%	59%	
3 SL	225	193	2	29	
DH	567	340	20	112	95
SUPPLY AS % OF DEMAND	40%	57%	11%	26%	
4 SH	336	299	5	32	
DH	567	340	20	112	95
SUPPLY AS % OF DEMAND	59%	88%	22%	29%	
% SCENARIOS DEMAND>SUPPLY	75%	50%	100%	100%	

SL=SUPPLY LOW
SH=SUPPLY HIGH

DL=DEMAND LOW
DH=DEMAND HIGH

The use of ranges with low and high estimates results in four scenarios for each grade. The low and high estimates should not be averaged because the low estimate is as likely to occur as the high estimate.

Judging from the results, it is uncertain whether there will be enough markets to absorb all the blow molded bottles collected. In two scenarios, demand is less than supply; in the remaining two scenarios, supply is greater than demand. However, only in Scenario 2, with high supply, low demand, does supply greatly exceed demand (by 170%).

The supply of extruded packaging consists of merchandise sacks. The demand for these bags -- which includes the blow molded bottle, extruded pipe, and extruded film markets -- is greater than supply. In all four scenarios there are adequate markets for this film.

The supply of injection molded recycled HDPE packaging is, for the most part, base cups. Demand for these recycled resins comes from injection molded applications only. Supply is relatively small compared to demand in all four scenarios because there is little easily collectable injection molded packaging, yet many injection molded applications such as pallets and crates can use these resins.

As can be seen from these results, demand exceeds supply in almost every scenario. However, for blow molding recycled HDPE, which has by far the largest impact (accounting for 86%-89% of all supply), the results are ambiguous in that for two scenarios, supply exceeds demand and in the other two, demand exceeds supply.

In addition to blow molding, extrusion and injection molding, a fourth market, "Other," is built into the model (see Figure 1). As can be seen from the numerous charts in Chapter 4, "Other" includes rotomolding and various other processes. While rotomolding can theoretically absorb some recycled resins, little is being used (Schedler 1990). Because there is uncertainty over what these markets are or what types of resins they require, an approximate demand for all recycled resins was given. No supply estimates were given because rotomolded products cannot be recycled.

3.0 ASSUMPTIONS AND UNCERTAINTIES OF THE MARKET ANALYSIS

The market analysis contains many assumptions and uncertainties which should be made explicit. Some of these assumptions relate to the narrowly defined scope of this thesis.

3.1 **Why 1993 was chosen**.

The model estimates supply of, and demand for, recycled resins in 1993. The year 1993 was chosen because, assuming sufficient investment by the public and private sectors, it will take several years before a large scale HDPE recycling infrastructure could be established which would include adequate and reliable collection mechanisms, processing facilities and end markets.

Currently, demand for recycled HDPE exceeds supply; what little recycled HDPE is collected is easily absorbed by end markets. Many manufacturers claimed that tight supplies are currently the largest constraint on increased HDPE recycling; they want to use more recycled HDPE but it just isn´t available (Claes 1990; Miller 1990; and Twomey 1990). However, this situation could change rapidly if several large states began collecting post-consumer HDPE. What this model examines is whether enough end markets exist to absorb large quantities of post-consumer HDPE once they become available.

3.2 **Only HDPE end markets were considered.**

Closed loop recycling systems -- in which post-consumer materials are recycled back into their original end uses -- minimize the use of virgin resources and the negative impacts of virgin production. Since plastics recycling can never hope to be a closed loop system, this model aims at the creation of a semi-closed loop system, whereby recycled HDPE would be used in HDPE applications. Ultimately this system could become increasingly closed loop as bottles are recycled into bottles and film into film.

This model, therefore, did not consider demand for recycled HDPE -- either as a single resin or mixed with other plastics -- based on substitution for products that are currently made of wood, metal and other materials. In addition, the use of upgrading technology that would allow recycled resins to be substituted for higher grade resins was not considered because at this time, it is highly underdeveloped. Nor did the model consider the possibility that the recycled HDPE might substitute for other types of virgin resins, such as polypropylene. While not displacing virgin HDPE, market shifts between recycled HDPE and other resins could reduce the total amount of virgin plastics produced.

For obvious reasons, the plastics industry advocates the use of recycled resins in former wood and metal applications. According to Du Pont´s Frank Aronhalt, "the secret to finding markets is creating new uses for recycled plastics" (Sherman 1989).

A commonly considered market for post-consumer plastics is in mixed plastic products, which are made by granulating different types of plastics, mixing them with additives (including compatibilizers which weld the diverse types of plastics) and heating them. The mixture is then molded into lumber-like shapes. The main advantage of mixed plastics is that they eliminate the need to sort collected plastics by resin type. Most mixtures consist of a large proportion (up to 60%) of polyolefins (HDPE, LDPE and PP) (PIA/Sutherland 1989a).

Mixed plastics often characterized as "plastic lumber," are used to produce thick, heavy items, such as surfaces and protective pilings for boat docks, park benches, animal pens, picnic tables, industrial pallets, roadside posts, playground equipment and car stops. Plastic lumber offers several advantages over wood and wood. It competes with these materials in many of these outdoor and marine applications, where weather resistance is an important factor. Unlike wood products, plastic substitutes do not require pressure treatment with toxic chemicals to retard decay in wet environments (Bennett 1989a and Selke 1989). In addition, in some cases, plastic lumber may substitute for precious woods such as redwood, teak and mahogany. Furthermore, because plastic lumber lasts longer than wood, it keeps stays out of the waste stream longer.

However, plastic lumber may be more costly than wood except in applications requiring high maintenance and/or frequent replacement. In addition, some wood-replacement markets may not be that large, or, once saturated, not able to absorb much mixed plastic over time (Brewer 1988). Mixed plastic products are also criticized as heavy and unattractive and cannot be used in structurally demanding applications. In sum, by combining resins with different properties, mixed plastics eliminate the intrinsic value that would be retained by separating plastics by resin type.

Undoubtedly, new markets will be found for recycled HDPE as plastics increasingly penetrate markets dominated by other materials. However, substitution of plastics for other materials is expected to occur at a much slower rate than in the 1960s and 1970s (*U.S. Industrial Outlook* 1989).

In conclusion, the development of plastic lumber markets should not be the focus of a plastics recycling program. Plastics should be separated to the greatest extent possible to retain their intrinsic value and their ability to replace virgin HDPE. However, commingled plastic applications could absorb all the plastic which is difficult to sort and for various other reasons cannot be readily recycled for use in other applications.

3.3 **Competition in price and quantity between post-consumer residential HDPE and other types of recovered HDPE was not evaluated**.

Most applications that can absorb post-consumer residential HDPE could also absorb industrial scrap, post-consumer commercial or virgin off-spec HDPE, or, as a category, "competing recovered resins." Post-consumer residential HDPE is particularly sensitive to the price and availability of these resins because they are often cleaner and more homogeneous in their properties.[1] The competition of these different resins, particularly off-spec, which can be stockpiled or dumped onto the market in large quantities, adds another element to the instability of prices faced by post-consumer HDPE.

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[1]However, it is important to note that, in some cases post-consumer HDPE sells at a premium over industrial scrap of a higher quality, due to demand by large consumer retail manufacturers like Procter and Gamble who want to be able to advertise their use of recycled materials.

The amount of competing recovered resins currently being collected and used is unknown. The Office of Technology Assessment (OTA) estimates that 95% of clean pre-consumer industrial scrap and off-spec resins are recycled, comprising 10% of all plastics production. The amount of contaminated industrial scrap material that is recovered is unknown but, they claim, significant. The uncertainty of these estimates stems from the fact that businesses either do not want to admit that they are using these materials or do not want to reveal their supply sources (OTA 1989).

The market analysis only examined the displacement of virgin HDPE -- and not the displacement of these competing recovered materials -- by post-consumer residential HDPE. For example, while it is estimated that 400 million - 500 million lbs. of corrugated pipe is produced each year, only 103 million lbs. is made with virgin "on-spec" resin (Christiansen 1990a). Increased penetration by post-consumer residential HDPE into the remaining 300 million - 400 million lb. market was not considered.

Displacement of competing resins is not the aim of a post-consumer residential recycling program. Post-consumer residential and other recovered resins generally compete for the same markets. Unless additional markets are established as more post-consumer residential HDPE is collected, these materials will displace competing recovered materials and significantly reduce the price for recovered materials. This is not to say that in an efficient allocation, some post-consumer residential HDPE would not displace other recovered HDPE in certain applications. Post-consumer resins could for example, displace industrial scrap in lower quality end uses, freeing it to be used in higher quality applications.

The market development analysis also did not consider the impact of a growth in the collection and use of competing recovered resins. Municipalities are not responsible for collecting industrial scrap and post-consumer commercial HDPE; businesses pay for their own waste hauling services. Since more waste haulers are turning to recycling as landfilling and incineration costs skyrocket, it is likely that more of this material will be dumped onto the market.

The impacts of a growth in these resins would vary according to the end market. A growth in the availability of competing recovered resins could open new markets which would not be available to post-consumer resins. Because little post-consumer injection molded packaging exists which can be collected, other recovered injection molded materials could easily penetrate the injection molding markets with little effect on the amount of post-consumer residential HDPE recycled. Film markets could also be expanded to include industrial scrap without significantly closing off the market to post-consumer film because there is little post-consumer film that can be expected to be recycled. However, in other extrusion and blow molding markets, increasing the supply of these competing recovered resins could significantly reduce the demand for post-consumer residential HDPE.

3.4 **The impacts of future changes in HDPE demand was not considered**.

The production of HDPE grew at an annual rate of 7% from 1978 to 1988, but began to mature and slow in the latter part of this period, at 5% from 1987-1988, for example. This latter rate is expected to continue into the early to mid-1990s (*Chemical & Engineering News* 1989 and *Modern Plastics* 1990b)

With the exception of base cups, changes in demand for HDPE were not included in the model. Since the change in demand in individual HDPE markets is uncertain, all other estimates are based on 1989 virgin resin sales figures.

It is possible that, overall, increased demand for HDPE would have little effect on the model. Increased demand for HDPE could mean increased demand for recycled resin and increased supply of post-consumer resin. Therefore, the effects of increased supply and demand could cancel each other out.

This conclusion, however, is highly sensitive to the growth of particular sources of supply and demand markets. Because base cups are a source of supply as well as an end market, a drop in demand for HDPE could easily be built into the model. A change in demand for HDPE in other markets, however, could have different effects depending on whether the market was a source of supply or demand for HDPE.

3.5 The impacts of future technological change are uncertain.

The size of demand markets is based on the current state of recycling technology. However, recycling technology is advancing quickly. The recycling of HDPE film was thought unlikely six months ago; today it is becoming increasingly possible. Products such as bottles made of 100% recycled HDPE, which have only been produced in the laboratory, may soon become feasible on a large scale. With technological improvement, the cost of recycling could drop making recycled resins more attractive. The versatility of plastics makes a wide range of technological innovations conceivable.

3.6 <u>The effects of resin price changes were not accounted for</u>.

Virgin and recycled resin prices were not taken into consideration in determining end market size or the willingness to collect plastics. A drop in virgin prices could dry up demand for recycled HDPE. With additional HDPE capacity expected to come on line (see Chapter 2), this is a possibility.

Under another scenario, rapid increases in the collection of post-consumer HDPE without commensurate gains in processing capacity (especially in a bottleneck like washing capacity) and end market availability could result in a market glut and price decline. Eventually, lower prices would entice more processors and end-manufacturers to enter the market. However, communities and undercapitalized regrind operations might not be able to weather the lower prices for long periods resulting in the abandonment of plastics recycling programs (Ruston 1990).

3.7 **Current constraints do not present significant barriers**. On the supply side, the model assumes that no significant barriers -- such as shortages of funds in public sector budgets and a lack of investment by the private sector -- exist to prevent collection programs from starting up quickly and new processing and cleaning facilities from being built. On the demand side, the model assumes that attitudes of manufacturers and product consumers will not be a major constraint in market segments that technically could be filled by recycled resins.

3.8 **Supplies and markets may be mismatched**. The blow molded supply source consists of many different types of bottles; milk jugs are in greater demand than laundry detergent bottles. If, for example, large amounts of milk jugs were absorbed in the pipe or flower pot markets -- markets which could easily absorb laundry detergent bottles -- milk jugs would be in short supply in other markets. Another allocative mismatch would result if segregated HDPE was used in markets that could use mixed recycled resins, such as the pallet market.

A second type of mismatch between sources of supply and demand would be geographical. Transportation costs for recycled plastics are high because of their low bulk density. A lack of local markets could make recycling uneconomical.

Sources of supply come mainly from concentrated urban areas. The mid-Atlantic region (NY, NJ and PA), for example, could be a large potential source of supply. Demand comes from plastics manufacturers which are dispersed throughout the country, the largest number of blow molders and extruders (the most important type of end-manufacturers for recycled HDPE) being in the East North Central (which encompasses IL, IN, MI, OH and WI) and mid-Atlantic regions (*Plastics Technology* 1989b). (See Table 5.3. Note however, that this Table presents data on all plastics manufacturers, not just those that use HDPE.) A complicating factor is the location of HDPE processing and cleaning facilities. These facilities are for the most part also located in the East North Central and Mid-Atlantic regions (Bennett 1988). (See Map 1.) East coast sources of supply may be located near end markets, however, on the west coast, in states such as California, no end markets for HDPE exist (Brewer 1990b).

TABLE 5.3: 1986 GEOGRAPHICAL DISTRIBUTION OF PLASTICS MANUFACTURING PLANTS

Geographical Area	Blow Molding # plants	Blow Molding % of total	Injection Molding # plants	Injection Molding % of total	Extrusion # plants	Extrusion % of tota
E. North Central (IL, IN, MI, OH, WI)	250	22%	1978	29%	735	24%
Mid Atlantic (NY, NJ, PA)	175	17%	1092	16%	525	17%
Pacific Coast (AK, CA, HI, OR, WA)	145	13%	955	14%	380	12%
S. Atlantic (DE, DC, FL, GA, MD, NC, SC, VA, WV)	139	12%	682	10%	390	13%
W. North Central (IA, KS, MN, MO, NE, ND, SD)	119	11%	546	8%	214	7%
W. South Central (AR, LA, OK, TX)	94	8%	409	6%	243	8%
New England (CT, MA, ME, NH, RI, VT)	81	7%	614	9%	311	10%
E. South Central (AL, KY, MS, TN)	72	6%	273	4%	176	6%
Mountain (AZ, CO, ID, MT, NV, NM, UT, W	37	3%	205	3%	57	2%
Puerto Rico	7	1%	68	1%	11	1%
Total Number of Plants	1119		6822		3042	

Source: Plastics Technology, 1986

4.0 CONCLUSIONS

From a hypothetical standpoint, this market assessment showed that it is likely that substantial amounts of the post-consumer HDPE estimated to be collected by 1993 could find homes in HDPE markets. However, as the uncertainties and constraints discussed in this and prior Chapters reveal, it will not be easy to ensure that this market potential is realized. The private sector must be convinced to invest in developing the recycling infrastructure; large quantities of supplies must be guaranteed; prices must be stabilized; standards which limit the use of recycled resins must be reevaluated; manufacturers must be convinced to use recycled HDPE; consumers must be convinced to demand products containing recycled HDPE; and sources of supply and demand must be matched in an efficient manner, both by material and location.

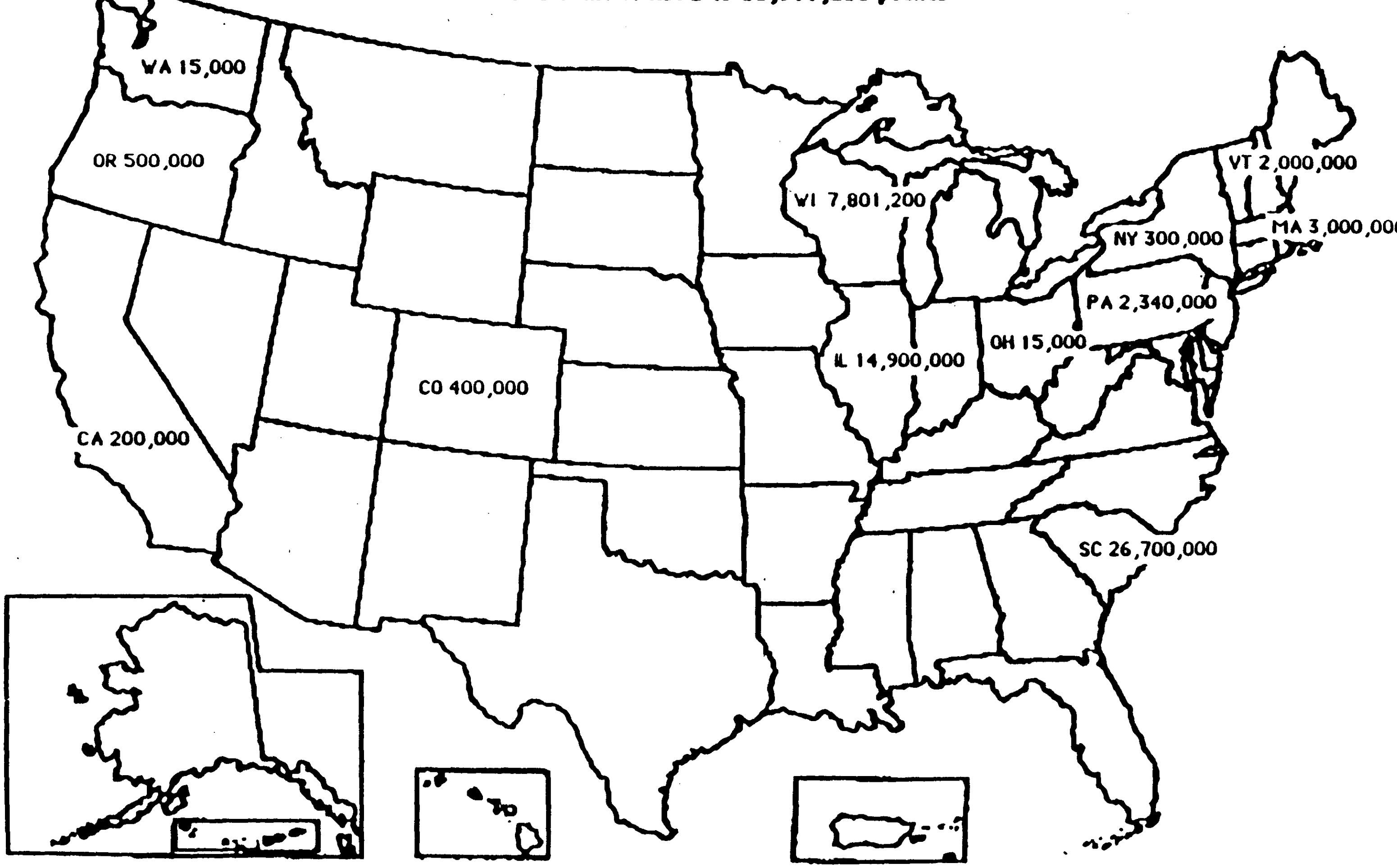
However, even if all these constraints and uncertainties could be overcome and markets are developed for most of the materials estimated to be collected by 1993, the question arises:

Is it enough?

The total amount of post-consumer HDPE packaging likely to be collected by 1993 was estimated to be a mere 6.9%-10.3%

UNITED STATES

Total amount of HDPE is 58,971,200 pounds



MAP 1

of all HDPE used in residential disposable applications. (This percentage correlates closely with the U.S. Office of Technology Assessment (OTA) estimates which state, "If market projections are realized for PET and HDPE, by the mid-1990s the Nation could achieve a 10% recycling rate for containers and packaging" (OTA 1989).)

On the demand side, any significant increase in post-consumer residential collection (above the levels estimated in this analysis) would affect the availability of end markets. While the 280 million to 567 million pound end markets could absorb 9.8% to 19.9% of the 2856 million pounds of collectable post-consumer residential HDPE, this conclusion assumes an unlikely scenario in which the grades of HDPE being collected exactly match those being demanded. For blow molded applications, the largest source of supply and demand, only two scenarios showed that demand outweighed supplies. For one of these, supply accounted for 88% of demand, not allowing for much additional absorption by end markets. In only one blow molded scenario did demand significantly outweigh supply (in Scenario 3 -- low supply, high demand -- supply accounted for only 57% of demand). Due to a combination of technological, economic, infrastructural, institutional and attitudinal constraints, there is little promise that the majority of HDPE packaging will ever be collected for recycling. While HDPE and other plastics can never hope to achieve the recycling rate of over 50% for aluminum cans and corrugated boxes, the amount of HDPE estimated to be recycled also compares less than favorably with other materials, such as newsprint (33%) and container glass (30%) (Ruston 1990). The implications of these conclusions for the public and private sectors will be discussed in Part 3, Implications of the Market Development Analysis.

PART 3

IMPLICATIONS OF THE MARKET ANALYSIS

Government will largely determine whether end markets for recycled HDPE progress from hypothetical viability to established fact. Through a wide range of regulatory and economic mechanisms, government can influence the direction HDPE recycling will take. However, it is also up to government to weigh the costs and benefits of plastics recycling against increased restrictions on the use of plastics and to determine which option should be encouraged.

Part 3 consists of two chapters:

Chapter 6, suggests a Market Development Strategy for increasing the viability of HDPE recycling. The role of the public sector in developing such a strategy is discussed.

In Chapter 7, Conclusions, HDPE recycling will be discussed from a broader perspective: What are the implications of this market development analysis for the future of plastics recycling? The chapter will address the limitations posed by markets on HDPE recycling, the need for greater efforts on the part of the private sector, and the role of the public sector in evaluating whether plastics recycling should be encouraged or restrictions on the use of plastic increased.

CHAPTER 6

MARKET DEVELOPMENT STRATEGY

1.0 INTRODUCTION

The integrated market development analysis presented in Part 2, paves the way for the development of an integrated market development strategy. This strategy emphasizes the interrelationship between supply and demand and recognizes the constraints on plastics recycling posed by end markets. Such an approach is critical to the successful planning and implementation of plastics recycling programs.

Recycling programs have failed in the past because they have not paid enough attention to end market development; demand for the materials is not carefully assessed and little effort is put into expanding end markets. Rather, the focus has been on supply side issues; mandatory collection legislation is enacted, collection programs are set up, and intermediate processing facilities are built. A supply driven strategy encourages investment in processing post-consumer materials in the hope that they meet manufacturers' specifications. It is often assumed that once supplies become available, "the market" will take care of finding homes for them (Kovacs 1988). But, as former Congressional staffer, William L. Kovacs points out, "It is questionable... whether additional supply by itself creates markets (Kovacs 1988)."

Because HDPE recycling is in its infancy, communities have been able to avoid active market development without causing significant harm to their programs; there are enough end markets available to handle the small amounts of HDPE collected. However, as large states and waste hauling companies begin to recycle HDPE, such short sighted strategies could backfire. If resources are not devoted to identifying and establishing end markets as collection programs are implemented, existing end markets could become glutted and the viability of recycling programs would be threatened (Kovacs 1988).

As discussed in Chapter 5, the size of future end markets for post-consumer HDPE is uncertain at best. Many factors such as falling virgin resin prices, competition with other recovered materials and allocative mismatches could significantly diminish the viability of these end markets. While potential end markets for recycled HDPE exist, many are not just sitting out there waiting for supplies to come rolling in. Rather, these end markets must be actively sought out and developed.

Recycling program planning must change from a supply driven focus to a focus on the interaction between demand and supply. A strategy must be created which links end markets to sources of supply. Such a strategy would identify local and regional end markets, assess the needs of these end markets and then target resources to developing supplies that meet manufacturers' needs. In cases where end markets are underdeveloped or non-existent, resources could be devoted to their development. This integrated market development strategy would enhance the economic and practical viability of recycling programs by creating demand for materials.

This Chapter is devoted to a discussion of the development of an integrated market development strategy. The role of the public sector and the market development tools to implement such a strategy will be addressed.

2.0 THE PUBLIC SECTOR ROLE IN MARKET DEVELOPMENT

Through its roles as regulator, taxing authority, financer, waste collector, purchaser of materials and planner, the public sector can have a substantial impact on the development of end markets for recycled HDPE.

Market development can be carried out most effectively at the state level. The state is responsible for long range solid waste planning and can control the flows of large quantities of materials to end markets. Of course, local government has an important function in its role as waste collector. Collection must be coordinated with end markets and therefore state governments must coordinate their market development activities with local governments. However, because market development depends on the guarantee of large steady supplies and substantial financial and technical resources, only the largest municipalities can be effective in market development planning.

Local and state governments have recently become involved in recycling by setting recycling targets and enacting mandatory recycling legislation. Rhode Island, Oregon and New Jersey were the first States to enact some type of "mandatory" recycling legislation and nine other States[1] have followed suit (Kovacs 1988; Brewer 1990b; and Ruston 1990). Of these States, only Rhode Island has a statewide collection program that includes PET and HDPE. However, States such as New Jersey, New York, Pennsylvania, Massachusetts and Connecticut are assessing the feasibility of collecting plastics.

Since few states and communities are collecting HDPE, end markets are not likely to present an immediate problem. However, this situation can change rapidly as it has in the past for other materials. Unless end markets are expanded as more states recover plastics, existing end markets will be exhausted and the viability of recycling programs threatened.

The need for regional cooperation in market development -- either among several communities or states -- is underscored by the potential for market flooding if several states in a region decide to develop HDPE collection programs during the same period. As existing end markets became saturated, competition would increase and each state would have to accept price cuts to maintain its market position (Kovacs 1988).

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[1] These nine States are California, Connecticut, Florida, Illinois, Maine, Maryland, New York, Pennsylvania and Vermont.

States and communities have much more to gain by cooperating than by competing. Coordinated market development on a regional level offers the potential for larger and more reliable supplies, shared infrastructure investment, attracting end markets to the region, and other benefits that result from improved economies of scale. One example the Northeast Recycling Coalition (NERC) -- a group of recycling and solid waste officials from ten New England and Mid-Atlantic States established under the auspices of the Council of State Governments -- promotes market development of recyclable materials on a regional level. In addition, the New Hampshire Resource Recovery Association coordinates cooperative transportation and brokering within northern New England.

The federal government can have a limited, but important role in market development. End markets are locally-based and the federal government is too removed to be effective in most instances. However, because end markets are not confined to state boundaries, the federal government could play a critical coordinating role. If each state individually regulated packaging requirements manufacturers would be faced with haphazard market conditions. The federal government could, for example, standardize resin identification labelling for plastic products and recycling content standards. Research and development would, under many circumstances, be most efficiently carried out at the federal level. Finally, the federal government could make a substantial impact through the procurement of products made with recycled materials; although it has made little effort to revise its procurement standards to include such products.

2.1 Stimulating Private Sector Investment

Market development for recycled plastics will require a joint effort by the public and private sectors. Neither sector acting alone can guarantee stable sources of supply and adequate end markets -- the two key elements for a successful recycling program. Because it is responsible for residential waste collection, the public sector controls the supplies. On the other hand, the private sector largely controls the markets for the materials and has the financial resources available to make needed infrastructure improvements.

Thus far, the public-private sector relationship has largely been one of regulator to regulatee. Cooperation from the plastics industry has not come easily. Unlike the aluminum, glass and paper industries, the plastics industry has made few investments in the collection, processing and manufacturing infrastructure for secondary materials (Mt. Auburn Associates 1989). Until recently, large resin companies had little incentive to invest in plastics recycling; recycled resins displace virgin resins and, unlike recycled aluminum, their current market price does not reflect significant cost savings over virgin materials[2]. It has only been through legislation limiting or banning the use of plastics that resin producers have been motivated to start investing in recycling infrastructure.

The public sector is likely to continue to be a motivating force for plastics recycling until plastics manufacturers and their customers accept the use of recycled resins and the market for resins is stabilized. Government intervention could either take the form of additional command and control legislation or more cooperative efforts such as economic incentives, technical assistance, joint public-private market development research and education programs. The next section is devoted to discussing some of these market development mechanisms.

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[2]It should be pointed out that virgin resin prices are artificially low due to depletion allowances and the depressed petroleum prices. In addition, the price of oil and virgin resins do not incorporate externalities such as U.S. military expenditures to assure access to oil and environmental externalities (Brewer 1990b). If these costs were reflected in virgin resin prices, the use of recycled resins would offer a significant competitive advantage. (See also Chapter 2.)

3.0 AN INTEGRATED MARKET DEVELOPMENT STRATEGY

Market development for recycled plastic requires the pairing of sources of supply with end markets. If one of the pair is ignored, markets will be unstable. The following market development strategy recognizes the need to address both halves of the pair.

The market development strategy that follows is broken into three sections: identifying and developing potential end markets; developing sources of supply to meet end market needs; and linking buyers to sellers. Although end market development is meant to precede decisions on what to collect and how it should be processed, the actual market development process is likely to be much more dynamic. Programs are likely to be developed incrementally with easily recycled materials being incorporated into the program first (Mt. Auburn Associates 1989). As more end markets are found or created, more communities within a state will be included in the program.

While most of the market development tools discussed below are addressed to state government, references are made to other levels of government when applicable. In addition, many tools would be most effectively implemented through regional efforts.

Several are currently being used for other recyclable materials but could be easily adapted for recycled plastics. Finally, while much of the discussion is targeted to the public sector, many of the tools are also applicable to the establishment of private sector plastics recycling programs.

3.1 IDENTIFY AND DEVELOP POTENTIAL END MARKETS

Since it is likely that most states have some HDPE manufacturers that can use recycled HDPE, there is a role for almost every state in identifying and developing end markets. Efforts are likely to be targeted at blow molding and extrusion manufacturers who can most easily use post-consumer residential HDPE. Developing local end markets is important in that transportation costs for recycled plastics are high due to their high bulk density. It also buys the state some insurance of future demand (if long term contracts can be arranged with these manufacturers).

In addition to plastics manufacturers, manufacturers' customers -- private companies, government procurement officials, as well as consumers -- should be targeted for "buy recycled" programs. Finally, export markets should be pursued as part of an effort to increase the demand for recycled materials.

3.1.1 <u>Plastics Manufacturers</u>

3.1.1.1 Market Studies and Surveys

Before implementing HDPE collection programs, the state should conduct a market development study. The study should assess potential end markets within the state, the region and outside the region and the demand for specific types of supply. As part of the study, the state should survey their plastics manufacturers to determine how many there are, which ones are consuming HDPE, how much HDPE they are consuming and their willingness or ability to use post-consumer HDPE. The purpose of these surveys is to determine whether viable end markets exist and where market development efforts should be targeted. When the survey is complete a database of potential end markets should be created to assist in future outreach efforts. States such as New Jersey, Minnesota, Connecticut and Michigan have conducted market development studies and surveys for plastics (EDF 1988; Mt. Auburn Associates 1989; and RIS 198?).

3.1.1.2 **Promoting Recycling Among Existing Manufacturers**

In those states in which potential HDPE end markets have been identified, contact with manufacturers must be established to assess their needs. Promoting greater use of recycled materials by manufacturers often means providing financial and technical assistance. Outreach with manufacturers can require a one-on-one, "knocking on doors" approach. The State of New York, for example, has included such outreach as an integral part of its market development program.

Needs Assessment:

It is important for the state to learn what types and quantities of recycled materials manufacturers could use and what their specifications would be including: the grade of the material (blow molding, extrusion or injection molding), the quality of the material (acceptable level of contamination, degree of cleanliness, color) and its acceptable form (baled, granulated or pelletized).

In addition to the types of materials required, the state should assess the equipment needed -- such as screen changers and feeders -- to facilitate a conversion to recycled resins. Manufacturers that could potentially use large quantities of recycled HDPE could be encouraged to integrate into recycling operations by purchasing front-end washing systems, granulators and pelletizers. Some of this equipment could be financed through the economic development tools discussed below.

<u>Economic Incentives</u>:

A wide range of economic incentives are being used by states to promote investment in recycling processing capacity and end market infrastructure development. In some instances existing economic development programs are being used to finance recycling investments; in other instances programs have been created specifically to encourage investment in recycling. Often these programs are administered by a state's department of economic development which may not necessarily be geared to support recycling efforts.

Economic incentives share the risks of plastics recycling ventures --such as demand, supply and price instability -- between the public and private sector. They should be used to support needed, but perhaps currently, unprofitable enterprises. Resources should be carefully targeted so as not to support private investment that would have occurred anyway. While funding for these programs can come out of a state's general fund, other more economically efficient mechanisms which link the cost of waste disposal to packaging demand -- such as surcharges on incineration and landfilling or packaging taxes directed at the private sector purchaser level (see previous section) -- can be devised (EDF 1988).

The following are some examples of economic incentives being offered by states:

Tax Credits and Exemptions: At least three states -- New Jersey, Oregon and North Carolina --offer investment tax credits (ITCs) against certain state or local taxes for the purchase of recycling equipment. About six other states have recycling ITC legislation pending. Credits can be received for collection, processing and manufacturing equipment and for recycling facility purchases. The States of New Jersey and Oregon offer credits of up to 50% for many of these purchases. In the past, the state of Oregon offered a special plastics recycling tax credit (Mt. Auburn Associates 1989). Other tax credits include exempting recycling equipment from sales taxes and facilities from property taxes.

Manufacturers can also be encouraged to use recycled materials through secondary materials use tax credits (SMUCs). SMUCs are tax credits which credit a portion of the purchase price of recycled materials. These credits have been proposed but never enacted (Brewer 1990b and Ruston 1990).

Tax credits may not be the most effective means for promoting investments in recycling. They are often used by processors and manufacturers that would likely have made investments without the credit, and do little to encourage new businesses to invest in recycling (EDF 1988 and Kovacs 1988).

Low Interest Loans and Direct Grants: Low interest loans and direct grants -- for new facilities and/or recycling equipment -- are often more effective than tax credits because they can be targeted toward specific projects that the state feels are in need of development. Tax credits, on the other hand, do not distinguish between projects which are more or less needed (EDF 1988).

Technical Assistance:

As discussed in Chapter 2, manufacturers' lack of knowledge about recycled resins is one of the main barriers to increasing demand. Gaining manufacturers' acceptance of recycled resins will require hands-on training and education. Workshops and extension programs could be established. Manufacturers must be provided with information on the properties of recycled resins and on recycling equipment as well as the names of processors they can contact. They must also be given the opportunity for experimentation; samples of recycled materials should be sent to them for testing. (See sections 3.2.2 and 3.3.2 for additional mechanisms that can be used to provide technical assistance to end-manufacturers.)

3.1.1.3 **Attracting End Markets to the State**

If, through the market survey, it is determined that viable end markets do not exist for recycled packaging materials in the state, end manufacturers can be attracted to the state through the use of economic incentives and by the guarantee of large supplies. Such efforts are more likely to succeed if done on a regional level.

3.1.2 <u>Product Purchasers</u>

Manufacturers often don't have control over the materials they use; their customers -- both from the private and public sectors -- specify the materials to be used. These customers must begin to demand that their products be made using recycled resins.

3.1.2.1 **Private Sector Purchasers**

Large purchasers -- such as Proctor and Gamble -- who are demanding the use of recycled materials in the products they buy are changing the face of HDPE recycling. McDonalds is establishing a toll free phone number to encourage contact from potential suppliers that make products using recycled materials.

The state should identify businesses that purchase products that could be made using recycled resin and work with them to change their product specifications. Educational and outreach programs will be needed here as well. These efforts will likely take the form of direct negotiation over greater voluntary use of products with recycled content.

Often businesses have their products manufactured in another state. If these outreach efforts were conducted on a regional level, states would less likely be placed in a position in which they pay the costs of market development without reaping the benefits.

Another way that states can increase the use of recycled materials by these businesses is through mandatory recycled content legislation. The state of Connecticut has enacted such legislation for newsprint, whereby all newspapers practices. Such a situation, in fact, exists. As discussed in Chapter 2, States promoting recycling are pursuing pipe manufacturers who violate procurement requirements for the use of virgin resin in corrugated pipe.

Twenty three states have legislation or executive orders requiring state agencies to procure products made with recycled material (EDF 1988 and Kovacs 1988). Several procurement programs are geared to the purchase of recycled paper and should be broadened to include plastics.

The federal government and many local governments also have procurement programs for recycled products. The federal procurement program is almost non-existent. The Resource Conservation and Recovery Act (RCRA) requires federal government agencies to procure products composed of the highest percentage recovered materials practicable, once EPA publishes regulations for particular products. Prior to October 1987, the federal government had only developed one procurement guideline (Kovacs 1988). After being sued on this issue by the Environmental Defense Fund, the EPA issued three additional procurement guidelines (Ruston 1990).

As discussed in Chapter 2, many government procurement specifications require the use of virgin resin even though recycled resins could meet performance specifications.

entering the state of Connecticut must contain a certain percentage of recycled content. Similar laws could be enacted for plastic bottles and other plastic products. Although it is unlikely to gain support, legislation requiring that certain products -- such as oil bottles -- be black to increase recycling content is an option. Efforts to regulate product specifications should be done at the regional level to create a uniform, rather than haphazard, market for businesses. The Northeast Recycling Coalition (NERC) is establishing standards for recycling content (EDF 1988).

Packaging taxes, though not in use at this time, can be placed on the packaging these businesses purchase according to its recyclability and/or recycled content. Even a small tax placed on each of the thousands of plastic bottles a laundry detergent company buys could make a substantial impact. Lastly, secondary materials use credits can be extended to these businesses.

3.1.2.2 Government Procurement

Promoting recycling should begin at home. An unfavorable impression would be created if government promoted recycling in the private sector but did not revise its own purchasing

These standards should be re-evaluated to determine whether recycled materials could be used. When recycled resins are found to be acceptable, procurement standards should be revised to require the use of a minimum percentage of recycled content (EDF 1988).

In many cases products made of recycled resins may have to be tested. Du Pont and the Illinois Department of Transportation are jointly testing such products to determine whether they can replace currently purchased products made of virgin materials (CSWS 1989b).

Under Florida's procurement program, any manufacturer making a product using recycled materials can request that the state evaluate it to determine whether it can replace a currently purchased product made of virgin materials (Kovacs 1988).

Whenever possible, bidding requirements could include price preferentials which allow for the purchase of products made from recycled materials as long as they fall within a certain percentage of the lowest bid. The States of Florida and New Jersey, for example, include price preferentials in their procurement regulations (EDF 1988 and Kovacs 1988).

Some procurement programs for recycled products are more effective than others. In many instances the modification of procurement specifications to include products made of recycled materials is left up to the discretion of individual state agencies. Many modifications that are made are "on the books" only. Procurement programs often fail because they do not gain the support of procurement officials and users. A successful program therefore requires outreach and education including vendor shows and workshops. These programs should be carefully targeted and incrementally implemented. Efforts which try to tackle every government agency at once will likely be ineffective (EDF 1988).

3.1.3 Individual Consumers

Ultimately it is the consumer that will determine demand for recycled products. The state should promote greater acceptance of products made of recycled materials through educational and "Buy Recycled" publicity campaigns. These programs can also be targeted to businesses and state and local agencies.

Product labelling is an important aspect of any program targeted at consumers. Recycling terminology is often misleading and confusing to consumers. Products are labelled "recycled" even though they have little recycled content. Companies using their own rework material label their products "recycled." Products are labelled "recyclable" even though no local recycling programs exist. Products labelled "recyclable" are confused with those labelled "recycled." Regulations standardizing recycled content should be enacted. Labels on items made with recycled materials should also be standardized and should inform the consumer as to the level of recycled content. This should be done at the regional or federal level to ensure consistency (Abt 1989; Christiansen 1990a; and Smith 1990).

3.2 DEVELOP SOURCES OF SUPPLY TO MEET END MARKET NEEDS

As discussed in Part 2, end markets for recycled HDPE largely depend on the quality of the material. Sources of supply should be developed to match the specifications of end markets. Based on knowledge of manufacturers specifications gained through the market development survey and needs assessment (discussed in the previous section), determinations can be made regarding which materials should be collected and the degrees to which they must be processed. Resources can then be targeted to increasing quality control and encouraging infrastructure investments in processing -- strategies which will make recycled resins more attractive to manufacturers and their customers.

3.2.1 **Collecting materials that end markets can absorb**

HDPE can be targeted for collection as end markets are found for it. Plastics recycling programs are likely to begin on a small scale and grow incrementally as manufacturers demand more recycled resins. Items, such as milk jugs, which are easily identified and in greatest demand will likely be targeted first. As attitudinal and technical constraints are overcome and infrastructure expands, harder to recycle items could be collected (Mt. Auburn Associates 1989). The State of New Jersey links market demand to its collection programs. Communities can receive an exemption for up to one year from collecting mandated materials for which no end markets exist. During this time the State must help them develop these end markets (Kovacs 1988).

The first HDPE items to be selected for recycling will most likely be the most valuable and the least expensive to recycle. As more HDPE items are collected, the per-ton value of the resulting secondary material will most likely decrease and/or collection and processing costs will increase. It may be a long time before communities will feel that collecting anything other than milk jugs, base cups and perhaps, laundry detergent bottles, is worthwhile. Unless viable end markets are found for such items as shampoo bottles, ice cream containers and plastic bags, it is unlikely that they will be collected. For each additional item added to a collection program, trade-offs between higher collection and processing costs must be weighed against the value of diverting it from landfills and incinerators.

3.2.2 <u>Setting Standards for Recycled Materials</u>

When manufacturers purchase virgin resin they know what they are getting. There are only a handful of virgin HDPE producers; they are large companies, make HDPE in huge quantities, and have tight quality control. Recycled resin quality, on the other hand, varies from processor to processor. Inconsistent quality has been one of the major causes of manufacturers' reluctance to buy recycled resins. It has also discouraged agencies such as state departments of transportation to allow the use of recycled materials in the products they purchase. No standards exist to ensure reliability and protect the purchasers of these resins from receiving poor quality materials (Christiansen 1990a).

Just as performance standards, tests and definitions exist for virgin resins, so too, must they be developed for recycled resins. Definitions of recycling terminology must be clarified and standardized. Standardized methods are needed to test the performance and control for the quality of recycled materials (OTA 1989).

The potential for a government role in establishing these standards is at best ambiguous. While the public sector can develop their own procurement specifications, it is more difficult to mandate product standards for the private sector. Virgin resin standards, for example, are developed by the plastics industry and ASTM. While the ASTM draft guidance for the use of recycled resins is a move toward developing standards for recycled resins, it is currently too general to be very effective.

Government and industry can possibly work cooperatively to develop standards and definitions. Standards could classify recycled HDPE according to its grade (i.e. blow molding, extrusion and injection molding), quality (degree of cleanliness) color, and properties (melt index, density, etc.) (Christiansen 1990a). (See Table 6.1 for an example of a classification system proposed by Eric Christiansen.)

Another possible avenue for state level involvement in quality control would be the certification or licensing of processors. The quality of recycled resins could be

TABLE 6.1
RECYCLED RESIN CLASSIFICATIONS

Classifications apply to flakes or pellets.

Grade A: Cleaned, natural color, single resin flakes and pellets good enough to replace virgin in any product except food-contact products. Grades A and B differ primarily in degrees of quality control and testing and product warranties.

Grade B/N: Cleaned, natural color, single resin flakes and pellets good enough to replace virgin resin in engineering grade or high appearance products. Typical end uses: clear egg cartons and light colored bottles in any product except food-contact products.

Grade B/C: Cleaned, colored, single resin flakes good enough to replace virgin resin in engineering grade products where black or off-color is acceptable. Typical end use: black corrugated drain pipe.

Grade C/N: Cleaned, natural color, single resin flakes and pellets good enough to replace virgin resin in non-engineering grade products. Typical end uses: Colored highway cones and barrels.

Grade C/C: Cleaned, colored, single resin flakes good enough to replace virgin resin in non-engineering grade products where black or off-color is acceptable. This grade of HDPE may have a slight temporary odor (soapy) and require hourly screen changing (replace clogged filter) during extrusion. Typical end use: black nursery pots.

Grade D/N: Uncleaned, natural color, single resin material. Includes bottles, bales and flakes but not pellets (pellets have been at least partially cleaned by pelletizing, thus classifying as B or C).

Grade D/C: Uncleaned, mixed color, single resin material. Includes bottles, bales and flakes but not pellets.

Grade E: Cleaned, mixed resin material good enough to replace virgin resin in products where a mixture of two or more resins is acceptable. Typical end use: Plastic lumber.

Grade F: Uncleaned, mixed resin material good enough to replace virgin resin in products where a mixture of two or more resins is acceptable. Typical end use: Plastic lumber (for processes not requiring cleaning).

certified in a similar manner to the way in which the U.S. Department of Agriculture (USDA) certifies products such as beef and dairy items. A materials testing center could be established as part of the program which would test materials that processors submitted for certification (Bennett 1988 and Christiansen 1990a). Certification would offer a means by which manufacturers could distinguish between reputable and disreputable processors, thereby reducing the risk of purchasing recycled resins (Ruston 1990). One potential problem could be monitoring and enforcing certification requirements.

The state would then act as a clearinghouse for manufacturers interested in purchasing specific grades of recycled resins. The government could supply a list of certified processors who make specific grades as well as technical information on each grade such as its properties and potential end markets.

A similar role was envisioned for the US Department of Commerce (DOC) under RCRA. DOC was "required to publish, by the end of 1978, uniform specifications for the classification of recovered materials with regard to their physical and chemical properties and characteristics,... the ability of the materials classified to replace virgin in various industrial, commercial and government uses... [and]

to identify existing and potential markets for recovered materials" (Kovacs 1988). DOC took little action to implement these requirements and during the Reagan administration the program was eliminated from the budget.

3.2.3 Offering Economic Incentives for Infrastructure Development

In order to bring post-consumer plastic from the point at which it is likely to be viewed as solid waste[3] to the point at which it becomes a valuable resource able to meet manufacturers specifications, in most instances, takes extensive processing. Without adequate cleaning, separation and pelletizing and/or granulating capacity little recycled material will be demanded. In 1987, 83 million lbs. of HDPE was recycled. Because only 16.6 million lbs. of washing capacity existed at the time, most of this recycled material could only be used in very low quality end uses (Mt. Auburn Associates 1989).

Processing capacity is being built at a rapid pace as large companies such as Plastipak, Du Pont, Dow and Sonoco Graham enter the HDPE recycling industry. It is estimated that over 100 million lbs. of HDPE processing capacity is being

[3] In other countries, what we consider "solid waste" is viewed as a valuable resource. In fact, scrap metal and waste paper are the leading exports from the port of New York and New Jersey (Kovacs 1988). U.S. attitudes must change if recycling is to succeed.

built east of the Mississippi (Schedler 1990). In addition, many new MRFs -- which will provide initial processing -- are being planned.

Plastics recycling has an advantage over newsprint recycling in that the cost of plastics processing equipment is relatively inexpensive compared to that of a deinking mill. Therefore facilities can be built either close to the supply source or end market manufacturer. In some instances, it may be economically feasible for manufacturers to buy their own recycling equipment.

Except for secondary materials use credits, the economic incentives used to promote investments in processing facilities are similar to those used to promote investments by end manufacturers discussed in section 3.1 above. In addition to tax credits, low interest loans and grants, avoided disposal cost sharing is an economic incentive mechanism used to support processing costs and investments.

Avoided cost credits are administered at the local level and are usually offered to privately owned MRFs and buyback centers. Since these companies reduce the collection and disposal costs to a local government they receive a portion of the local government's avoided disposal costs.

For private recyclers, costs (for collection, processing, etc.) must be less than or equal to the price they can get for the recycled resin. For the public sector, however, recycling costs can greatly exceed revenues as long as the net costs are less than the next least expensive disposal alternative (i.e. incineration or landfilling), in other words, its avoided cost. Therefore, in cases where recycling is unprofitable for businesses, it may be efficient for the public sector to pay for the services provided by private recyclers.

New York City and Newark offer avoided cost credits to buyback centers. Under New Jersey law, municipalities can pay brokers or processors to take their materials, as long as the cost is less than the cost of incineration and landfilling (Kovacs 1988).

3.2.4 Regulating Resin Production and Labelling

The quality of post-consumer supplies can be more tightly controlled through regulation. Restrictions or bans can be placed on the use of multi-layer packaging such as the squeezable ketchup bottle which contains 7 layers of different resins and adhesives and is virtually unrecyclable. Further restrictions could be placed on the use of different resins for specific applications. For example, shampoo bottles are made of many different resins; some are of PVC, others of HDPE, and still others of PP. If it were mandated that all shampoo bottles be made of HDPE, they could be easily recycled. These bottles would then be easily recycled. Finally, increased use of resin identification coding systems, particularly the development of optical reading separation systems, would increase quality control. These regulations would be most effective if promulgated at the national level.

3.3 LINK BUYERS TO SELLERS

3.3.1 Recycling Exchanges and Databases

The state should provide various information exchanges to facilitate the linking of processors and end-manufacturers. A database of processors, brokers and end-manufacturers should be maintained and made available to interested parties. The list of processors could be those certified by the state (see above). In addition, the state could operate a recycled materials exchange through which processors and end-manufacturers could buy and sell their materials. Finally, the state should establish a technical assistance service to provide technical information to plastics manufacturers and processors and assist them in the development of their plastics recycling ventures.

3.3.2 **Research and Development**

Research and development is critical to market development for recycled plastics. It is through testing, experimentation, and the development of new technologies that the size of end markets for recycled plastics will grow. A cooperative public sector-industry-university research and development center should focus on the identification of new end markets and on refining the quality of recycled HDPE. The center would function as an information service, offering guidance and technical information. The applied research center should be accessible to both processors and end-manufacturers who are interested in testing their products. Pilot projects to test new technologies could also be established by the center.

In addition to the establishment of a research and development center, the public sector can support research and development through grants for feasibility studies. These grants would be given to processors and end-manufacturers in order that they can test their ideas for increasing the development of plastics recycling end markets. New York State's Department of Economic Development is supporting two such feasibility studies for plastics recycling. The states of Colorado and Minnesota offer a tax credit for recycling R&D (EDF 1988; Kovacs 1988; Mt. Auburn Associates 1989; and Brewer 1990b).

4.0 CONCLUSION

The "horse before the cart" integrated market development strategy presented in this chapter emphasizes incremental end market development before supply-side collection and processing planning. Efforts are geared toward matching the quality of resins with manufacturers' needs.

The public sector has an incentive to promote recycling because it is less expensive, more environmentally sound and more politically expedient than alternative waste disposal methods such as landfilling and incineration. In assessing the extent to which economic incentives and resources should be used to develop end markets for recycled plastics, it is useful to place recycling in the context of the public sector's efforts to promote incineration. The public sector has secured the economic viability of incineration through tax exempt bonds; guaranteed tipping fees; the federally-mandated guaranteed sale of the electricity produced by incineration plants; and the guarantee of minimum waste flows. Recycling should be promoted just as, if not more, enthusiastically because it is a more environmentally sound alternative than incineration.

Despite the value of promoting recycling, the desirability of promoting plastics recycling is still questionable. The most concerted market development efforts by the public sector may only succeed in ensuring end markets for a small percentage of all the residential HDPE disposed of each year. Ultimately, it is the private sector which will determine the viability of plastics recycling. The next chapter, Conclusions, will examine the whether HDPE recycling is viable, the private sector role in ensuring its viability, and the extent to which the public sector should stimulate investment in plastics recycling.

CHAPTER 7

CONCLUSIONS

The "jury is still out" on HDPE recycling.

This thesis has shown that -- while it may not happen for several years -- a lack of HDPE end markets for recycled HDPE will pose considerable constraints on HDPE recycling. It has been estimated that 1993 demand for recycled post-consumer HDPE in current virgin HDPE end markets is 280 million to 567 million pounds. Assuming that this market potential is realized, recycled HDPE will displace only 3.5% - 7% of the over 8 billion pounds of virgin HDPE produced each year. Furthermore, these estimates show that there will not be enough end markets to handle more than a fraction of the 3278 million pounds of HDPE used in residential disposable applications.

On the supply side, this thesis has shown that only 225 million to 336 million pounds, or 6.9% - 10.3%, of the 3278 million pounds of HDPE used in residential disposable applications will likely be collected by 1993.

While a significant proportion of the base cups, milk jugs and laundry detergent bottles could be collected and absorbed in HDPE end markets, there currently seems to be little promise for these end markets to absorb "difficult to recycle" items -- such as films; unrecognizable shampoo bottles and food containers; and non-collectable caps and coating -- which account for approximately 50% of all HDPE residential disposables.

In order for plastics recycling levels to increase beyond those estimated in this analysis, it is likely that recycled plastics, in the form of plastic lumber, will have to displace wood and metal. While plastic may offer certain advantages over wood and metal in some applications, the size of these markets may not be very large and, as discussed in Chapter 5, policy makers must be aware of the fact that the use of recycled plastic to replace wood and metal does nothing to curtail virgin resin production and its associated environmental costs. The fact that the success of plastics recycling may depend on the replacement of other materials, sets plastics recycling apart from the closed loop recycling systems of other packaging materials such as aluminum and glass.

Ultimately the burden of proof is on the plastics industry, both resin and product manufacturers, to demonstrate that HDPE packaging is more recyclable than what this analysis has concluded and that it is as recyclable as other packaging such as glass containers and aluminum cans. It must increase the recyclability of the "difficult to recycle items". It must increase the amount of post-consumer milk jugs and laundry detergent bottles recycled by developing inexpensive collection mechanisms which will encourage more communities to collect them. It must increase the potential for HDPE end markets to absorb recycled HDPE by developing more effective processing systems which will improve the quality of recycled HDPE.

Furthermore, the plastics industry must redirect its efforts from promoting the use of recycled resins in wood and metal applications to the development of a semi-closed loop HDPE recycling infrastructure, whereby recycled HDPE will displace virgin HDPE. Resin producers will demonstrate their commitment to plastics recycling once they develop recycled HDPE resin product lines and encourage their customers to purchase them. In addition, virgin HDPE capacity expansion must be curtailed and the resources funneled into developing a plastics recycling infrastructure. It is difficult to take the plastics industry's recycling promotional efforts seriously when polyethylene capacity expansions totalling 22% of existing capacity are expected to come on-line in the next few years (*Modern Plastics* 1990b).

In the long run, investments in recycling facilities may prove profitable. Capital investments in recycling facilities are only a fraction of the cost of virgin resin capacity expansions. It is estimated that plastics recycling facilities use 40% to 60% less energy than virgin resin. Furthermore, hazardous waste and other disposal costs are much lower for plastics recycling facilities (Brewer 1990b).

So far, most investments in plant and equipment to build a secondary plastics infrastructure have not been made by large resin companies. They have had little incentive to develop a semi-closed loop recycling system which would ultimately displace virgin resins. A second factor discouraging investment by these companies is the negligible price differential between virgin and recycled resins, at least in part, due to the fact that oil prices are currently depressed, do not reflect environmental and other externalities and are subsidized through depletion allowances.

Private sector investments in developing a plastics recycling infrastructure have come from small to medium sized recycling companies (such as Wellman, Eaglebrook and Mid-West Plastics), buyback centers (such as R2B2), consumer product companies (such as Procter and Gamble) and plastic packaging manufacturers (such as Sonoco Graham and Plastipak) (Brewer 1990b and Mt. Auburn Associates 1989). As noteworthy as these efforts are, currently less than 1% of HDPE is being recycled. Large scale plastics recycling will occur only when more large consumer product companies and consumers begin to demand more recycled content in packaging, or when large resin companies become motivated to invest in recycling.

This motivation may have to come from the public sector. If the public sector determines that plastics recycling should be encouraged, it can either take a "command and control" approach by increasingly regulating plastics -- a strategy which has effectively stimulated some action on the part of the plastics industry[1] -- or it can use economic incentives such as the market development initiatives discussed in Chapter 6. It is likely that both approaches will be necessary. Whatever strategy it takes, emphasis must be placed on the demand as well as on the supply side; the development of end markets for recycled materials cannot be ignored.

The role of government in promoting plastics recycling or recycling in general, must be placed within the context of

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[1]Regulation has also been effective in other industries such as the newsprint industry.

tight budget constraints and a lack of technical resources. There are several low cost strategies that can be used to promote recycling such as standardizing labelling for recycled and recyclable packaging and other products, revising procurement specifications to include recycled materials and direct negotiation with consumer product and plastics manufacturers.

Despite tight budget constraints, resources used to promote recycling should not be viewed as a financial burden to the public sector. Since recycling is less costly and less environmentally harmful than incineration, resources should be channelled away from incineration to recycling. The same advantages given to the incineration industry -- such as guaranteed tipping fees, waste flows and end markets (for the energy produced); facility siting; and tax exempt bonds -- should be given to the recycling industry. In addition, the public sector's avoided disposal costs should be shared with private recyclers for the disposal services they provide. Finally, recycling could be financed with surcharges on landfills and incinerators. These surcharges would increase the costs of these other disposal methods to reflect their true environmental costs, thereby making recycling more attractive. States such as Connecticut, New Jersey, Iowa and Illinois have instituted landfill surcharges.

An outright ban on all disposable HDPE products is probably too premature and from a political perspective, not practicable. However, state and local governments should critically evaluate the recyclability of particular HDPE applications. Items that are shown to be difficult to recycle, and for which no recycling infrastructure is being developed, could be limited or banned. If it is concluded, for example, that plastics bags are unlikely candidates for large scale recycling and that paper bags are more recyclable and less environmentally harmful, they may decide to limit or ban the use of plastic bags. At the same time, they may conclude that milk jugs are fairly easy to recycle, offer advantages over coated paper cartons, and therefore, should not be restricted.

Unfortunately the information needed to make such an evaluation, often does not exist. A cradle-to-grave analysis -- evaluating all packaging items according to their toxicity in production, toxicity in disposal, recyclability and the impact recycling would have on reducing demand for virgin materials and toxicity in production and disposal -- would be helpful but is likely to be costly to conduct (Wirka 1989).

It is hoped that this market development study, by offering a greater understanding of the recyclability of HDPE, will contribute a small piece to such a cradle-to-grave analysis. It is also hoped that this market development analysis will provide a valuable methodology and decision making tool for solid waste officials for assessing and implementing HDPE and other plastics recycling programs. The analysis offers useful information on the complex economic, technological and attitudinal issues which impact the recyclability of HDPE; stresses the need to assess the recyclability of disposable HDPE products from both demand and supply side perspectives; and suggests a market development strategy for increasing the viability of plastics recycling. With these tools, solid waste officials will be in better position to determine whether HDPE and other plastics recycling are worth promoting.

With the possible exception of PET, HDPE is the easiest plastic to recycle. Unless HDPE recycling is demonstrated to be viable, the future of other plastics recycling efforts -- and perhaps the future of plastics -- will not be optimistic. The plastic industry's efforts to develop an HDPE recycling infrastructure will therefore be closely watched by the public, environmentalists, solid waste officials and legislators.

APPENDIX 1
GLOSSARY

COMMINGLED PLASTICS: A wide-spec mix of two or more types of post-consumer plastics, often used in low quality end uses.

INDUSTRIAL PLASTIC SCRAP: By-products from the manufacturing process, also known as plant scrap. Can include sprues, runners and defective parts. It is often ground and re-fed into the process.

OFF-SPEC OR OFF-GRADE VIRGIN PLASTICS: Resin that does not meet its manufacturer's specification, but which can be used in less demanding applications.

POST-CONSUMER PLASTICS: Plastics derived from finished goods that have served their intended economic function and would otherwise be destined for disposal unless diverted for the purpose of recycling. These plastics can be generated by the commercial or residential sectors.

PRIMARY RECYCLING: The recycling of relatively uncontaminated waste plastics into a product with characteristics similar to those of the original product.

RECOVERED PLASTICS: Plastics diverted from the waste stream for the purpose of recycling. Does not include those materials generated from, and commonly reused within, an original manufacturing process.

RECYCLED PLASTICS: Plastics diverted from the post-consumer or industrial waste stream for use within a manufacturing process. These materials may or may not have been subjected to additional processing steps.

REWORK PLASTIC: A plastic generated from, and reused within, a processor's own operation.

SECONDARY RECYCLING: The processing of waste plastics into materials that have characteristics different than those of the original plastic product.

TERTIARY RECYCLING: The production of basic chemicals and fuels from plastic waste. Pyrolysis and hydrolysis are examples of these processes.

VIRGIN PLASTIC: Plastic material made of raw materials that has not been subject to use or processing other than that required for its original manufacture.

Sources: Christiansen Associates 1990f; Mt. Auburn Associates 1989; ASTM 1989b.

APPENDIX 2
MANUFACTURING PROCESSES FOR HDPE PRODUCTS

EXTRUSION

Extrusion is used to make continuous products of constant cross section such as film and sheet, profiles, and pipe and tubing. The process is also used to compound and pelletize resins and to coat wire and cable (Wilder 1988). The extruder consists of one or two screws which rotate inside a long barrel or cylinder. Resin, in the form of powder, granules, pellets or beads, is poured into a hopper and is picked up by the rotating screw which mixes, melts and pumps the resin through the barrel. Ensuring a steady stream of uniform melt is critical to producing a high quality product. As the resin is pumped along the extruder cylinder it is melted by heaters placed along the cylinder walls and by friction created by the rotating screw. At the far end of the cylinder, the melt is pumped through a die which gives the product its shape. After leaving the die, the form is transported to an air or water cooling system. It is then continuously fed to other processing steps such as cutting, sealing or coating.

Before leaving the die, the melt passes through a screen pack, or filter, located between the screw and the die, which removes any unmolten polymer and accidental contaminants which could damage the die or final product (Leidner 1981; Powell 1983; Radian Corp. 1986; *Modern Plastics* 1989). The screen pack is of particular significance in the processing of recycled resins which may be contaminated. While useful for screening out contaminants, the screen pack can increase the pressure and temperature of the melt (Allen 1989 and *Modern Plastics* 1989).

Film: There are two main film processes: extrusion casting of film and blown film extrusion. Extrusion casting of film is similar to the process used to manufacture sheet. In the blown film process, a thin tube is extruded vertically. Air is blown into the tube to expand it. The film is then cooled and can be sealed to produce plastic bags.

Coextrusion: In coextrusion, two or more resins are extruded in multiple extruders to form multi-layer products which take advantage of the different properties of each resin.

The resins must have similar melt temperature and die flow characteristics. (*Modern Plastics* 1989). Products with a center layer of recycled material are produced by coextrusion.

INJECTION MOLDING

Injection molders can produce a wide range of products of varying sizes from tiny components to pieces that are many feet long. Products manufactured in this process have a high degree of dimensional accuracy and can be as finely detailed as a screw. Typical products include: housewares, toys, furnishings and automotive parts (Radian Corp. 1986).

Reciprocating-screw injection molding is the most widely used injection molding system. Similar to the extrusion process, the resin is pumped along and melted by a rotating screw in a heated barrel. Unlike extrusion, injection molding is a batch, rather than continuous, process. A valve at the end of the barrel closes and the screw moves back under pressure allowing the melt to accumulate. When a specified amount has accumulated, the valve opens, the screw stops rotating and it moves forward pushing the material through a nozzle and into the mold cavity. The material is injected under high pressure which is maintained until the form has solidified. Thermoplastics are cooled in the mold, often by an indirect water cooling system. After the piece has set, the mold opens and the part is ejected from the mold. The pieces are trimmed to remove sprues and runners and the thermoplastic scrap (reclaim) is usually ground and reused.

While the piece is solidifying, more material is being accumulated for the next piece. The cycle time can range from less than one second up to a few minutes. Most machines have multiple cavities allowing for several pieces to be molded simultaneously (Leidner 1981; Powell 1983; Radian Corp. 1986; *Modern Plastics* 1989).

BLOW MOLDING

Blow molding is primarily used to produce bottles such as HDPE milk jugs and the PET soda bottles. Other applications include containers used in packaging applications, auto fuel tanks, dolls and lighting fixture globes (Radian Corp. 1986).

There are two basic types of blow molding processes; extrusion and injection blow molding. Both processes begin with the creation of a preform which is expanded by air pressure to fill the inside of a mold. The difference between the two processes is the way in which the preform is made (Radian Corp. 1986).

Extrusion Blow Molding:
Extrusion blow molding is largely used to process plastic bottles from HDPE, PVC and PP. Pieces produced in this process can be recognized by the long scar, often found at the base of the bottle, created during the pinching step. A tube shaped preform is extruded downwards and positioned between the open halves of a mold. When the mold is closed, the tube is pinched together on the bottom. The tube is then expanded by compressed air inside the mold cavity and conforms to the shape of the mold. The top of the mold forms the threads in the neck of the bottle. After cooling, the part is ejected. Flash, created where the preform was pinched, can be trimmed. This scrap, along with defective containers, is usually ground and reused. Most extrusion blow molding processes use a rotary set-up, allowing several pieces to be manufactured simultaneously. All handleware bottles are produced through this process. Multi-layer blow molded bottles and other packaging is produced by coextrusion followed by blow molding (Powell 1983 and Radian Corp. 1986). This process is used to manufacture laundry detergent bottles with a recycled center layer.

Injection Blow Molding:
In this process, the preform is form by injection molding around a core pin. For bottles, the preform looks like a test tube with a threaded top. It is then transferred to the blow mold by the core pin while being kept at melt temperature. (The preform can also be stored and reheated for blow molding as needed.) In the blow mold, air is blown through the core pin and the preform is expanded to the size and shape of the bottle or container. The part is cooled and ejected. The process produces no scrap and the pieces do not have a pinch-off scar.

Injection Stretch Blow Molding:
Stretch blow molding is largely used to produce PET beverage bottles although they are also produced through conventional injection blow molding. PP and PVC are also stretch blow molded. Injection stretch blow molding is similar to injection blow molding. It is a more economical but is slower, requires more material and is more difficult to operate. In addition, the product's barrier properties are poorer and the system does not allow for the storage of preforms (the preforms must be blown immediately) to adapt to supply and demand cycles. The main distinguishing characteristic between the two methods is that in injection blow molding, the preform is transferred on a core pin, whereas in injection stretch blow molding, it is transported via neck rings.

Stretch blow molded products are almost always biaxially oriented (although biaxially oriented products can be manufactured in conventional injection blow molding systems). The bottle is stretched biaxially in the radial direction by compressed air and mechanically along the vertical axis, aligning molecules in both planes (Leidner 1981 and Allen 1989).

ROTATIONAL MOLDING

Rotational molding (also known as rotomolding) is used to make hollow, seamless products of all sizes including mannequins, dashboards, furniture, planters, light globes, trash cans, fuel tanks and dolls. Multilayer parts can also be easily produced.

The process is relatively simple. Plastic powder or liquid, is placed in a mold and heated while being rotated. The rotation uniformly spreads the melt over the entire surface of the mold. The mold is cooled and the part is removed. Rotomolding is an inexpensive process. The polymers most commonly used are LDPE, polypropylene, PVC and nylons (Leidner 1981; Radian Corp. 1986; *Modern Plastics* 1989).

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216-88