CHAPTER 7

RECYCLING AND DISPOSAL OF WASTE PLASTICS

James W. Jensen, James L. Holman,
and James B. Stephenson
Rolla Metallurgy Research Center, Bureau of Mines,
U.S. Department of the Interior, Rolla, Missouri

INTRODUCTION

Plastics Production and Waste

The United States generates about 300 million tons of domestic, commercial, and municipal solid wastes each year, comprising what is referred to as "urban refuse." The steady growth of plastics production during the last decade manifests the increased importance of recycling and disposal of the plastics in these wastes. A graph of national production of plastics in 1971, Figure 7.1, compiled from data appearing in *Modern Plastics* magazine, shows that the thermoplastics comprised nearly three-fourths of the total plastics produced.[1] According to a recent research report, it was determined in 1970 that plastics amounted to nearly two per cent of the total collectible wastes in the U.S., and current estimates are in the range of two to three per cent. This would indicate that several million tons of plastics appear in urban refuse, a sizable fraction of the total amount produced.

This paper is concerned primarily with the thermoplastic materials in municipal and industrial wastes. These are varieties of polymeric materials which become soft when heated and can be molded, extruded, and shaped by various techniques. In contrast, thermosetting or chemically hardened plastics do not soften upon heating and cannot be remolded. The thermoplastic types most commonly used are as follows:

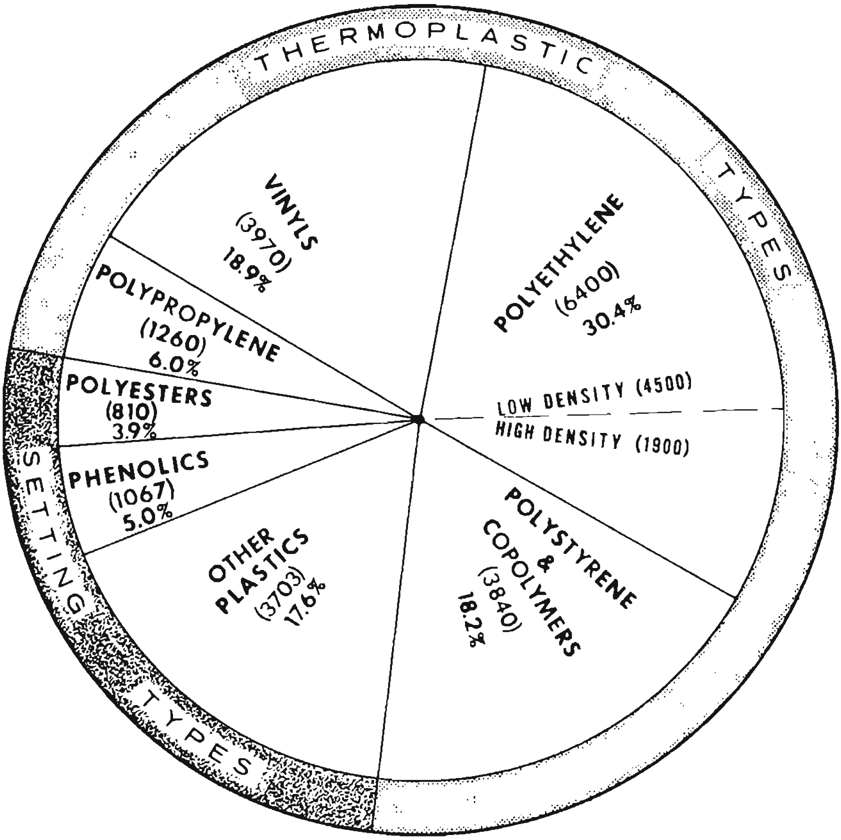

Figure 7.1. Plastics production in the U.S.A. in 1971 was 21,050 million pounds. Graph shows distribution by types, millions of pounds in parentheses, and per cent of total production.[1] *Reprinted by permission of* *Modern Plastics*, *McGraw-Hill, Inc.*

-- polyolefins, including high- and low-density polyethylene (HDPE and LDPE), and polypropylene (PP)
-- styrenes, including polystyrene (PS) and acrylonitrile-butadiene-styrene (ABS)
-- vinyls, primarily polyvinyl chloride (PVC) and polyvinylidene chloride (PVDC).

Role of Packaging

The packaging industry in 1971 consumed nearly one-fifth of the total plastics production. A breakdown of the types of packaging products and the quantities of polymer types consumed in each product group in 1971 is presented in Table 7.1. It has

Table 7.1

Plastic Resins Consumed by Packaging Industries in 1971[1]

	Consumption by Plastic Types, Millions of Pounds					
Products	*Polyethylene*	*Vinyls*	*Styrenes*	*Polypropylene*	*Other*	*Total*
Adhesives		43			11	54
Coatings	424	110		4	75	613
Closures	50	15	21	35	28	149
Containers and lids	1,030	145	810	65	80	2,130
Film and sheet	1,400	110	45	100	65	1,720
Total	2,904	423	876	204	259	4,666

been predicted that the total use of plastics for these products will increase to 7.5 billion pounds by 1980.[2] In 1966, according to an estimate by the Bureau of Solid Waste Management, 90% of all packaging materials promptly entered the solid waste stream, accounting for about 13% of the total solid waste volume.[3] The trends are sharply upward in the marketing of convenience packaging for consumer products and in the capture of these packaging markets by manufacturers of thermoplastic containers and other products. As a consequence, the role of packaging in municipal wastes is expected to grow rapidly in the 1970's. The appearance of these wastes will be prompt and they will be disseminated heterogeneously throughout municipal refuse.

Plastic items with longer service life, varying from 5 to 20 years or more, enter the scrap cycle at a much slower rate than packaging materials. Examples of these items are furniture and household goods, toys, hardware, components of automobiles, machinery, and structural products. Plastic waste may accrue as a by-product in recycling of other materials, as in the case of the thermoplastic coverings by-product in the recycling of insulated copper and aluminum electrical wire.

Disposability of Plastic Wastes

The disposability of plastic wastes has been studied in considerable depth and is the subject of ongoing research and much public attention.[4-6] Disposal by incineration has been an object of special concern because of corrosion and air pollution problems reportedly arising from the burning of plastic wastes. About one-half of the weight of polyvinyl chloride is accounted for by hydrogen and chlorine, which combine to form hydrogen chloride upon incineration of the plastic; this readily reacts with water to form hydrochloric acid. The study by DeBell and Richardson for the Manufacturing Chemists Association, released in 1970,[7] reinforced the position taken earlier by the Society of Plastics Industries[8] that a properly designed and operated incinerator will not have serious corrosion or combustion problems from the plastics in municipal refuse, and that available wet scrubbers and stack gas controls will be able to maintain effluents within air pollution standards. This viewpoint is not universally accepted.[9] It has been estimated that over 70% of all municipal incinerators in the U.S. were either too poorly designed or are operated so inefficiently that they will not be able to meet these standards.[10] All plastics can be incinerated, although some do not burn readily.

Besides incineration, the principal method now in use by municipalities to dispose of solid waste is to deposit it in sanitary landfills. Plastic containers, if intact, resist compaction in landfills and consume much space because of the voids they create. On the other hand, chopped plastics make a compact, inert landfill material, but may wash or float in wet conditions. Being nonbiodegradable, most waste plastics are not satisfactory for composting, but granulated waste plastics may have applications as decorative or inert ground cover.

Investigations of pyrolysis by the Bureau of Mines and other organizations have led to the conclusion that this method of disposal of plastic wastes may have an economic advantage by generating more by-product fuel gas than is needed to supply heat for the reaction and also yielding organic liquids and a char, both of which have value.[11]

A large portion of the plastic raw material used in manufacturing is recycled within the plant. Trimmings, sprues, runners, and other rejects are chopped and fed back into the forming machines. One manufacturer recently stated that 50% of his plastic supply was recycled in this manner.[12] This "home scrap" has essentially the same properties as the starting material, in particular, the rheological properties which must be held to close tolerances for advanced fabricating machinery. Waste scrap of mixed and unknown properties would be unacceptable in most plants using today's high-speed production methods. Commercial recycling of collected waste plastic was first reported in 1970 by a California firm manufacturing drainage tile from scrap high-density polyethylene milk bottles of a particular brand, which had been collected from housewives.[13]

WASTE PLASTICS AS RESOURCES

Bureau of Mines Involvement

The U.S. Bureau of Mines regards the approximately 300 million tons of urban refuse generated in the nation each year as "resources out of place."[14] The agency directs a major portion of its research effort to methods of separation, recovery, and recycling of metal, mineral, and energy-based materials in urban refuse and other wastes, under various legislative mandates that have been reaffirmed in the Mining and Minerals Policy Act of 1970.[15]

For more than two years Bureau scientists and engineers have had in operation a 1,000-pound-per-hour pilot plant to process, at a cost of about $4.00 per ton, the residue from municipal incinerators and thereby recover concentrates of metals, glass, and minerals worth about $15 per ton, materials that are currently being wasted by many cities. Using the same principles, the Bureau is now putting into operation a similar pilot plant to process unincinerated municipal waste, as delivered by the collecting vehicle, to separate the tin cans and iron, the nonferrous metals, colorless and colored glass fractions, paper, and plastics. This is in line with a trend to recycle wastes at or near the consumer level of the "scrap cycle."

This type of investigation concerns what has been described by one group of scientists as a "low energy path," referring to the energy required to recycle the materials in contrast to the high energy cost of winning new material from natural resources. Even in the absence of economic incentives, they noted, recycling schemes can be successful by virtue of the dedication or zeal of consumers who sort and collect the paper, glass, aluminum, iron, and other wastes that can be recycled at low energy cost.[16]

The Bureau of Mines efforts in waste treatment are considerably more sophisticated in relating cost to benefit. They deal with technical problems encountered in industrial processing plants and municipal disposal operations, and derive data that may be extended or scaled up for development of large waste management systems. By an informed and logical conceptual approach, unit processes that conform to the low-energy cost requirements can be taken from the fields of mining and metallurgy and applied to the recycling of urban waste.

The scope of the Bureau's Solid Waste and Recycling Program is extensive, as revealed in a report released in 1971.[17] Four main areas of research, development, and demonstration are pursued: (1) extraction of mineral, metal, and energy values from urban refuse, (2) upgrading and recycling of automotive and related ferrous and nonferrous scrap, (3) utilization and stabilization of mine, mill, and smelter wastes, and (4) recovery and reuse of values from industrial waste products. The Bureau has maintained its traditional view, from the standpoint of conservation, that all types of wastes should be restored to the role of natural resources as efficiently as possible. The present level of public concern for environmental and ecological conditions accounts for the rapid rise of the Bureau's normal conservation efforts to a major role in the recycling of urban refuse.

Major Sources of Wastes

Waste plastics may enter the recycling stream from several major sources, and will vary accordingly in characteristics. From the viewpoint of one in the plastics industries, "waste or scrap plastic comes from three main areas, namely producers of primary polymers, fabricators of plastic products, and consumers themselves."[18] In this paper our main interest is in the consumer wastes. A certain amount of plastics can be made to circumvent the normal solid waste stream for recycling through individual consumers and volunteer groups, but this amount is not expected to be a very large percentage of the total plastics waste load.

A second supply, ultimately expected to be the major source of waste plastics for recycling, is from processing systems, of the type mentioned above, treating raw urban refuse. The Bureau system is not the only one designed to segregate a plastic fraction. The "Hydrasposal-Fibreclaim" demonstration project, built and operated under a grant from the Solid Waste Management Office of the U.S. Environmental Protection Agency in Franklin, Ohio, segregates a plastics "concentrate" from the metal, glass, and fiber in urban waste.[19] The plant will process up to 150 tons of unsegregated municipal waste per day directly from the city sanitation trucks.

Industrial processing plants can provide a major supply of plastic waste, with a specific example being the wire salvage industry. Many thousands of tons of wire stripping wastes have accumulated in localities where pollution controls have terminated the burning of the insulation from scrap wire. The scrap treatment consists of granulation or chopping of the wire into short segments, which releases the fiber, rubber, plastic, and other nonmetallic coverings. The metal is then recovered by separating the waste from it by screening, tabling, air separation, and other dry methods. The waste may be 10 to 20 years of age or older. It is often highly variable in composition, containing PVC, PE, neoprene, rubber, and fiber, and is usually heavily contaminated with metal. The high PVC content generally prevents the disposal of wire-stripping waste by incineration.

A PROCESSING SYSTEM FOR WASTE PLASTICS

The elements of a processing system to recycle plastics separated from urban refuse would consist of a group of unit operations of the type used in minerals processing, selected from a variety of methods to accommodate the variability of waste content.[20] On the basis of information obtained from literature on the properties of virgin plastics and by laboratory experimentation, a proposed system has been designed with the flow diagram shown in Figure 7.2. The main stages of this system are discussed below.

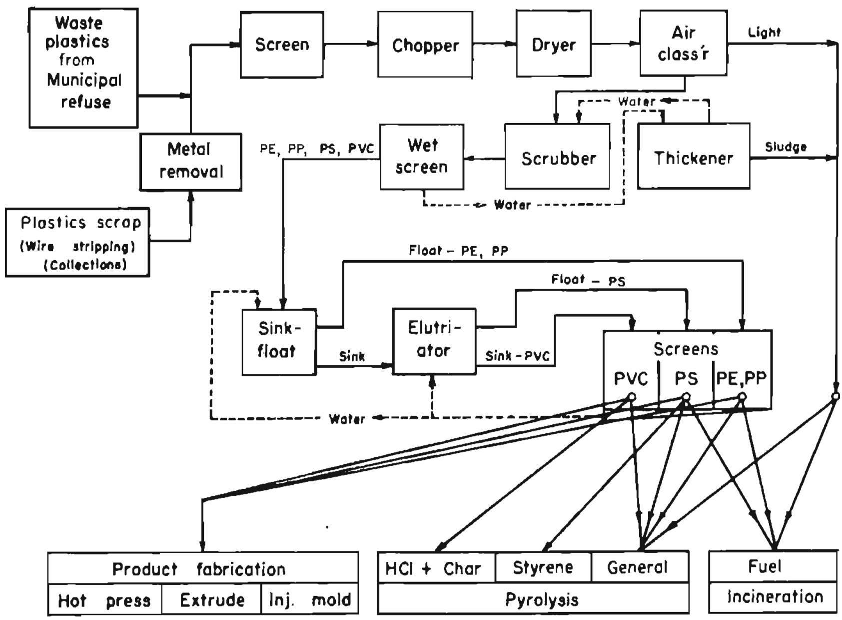

Figure 7.2. Proposed flow diagram of processing system for reclaiming waste plastics.

Waste Receiving and Preparation

Scrap containing metal would be treated to remove and recover the metal. Wire-stripping waste, in particular, would be processed for maximum metal extraction. As necessary, scrap would be granulated and dried.

Classification and Separation

Film, paper, and fiber would be removed by an air classifier (or other devices) and sent to a separate processor or an incinerator. The granular plastics would be scrubbed to remove labels, soil, and remains of contents, then screened from the wash solution and fed into the sink-float-elutriator units. This stage could be arranged to make separations in various ways. Only one component, PVC, might be removed from all the rest, or it could be set to isolate each of the five thermoplastics, PVC, PS, HDPE, LDPE, and PP, as separate fractions.

Utilization and Disposal

Depending on demand or market and other factors determining the recycling and disposal balance of the operation, various disposition schemes can be arranged for the separated plastic materials. Three classes of end use or disposal are illustrated.

Product Fabrication

The utilization of the recycled thermoplastics in production of useful articles by the methods used for virgin plastics is an important aim in recycling. The products and methods may require more tolerance of deficiencies in properties of the recycled materials, but generally they will be similar to the normal industrial ones. As shown in the diagram, all of the common thermoplastics would be fabricable if it is assumed that separation would be clean enough. Polystyrene, for example, would be sufficiently free of other plastics to be processed into a polystyrene product by a conventional molding method.

Pyrolysis

Several methods of pyrolytic treatment of materials are possible, and the one to be used would depend on the character of the available waste and the available equipment.[5,21] As shown in Figure 7.2, a polystyrene-rich fraction can be dissociated to form the styrene monomer and this could be recycled. The dissociation of PVC to yield a char, and HCl that could be used in a chemical or metallurgical process, is also placed under the general heading of pyrolysis. Pyrolysis may be used extensively in treatment of organic wastes of all types; beyond the indicated "general" category of the method, this paper does not cover it in any detail.

Incineration

For long range use, this may be the most favored and economical method to dispose of all of the plastics exclusive of the PVC. Plastics (other than PVC) separated from urban waste would have a heat content of up to 16,000 BTU per pound, in contrast to estimates ranging from 2,000 to 7,000 BTU per pound for the heat content of raw urban waste.[9] If a plastics separator could be set to divert the PVC from the incinerator to safeguard it from the problems associated with evolution of HCl, the other plastics could be readily utilized as a high-energy fuel.

EXPERIMENTAL INVESTIGATION

An 800-pound sample representative of the type to be obtained by segregation in a municipal collection system or a recycling center was obtained for this investigation by a waste plastics collection campaign in Rolla, Missouri. (The results of this work are presented in the Bureau of Mines Technical Progress Report 50.) In addition, samples of wire-stripping wastes were received from three recycling plants in Missouri, and some results of the investigation of these wastes are described. A more detailed account of this research and of experiments on samples of plastics from the College Park and Franklin waste processing plants is being prepared.

Analysis

The distribution of plastic types in the community collection was analyzed by hand-sorting half of the collected sample into four classes, and the results of this analysis are shown in Table 7.2. In the second column appears the distribution of the plastics in solid waste collected in the U.S. in 1969 according to an estimate made by DeBell and Richardson.[7] The community collection was probably biased in favor of blow-molded bottles made of polyethylene which would account for the high percentage of this class of material. Bottles predominated in the collection. Of a sample of 2,000 bottles, detergent containers accounted for more than 500, and cosmetic, food, and medicine containers made up most of the remainder. These

Table 7.2

Distribution of Plastics in Municipal Waste, weight-per cent

Type	*Distribution in Rolla Community Collection*	*Reported Distribution in Municipal Waste*
Polyethylene and polypropylene	74	54
Polystyrene	19	20
Polyvinyl chloride	5	11
Other plastics	2	15

containers have very low bulk density, and chopping the collected waste to pass through a 1/2-inch screen reduced the space it occupied to one-tenth of the original volume.

Rapid and practical methods were used to sort the plastics in the collection into types, based on feel, sound, appearance, flame behavior, and odor. For example, polyethylene feels greasy and is usually somewhat flexible, whereas polystyrene is brittle and is noisy when dropped or flexed. A scheme of analysis by flame behavior and odor was especially useful for chlorinated compounds. A hot copper wire touched to PVC and then placed in the blue flame of a gas burner produces a bright green hue. Differential thermal analysis and thermogravimetric analysis were used where simpler methods failed; the exothermic and endothermic reaction temperatures give clues to polymer identity.

Washing

For collected plastic waste that has not been processed through a waste treatment plant it is necessary to have a washing or cleaning step to remove contaminants such as dirt, labels, adhesives, and residues of contents. Labels, and the adhesives with which they are applied, are difficult to remove, and remnants may be deleterious in subsequent use of the plastics. Numerous small-scale trials of washing solutions and methods of agitation were made to remove labels from polyethylene bottle chips. Hot and cold water, aqueous mixtures of alcohol, acetone, benzene, and sodium hydroxide solutions were tested with stirring, blending, ultrasonic agitation, ball milling, and attrition scrubbing. Label-covered polyethylene clipped from bottles, chopped to minus 1/2-inch (Figure 7.2) and air classified to remove loose paper, showed on examination that about one-third of the pieces were free of paper and adhesive. Subsequent attrition scrubbing in the above solutions, and in some cases with sand added to the mixture, generally cleaned upwards of 90% of the particles.

On a more practical scale, washing tests were made on 1,200-gram plastic samples in 6,000 ml of solution in a laboratory scrubbing machine. One sample was composed of bottles chopped to minus 1/2-inch and air classified; the other was a composite from the waste plastics collection containing about the same proportions shown in the community collection in Table 7.2. In Table 7.3, the results

Table 7.3

Percentage of Sample Showing No Contamination After Attrition Scrubbing for One Hour

	Medium		
Material	*1N NaOH/ 150 g/l Sand*	*Tap Water 150 g/l Sand*	*Tap Water*
Composite plastic waste	93	95	92
PE-PP bottles	98	96	94
PS waste	95	93	91

of 1-hour scrubbing on samples in three different media are shown in terms of the percentage of pieces showing no contamination. It appears that the use of NaOH would not be justified in view of the cost of adding and disposing of the reagent, but the use of sand in the scrubber may be justified when the scale of operation is expanded.

Separation

The optional methods for separating plastics by polymer types are essentially those based on shape, density, selective dissolution, and electrical properties. Chemical dissolution may be feasible in some special situations, such as the recovery of paper from plastic-coated paper milk cartons, but it was not considered in this work on raw plastic waste. Electrostatic methods may also be used in separating plastics from paper and other wastes, but the similarity of the plastics to one another may render this method ineffective in separating generic types on a commercial basis.[22]

Air Classification

Air classification is a unit operation in the processing system that can differentiate the film, fiber, and foam in the plastic waste from the more substantial fragments of molded plastic articles and containers. Numerous experimental and commercial types of air classifiers have been described,[15,17,23] and a relatively small and simple device will process an appreciable volume of the waste. The one shown in Figure 7.3 was assembled from very inexpensive materials and powered with a household vacuum cleaner.

Figure 7.3. Demonstrating the separation of paper and fiber from plastic wire stripping waste with an air classifier.

The design is shown in a schematic diagram in Figure 7.4. This device is capable of classifying 50 to 75 pounds per hour of mixed plastics such as the wire stripping waste shown in Figure 7.3.

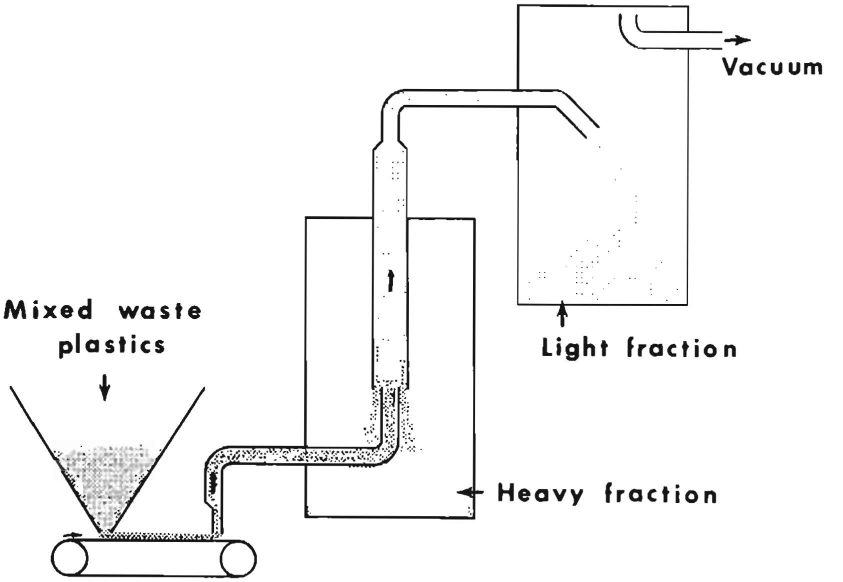

Figure 7.4. Schematic diagram of the air classifier used in separating film and foamed plastic from heavier varieties found in urban refuse.

Air classification experiments were conducted on 1,600-gram samples of a composite mixture of the community collection chopped to pass through a 1/2-inch screen, with the results given in Table 7.4.

Table 7.4

Air Classification of Community Collection

		Analysis, %				
Material	*Weight %*	*Mixed PE and PP*	*PS*	*Mixed Film*	*PVC*	*Mixed Foam*
Air light fraction	24	8	5	67	8	12
Air heavy fraction	76	77	19	0	4	0
Composite	100	60	16	16	5	3

It was apparent that the shape of the material, for example, the thickness and area of bottle fragments, strongly influenced the response to the air stream. The composite contained 60% mixed PE and PP, 16% PS, 5% PVC, 16% mixed film, and 16% mixed foam, by weight, and was differentiated by the air classifier on a weight basis of 24% light fraction and 76% heavy. The heavy fraction was upgraded in PE, PP, PS, and PVC, and had no film, foam, or fiber content remaining.

Liquid Media Separation

The densities of virgin thermoplastics are nearly the same as that of water, and vary in a manner that favors gravity methods in aqueous solutions for separating them by types. An assortment of virgin plastic pellets obtained from various manufacturers was analyzed to determine the relative densities.[15] They fell in the convenient and well-defined ranges shown in Table 7.5. Although

Table 7.5

Observed Densities of Virgin Pelletized Plastics

Type	*Density*
PP	0.90
LDPE	0.92
HDPE	0.94-0.96
PS	1.05-1.06
PVC	1.22-1.38

additives may alter these densities, results on plastic waste materials in the laboratory have confirmed that most scrap plastics are in the density ranges for their type given in the table.

Experimental separations of the five major types of plastic wastes were conducted in an unagitated vessel with distilled water, a calcium chloride solution, and two alcohol-water combinations (Figure 7.5. These media gave virtually complete separations of hand-sorted samples of waste. Only the polystyrene sample showed variance from clean

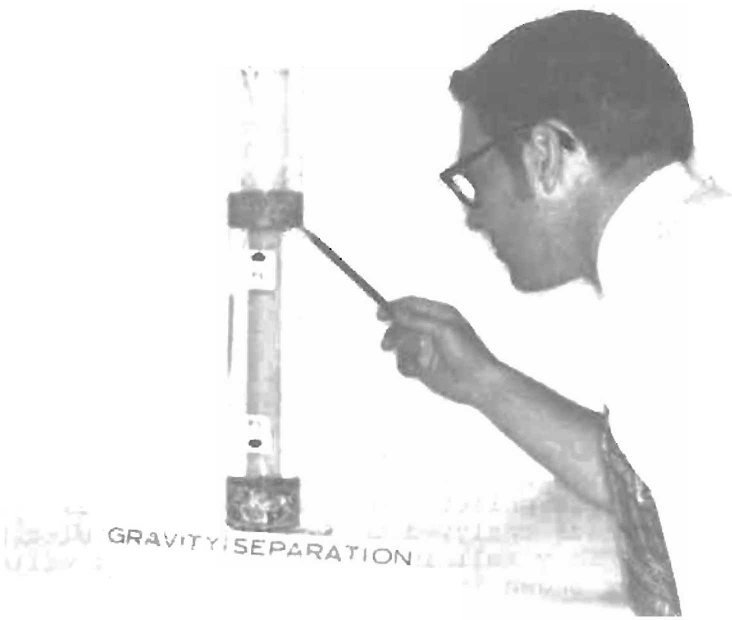

Figure 7.5. Differences in density of the plastic types found in urban waste.

separation and this result proved to be caused by an error in sorting, which permitted the inclusion of polyvinyl chloride with the polystyrene to the extent of 12%.

Based on this sink-float method, a theoretical scheme of separation for the five most plentiful components of waste thermoplastics in packaging wastes is given in Figure 7.6. This scheme relies on the use of fluids differing in composition and density and entails practical requirements for rinsing, waste disposal, and control of composition. A separator using only water as a medium was devised for separating waste plastics into three fractions, polyolefins, polystyrene, and polyvinyl chloride. As shown in Figure 7.7, the mixed plastics are fed into a sink-float separator that floats off the polyolefins; the other two components, after they sink, are transported by airlift to an elutriation column. The overflow from this column carries over the polystyrene, and the polyvinyl chloride sinks and is carried by a second airlift to its receptacle.

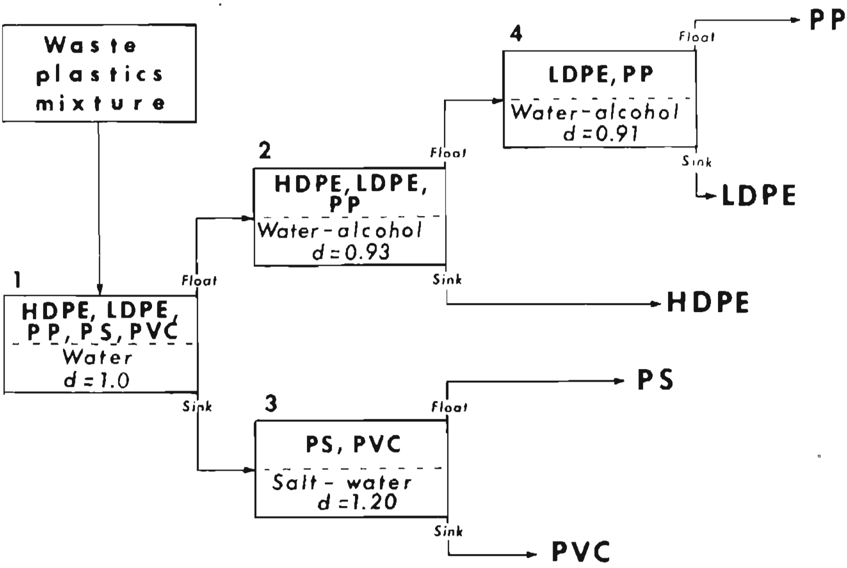

Figure 7.6. A method for isolating the five thermoplastics commonly found in packaging wastes by sink-float separations in four liquids with different densities.

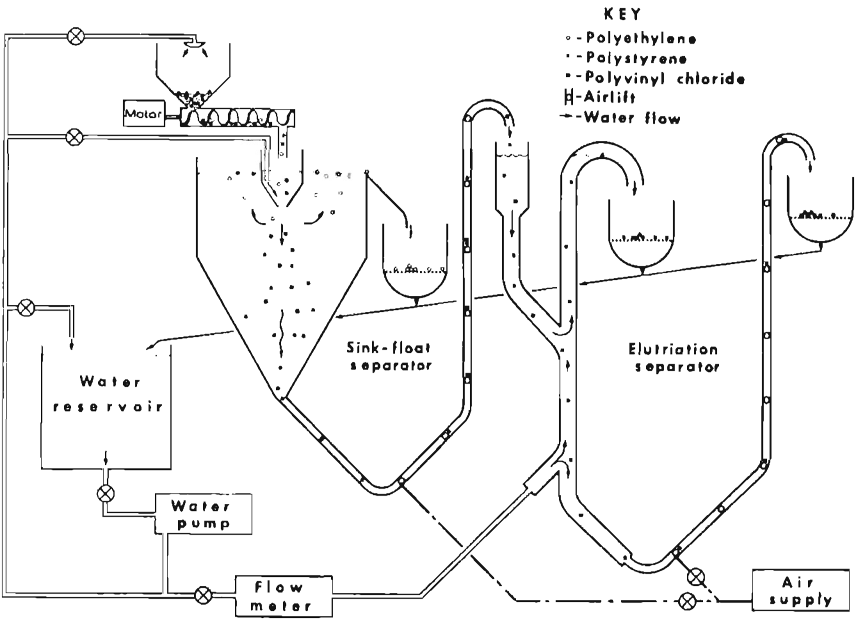

Figure 7.7. Schematic diagram of the hydraulic separator used for plastic segregation.

The laboratory model shown in Figure 7.8 has been used successfully to separate mixtures of virgin pelletized plastics, and of chopped waste plastics, at rates ranging from 5 to 50 pounds per hour.

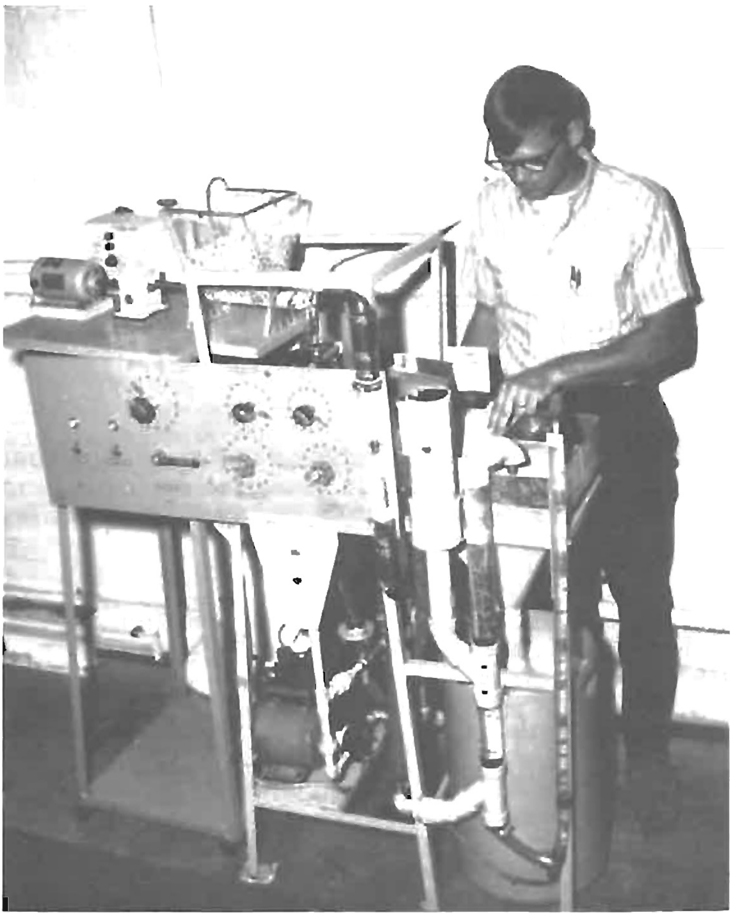

Figure 7.8. The laboratory hydraulic separator being used to demonstrate the separation of major plastic types according to their density.

Tests to determine the purity of the separated fractions at various feed rates were made on five-pound samples containing the following proportions of plastic types in weight per cent: 60 HDPE, 25 PS, 15 PVC. The impurity count in weight per cent of the separated fractions, presented in Table 7.6, indicates that very good separation was achieved, even at the higher feed rates.

Table 7.6

Quality of Separation of Plastics at Various Feed Rates by Hydraulic Separator

Feed Material	Feed Rate lb/hr	Impurity in Fraction, wt %*		
		HDPE	PS	PVC
Pellets of virgin plastic	17.6	<0.1	<0.1	<0.1
	24.0	<0.1	<0.1	<0.1
	36.6	<0.1	<0.1	<0.1
	50.0	<0.1	0.8	1.3
Collected waste chopped to minus 1/2-inch	5.1	<0.1	2.2	0.3
	8.6	<0.1	3.9	0.4
	19.7	<0.1	3.9	0.4
	30.0	<0.1	3.7	<0.1

*Impurities were extracted from the separated fractions by the sink-float method using solutions with densities of 1.00 and 1.20 g/cc, and were then weighed.

The performance of the laboratory model of the hydraulic separator, shown in Figure 7.8, has been successful enough to recommend it as a prototype for designs on a larger scale that would treat quantities commensurate with the outputs of municipal waste treatment plants. It has also shown that standard equipment in use in the minerals processing industries can be adapted to the separation of plastic types with slight modifications.

Metal and PVC From Wire-Stripping Waste

Three typical commercial chopped wire stripping waste samples studied thus far contained various amounts of residual metal, most of which was in the form of fine copper wire. As shown in Table 7.7, the copper content ranged from 1.0 to 5.2% and aluminum from 0.2 to 1.3%. The chopping process to strip the metal from the insulation[24] reduces the

Table 7.7

Results of Air Classification of Wire Stripping Wastes

Material Sample		*Fraction %*	*Metal Analysis %*		*Metal Distribution wt %*	
			Cu	*Al*	*Cu*	*Al*
	Raw sample	100	3.8	0.4	100	100
A	Air light	24	6.4	0.6	41.0	32.9
	Air heavy	76	3.0	0.4	59.0	67.1
	Raw sample	100	1.0	1.3	100	100
B	Air light	11	2.6	2.0	28.0	16.6
	Air heavy	89	0.8	1.2	72.0	83.4
	Raw sample	100	5.2	0.2	100	100
C	Air light	9	2.9	0.2	5.1	9.1
	Air heavy	91	5.4	0.2	94.9	90.9

major portion of the waste material to a particle size on the order of 8 mesh. The heterogeneity of these waste samples makes it difficult to obtain consistent chemical analyses; the data reported are average values based on duplicate analyses.

As mentioned previously, air classification and screening were used for upgrading this waste material. Samples were sized using 10-, 14-, and 20-mesh screens mounted in a mechanical shaker. One means of recovering fine wire from stripping wastes involves the use of the electrostatic separator,[22] which performs best on uniform small material. As the material is fed onto a grounded drum rotating in a highly charged electric field, the plastic is pinned to the drum and removed by a fixed wiper blade; the wire is thrown into another compartment. Adjustable bins are available to receive the products and the material in the middle bin may be rerun for additional separation.

Another method being tried for concentrating metal from wire stripping wastes is the mineral jig.[25] In this unit the material is fed onto a pulsating liquid-solid bed. As the liquid is pulsed, the gravel bed is forced apart repeatedly, allowing the heavy material to sink into the bed and eventually through the slotted screen at the bottom into a collecting chamber. At the same time, water fed into the unit carries off the lighter material in the overflow. The jig (Figure 7.9) has been very effective for removing wire from sized, air-heavy wire strippings.

Figure 7.9. Laboratory jig, being used to concentrate wire from stripping wastes.

To make separations of the three samples, air classification was first used to remove fiber and dust which made up about 10 to 20 weight per cent of the material. In most cases, the fibrous air-light material entrapped a higher metal percentage of fine wire than the air-heavy fraction, as revealed in the data in Table 7.7.

Screening usually concentrated the metal in the smaller size fractions. In sample A, the metal content of the air-heavy fraction was upgraded from 3% to 12% by screening the material on a 10-mesh screen. Usually 40-60% of the copper was concentrated in the minus 20-mesh fraction. Table 7.8 shows the analyses and distribution of copper and aluminum after screening the air-heavy material.

Table 7.8

Screen Test Results

Material	*Mesh Size*	*Fraction wt %*	*Analysis, %* Cu	*Analysis, %* Al	*Metal Distribution, %* Cu	*Metal Distribution, %* Al
A	+10	71.8	0.7	0.4	13.3	61.4
	-10+14	21.0	2.3	0.5	12.8	22.4
	-14+20	4.4	11.6	0.7	13.5	6.6
	-20	2.8	81.8	1.6	60.4	9.6
		100.0	3.8	0.5	100.0	100.0
B	+10	66.4	0.3	1.6	23.1	77.6
	-10+14	18.4	0.9	1.0	19.2	13.4
	-14+20	10.7	1.1	0.9	13.7	7.0
	-20	4.5	8.4	0.6	43.9	2.0
		100.0	0.9	1.4	100.0	100.0
C	+10	9.0	3.5	0.3	6.6	18.9
	-10+14	24.9	2.0	0.2	10.5	34.8
	-14+20	42.2	3.2	0.1	28.5	29.5
	-20	23.9	10.8	0.1	54.4	16.8
		100.0	4.7	0.1	100.0	100.0

The aluminum was not concentrated appreciably by screening. Screening the air-heavy material on 10-mesh provided a quick method for upgrading the copper content prior to electrostatic separation and jigging.

As can be seen in Table 7.9, jigging was somewhat more efficient than the electrostatic route for removing the metal from this waste. In material A the metal content was lowered from 12.5% to 0.4% by jigging; in comparison, electrostatic separation lowered the metal content to only 1.1%.

These experiments, which are not completed, demonstrated the feasibility of recovering valuable

Table 7.9

Metal Removal from Wire Stripping Waste by Electrostatic vs. Jigging Methods

Material	Material Fraction wt %		Metal Analysis wt %		Metal Distribution %	
	Electro-static	Jig	Electro-static	Jig	Electro-static	Jig
A (-10 mesh)						
Tails	78.4	86.3	1.1	0.4	6.5	2.8
Concentrate	21.6	13.7	57.0	88.6	93.5	97.2
Composite	100.0	100.0	13.2	12.5	100.0	100.0
C (-10 mesh)						
Tails	95.5	94.0	1.5	0.7	21.9	19.3
Concentrate	4.5	6.0	83.9	45.8	78.1	80.7
Composite	100.0	100.0	5.2	3.4	100.0	100.0

metals from the wire stripping wastes. Of the remaining waste, it was deduced that 50-75% of the air-heavy fraction was in the density range of 1.20-1.58 g/cc. This fraction analyzed 24-27% chlorine and apparently contained 90-95% of the polyvinyl chloride in the waste. The air-light fraction can be safely incinerated after metal removal.

Utilization or Disposal

The final disposition selected for plastic wastes will be a decisive factor in determining which of the methods described will be used in the treatment of the waste. Of the end uses shown in Figure 7.2, incineration and general pyrolysis are subjects beyond the scope of this report. Technical aspects of the dissociation of PVC for process resources have been investigated and will be discussed. Some attempts to determine the amenability of the available wastes to product fabrication will also be described.

PVC Dissociation

Pure PVC resin contains approximately 60% HCl but the material used in PVC products usually includes significant proportions of additives to vary the hardness, color, and other properties; the PVC content is generally 50% or less. A sample cable jacket, for example, contains 50 parts PVC resin, 30 parts plasticizer, 20 parts filler, and additions of stabilizer, lubricant, and coloring agent. Samples of PVC from two commercial blow-molding plastics contained 46 and 54% HCl, and the PVC portion of the Rolla community waste collection contained about 28% HCl.

It was advocated previously[26,27] that the dissociation of waste PVC to yield HCl and char, both having uses in process industries, offered a method of disposal with apparent economic incentive. It was also illustrated that, on the basis of freight charges in southwestern U.S., it costs twice as much to ship HCl in tank cars in the form of concentrated hydrochloric acid (20° Baumé, 31.45% HCl) as it does to ship an equivalent amount in boxcars in combined form as polyvinyl chloride.

Experiments on the thermal decomposition of PVC in a 1-liter reaction kettle showed that HCl evolution begins at 220°C and proceeds with increasing rapidity as the temperature is raised. Results of 1-hour thermal treatments of two virgin samples of PVC molding resins and the Rolla waste PVC are shown in Table 7.10. Dissociation was virtually completed after 1 hour at 300°C, liberating 99% of the HCl in the virgin samples and 92% in the waste.

Table 7.10

Liberation of HCl from PVC Samples
Reaction Time of 1 Hour

	HCl Liberation, wt %		
Temperature °C	Virgin PVC Sample A	Virgin PVC Sample B	Rolla PVC Waste
220	11.8	1.8	5.0
230	64.0	5.0	8.0
250	88.7	18.2	15.0
270	95.8	67.2	60.0
300	99.0	99.0	92.0
400	99.0	99.0	93.0

The other products of the dissociation, the char, the liquid condensate, and the off-gas, have fuel value. The char (Figure 7.10) from the waste sample contained 6.3% H_2O, 15% ash, 51% volatile matter, and 27% fixed carbon. Its heat content was 12,300 BTU per pound. Ten to fifteen per cent of the PVC from the Rolla collection dissociated as liquid condensate, which burned with thermal energy content of 14,000 BTU per pound, leaving about 1% ash. The off-gas, 10-19% of the waste PVC, contained water, methane, ethane, propane, and butane, and was estimated to have a heat content of 20,000 BTU per pound.

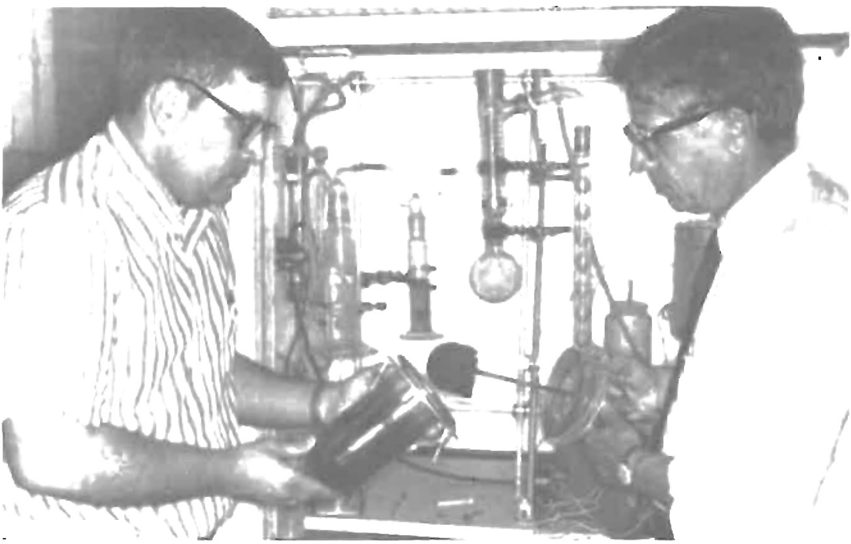

Figure 7.10. Examining char left when polyvinyl chloride was decomposed at 300°C.

It is evident that waste PVC merits consideration in chemical processing as a resource for HCl, char, and fuel. For the consumer of HCl in outlying regions, waste PVC could offer advantages in flexibility of supply, storage, and use; low hazard in shipping and storage; and low cost in shipping.

Fabricating Products from Waste Plastics

Hot pressing, a simple and straightforward method of fabricating objects from thermoplastic materials, lends itself readily to working with waste plastics for several reasons. The dies are usually of simple, geometric designs, with triangular, rectangular, or circular cross sections. Plasticity, rather than liquidity, will normally suffice for mold-filling. The mold is confined so that high pressure can be sustained long enough for viscous material to flow into voids; the cooling rate is not critical after pressing is completed. This method has been used with success to form chopped waste plastic into test wafers 2 inches in diameter. In the laboratory, at pressures of 3,000-4,000 psi and temperatures of 150°-170°C, briquets were easily formed of waste polyethylene, polystyrene, or polyvinyl chloride. Although the materials fused into impervious solids, the flow did not homogenize the plastics and the particles retained their bright hues. The method offers many ways of varying the ingredients of the mixture with virgin plastics, plasticizers, and inert filler and binder materials. The fabrication of traffic markers, parking barriers, paving blocks and tiles, and park benches and fixtures by hot pressing has been suggested as a useful way of utilizing the waste plastics from urban refuse.[26]

As described in a recent progress report,[15] the injection molding experiments with polyethylene from bottles collected in the Rolla campaign were also quite successful. The cleaned, chopped HDPE was substituted for virgin material in an injection molding production run in the manufacture of fairings for fan housings. The production continued without incident, except that the fairings made from 100% scrap showed inadequate flow in the mold. Subsequent examination and testing of samples cut from the fairings of virgin, mixed virgin and waste, and all-waste plastic yielded the information in Table 7.11. The 100% waste had a low melt index, as would the polyethylene used for blow molding bottles; the addition of a diluent with a high melt index would undoubtedly have made an acceptable substitute for the scrap, except for color requirements. Although it is less flexible and accommodating of variations in material than is hot pressing, injection molding is a high-volume method of fabricating products from waste plastics.

Table 7.11

Comparison of Properties of Injection Moldings from Virgin and Waste High-Density Polyethylene

Material	*Hardness Shore Units*	*Tensile Strength psi*	*Elongation %*	*Melt index g/10 min*	*Density g/cu cm*
Virgin	39.6	4,120	500	0.77	0.960
Mixed	38.8	4,090	525	0.74	0.955
Waste	38.4	3,940	380	0.37	0.955

Extrusion is the method used in what was announced as the first commercial recycling of collected waste plastic, in which plastic milk bottles were converted to drainage tile.[13] A screw-type extruder homogenizes the heated plastic and forces it through a die to form an extension of the die shape in a rod or strip form. Laboratory experiments on a 1-inch extruder revealed that the lack of the confining die used in hot pressing or injection molding required greater uniformity in the melt index and viscosity of the plastic. Sheet extrusions approximately 3.5 inches wide by 1/16-inch thick were made from three virgin PE pelletized materials and six PE wastes and mixtures. The average tensile strengths and per cent elongation for five specimens of each material are given in Table 7.12. As shown, the tensile values for waste HDPE from bottles are almost as high as those from virgin material. This is consistent with reports that most blown bottles are made from HDPE having a melt index close to 1.0 g/10 min. The waste bottle fraction represents a more uniform material than the separated waste PE which is a mixture of high and low density PE having large differences in melt index. The data show that, given a suitable volume of waste plastic with moderately uniform composition, it should be feasible to produce plastic extrusions comparable to those of commercial grades of virgin plastics.

Other Uses

Numerous suggested ways to use the cleaned and chopped plastic waste are of interest but have

Table 7.11

Tensile Data from Extruded PE Sheet

Material	*Number Specimens Tested*	*Tensile Strength at Break psi*	*Elongation at Break %*
Waste HDPE from bottles	5	3485±162*	827±95*
Separated waste PE	15	1687±192	16±9
Mixtures of PE			
75-Waste 25-Virgin HD	10	1960±100	57±27
50-Waste 50-Virgin HD	10	2180±104	230±89
25-Waste 75-Virgin HD	10	2487±221	513±241
Virgin HDPE	15	3832±259	1006±61
Virgin MDPE	5	2560±132	600±50
Virgin LDPE	5	1375±65	66±9

*Standard deviation.

limited market or application. For example, a home craftsman making children's "bean bags" finds cleaned waste plastic, chopped to pass a 1/4-inch screen, to be an ideal filler--sanitary, washable, and inert. Chopped plastic film, which is a major constituent in plastic from urban refuse, appears to have merit as a soil conditioner and plant starter. PVC wire stripping waste, mixed with plasticizer and cured, makes a resilient pad useful in sound and vibration control. Small industries based on ideas of this type may thrive on recycling of waste plastics if a consistent supply of resources flows from urban or regional waste processing plants.

CONCLUSION

It has been demonstrated by laboratory experimentation that numerous optional courses exist for processing, disposal, recycling, and utilization of the plastics in urban and industrial wastes. By employing low-cost, high-volume methods of separation similar to those used in the mineral industries, heterogeneous waste plastic mixtures can be sorted into relatively pure portions of generic types. With some concessions to accommodate mixing of plastic types, colors, and impurities, commercial methods prevailing in production from virgin plastics can be used to make products from the principal waste fractions. In some cases, separations may be made to remove only one portion, *e.g.*, PVC from waste in order that the remainder can be incinerated with impunity.

The increasing public concern for environmental development and reaction to nondisposable, nonreturnable containers has had a noticeable effect on marketing of some new plastic products.[4,28] As stated in a recent announcement by the Society of Plastics Engineers, ". . . the full impact of the environmental campaign descended on industry and cast plastics in the role of super-villain." The announcement, for the Regional Technical Conference of the Society, proclaimed the conference title as "PlastEcology-1972,"[6] ". . . designed to broadcast the latest information on plastecology and related waste disposal techniques." Thus is revealed the importance of the recycling and disposal of waste plastics to a large segment of the nation's industry and economy.

As the development of urban waste treatment plants tends toward large, integrated, regional systems, there is increasing probability that a plastic portion will be discharged in the process. From the results of the research and development described in this paper, guidelines for design or selection of facilities to process this plastic portion can be drawn, according to the options that can best be used under the prevailing circumstances.

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T. F. YEN, Editor

Associate Professor of Chemical Engineering, Environmental
Engineering Sciences, and Biochemistry
University of Southern California, Los Angeles

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