RECYCLING POST-CONSUMER POLYSTYRENE: ECONOMICS, MARKETS AND TECHNOLOGY

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ABSTRACT

This paper examines the handling and processing needed to convert post-consumer polystyrene (PS) waste into a form which will meet market specifications. It is based on ongoing economic research which evaluates the costs associated with recycling post-consumer PS.

As part of the economic analysis, the sorting, processing and marketing costs for several pilot PS recycling programs are evaluated. The different types of equipment used in these pilot programs are discussed. Some of the machines are prototypes. Regional market conditions, as well as market specifications, are described as they existed in Summer 1991. New markets and new processing equipment appear regularly, changing the potential results.

As with other recycled materials, the generation rate and source of the polystyrene, as well as the collection methods, affect the processing options and costs. The physical characteristics of post-consumer PS and the high percentage by weight of contamination—particularly food—may require additional processing in the form of washing and pelletizing to meet buyer specifications. Additional handling and processing increases the cost of recycling post-consumer polystyrene.

INTRODUCTION

In January 1990, the Recycling Economics Group, Department of Agricultural Economics, University of Wisconsin-Madison, began a research project on the cost of collecting, sorting, processing and marketing post-consumer polystyrene. The purpose was to determine the economic feasibility of recycling post-consumer polystyrene (PS). The university was asked to undertake this study as a result of public policy debates in the State Legislature during the passage of Wisconsin's Recycling Law (Act 335 1989).

Under Wisconsin Act 335, foam polystyrene waste will be banned from disposal in all public and private landfills and incinerators as of January 1, 1995.[1] This implies that Wisconsin communities will recycle foam polystyrene. Public officials responsible for implementing this law are, of course, interested in the costs associated with collecting, processing and marketing PS. To minimize recycling costs, they need up-to-date information on appropriate, cost-effective equipment.

In December 1991, the planning reports submitted by 875 local municipalities and counties which have opted to be official "responsible" recycling units were analyzed. A sample of 339 of these responsible units indicated that 73.7% plan to collect and recycle polystyrene before January 1995. In fact, 48.1% plan to have PS recycling programs in place by January 1, 1994.[2]

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[1] Along with foam PS, the following materials are also banned from Wisconsin landfills, January 1, 1995: aluminum containers, corrugated paper, glass containers, magazines, newspapers, office paper, plastic containers, steel containers, waste tires, and bi-metal steel/aluminum containers.

[2] Wisconsin Department of Natural Resources data on 1991 municipal recycling plans and budgets. The analysis performed by members

The Wisconsin Legislature also debated a proposed sales ban of disposable packaging considered difficult to recycle, including foam polystyrene.[3] Under the 1989 recycling law, communities can have a 1-year variance to exclude a material from their recycling program if no markets exist or if it is "economically impractical" to collect and market that material.[4] The number of communities asking variances for a recyclable material may indicate to the State Legislature that the material should be allowed in landfills, or alternatively that it should be taxed or banned. Thus the plastics industry also seeks to improve the economics of polystyrene recycling.

The Wisconsin research project analyzes the cost of recycling extruded foam, expandable bead (EPS) and rigid polystyrene plastics in several pilot PS recycling programs. Common consumer polystyrene items collected include: single serving hinged containers ("clamshells"), beverage cups, meat trays, and shaped and loose-fill packaging ("peanuts"). To determine the economic feasibility of recycling post-consumer PS, it is necessary to understand and evaluate the components of a recycling system: generation, separation, collection, processing and markets.

Two pilot polystyrene recycling projects are operated by established community recycling programs: a municipal collection program serving suburban single-family households and a rural nonprofit recycling processing center serving an entire county. In addition, two McDonald's restaurants agreed to participate in a study of their 1990 polystyrene recycling program. The fourth project evaluates the processing abilities of a new piece of equipment that was used for washing, drying and grinding foam polystyrene cups collected at the Minnesota State Fair during August 1991.

We will discuss the sorting, processing, pelletizing and market options and their costs. The source of the post-consumer polystyrene and the type of collection is also examined as these factors affect the processing and marketing options. We look at both residential, and food service post-consumer PS. (Food service generated PS includes: restaurants, cafeterias, fairs, sporting events, etc.) Intermediary processing of recycled materials is done in a wide range of facilities from municipal material recovery facilities (MRFs) to nonprofit community recycling centers to private operations specializing in one or two materials. Figure 1 is a flow chart which shows the various options so far identified in our research.

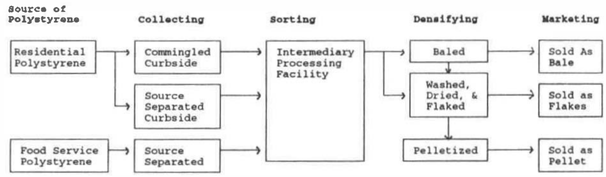

FIG. 1 FLOW CHART FOR PROCESSING POST-CONSUMER POLYSTYRENE FROM GENERATION TO MARKETS

SORTING OPTIONS

What follows is a brief description of the two collection systems and the results from waste characterization sample studies performed on each.

Residential Collection

In April 1990, the residents of single-family dwellings in suburban Fitchburg, Wisconsin added polystyrene to their existing curbside source separation collection program. As part of a 9-month pilot study, now continuing as a permanent program, the households sorted, rinsed and bagged their foam polystyrene. The bags were placed in the plastics compartment of stacking bins and set out at the curb for weekly pickup and hauling to a private recycling processor.[5] All materials were sorted by the truck driver into 10 compartments; the bags of polystyrene were tossed into the same bin as HDPE plastic (milk jugs and detergent bottles).

The incremental cost of adding polystyrene to this existing recycling program was negligible. Educational and motivational materials and specially-printed 17-gal plastic bags ($0.10/bag) were the added expenses; actual added time for the collection was insignificant, and the PS did not overflow the allotted space. One earlier analysis of polystyrene recycling predicted that collecting residential would be "very expensive," though the authors admitted that source-separated collection would be cheaper than collecting polystyrene alone (Denison et al., 1990).

Although the pilot study officially ended in January, 1991, Fitchburg continues to collect residential polysty-

of the "Economics of Recycling" class, Agricultural Economics, University of Wisconsin-Madison, Fall 1991.

[3] The only packaging actually banned in the final bill was the aluminum/plastic beverage can.

[4] Wisconsin Act 335 establishes strict financial criteria under which a community may ask for variances.

[5] The polystyrene was collected along with newsprint, cardboard, mixed paper, glass, steel, aluminum, high density polyethylene (HDPE) plastic and polyethylene teraphthalate (PET) plastic (See Gruder–Adams, 1990).

TABLE 1 FITCHBURG RESIDENTIAL POST-CONSUMER POLYSTYRENE COLLECTION

Components	*% By Wt.*
Packing PS	25.8%
Meat/Produce Trays	24.2%
Takeout Cups/Containers	11.8%
Reject PS	8.5%
Food, other non-PS waste	8.5%
Insulation	6.4%
Plates	6.4%
Egg Cartons	5.7%
Rigid PS	2.5%

Source: Gruder-Adams, 1990.

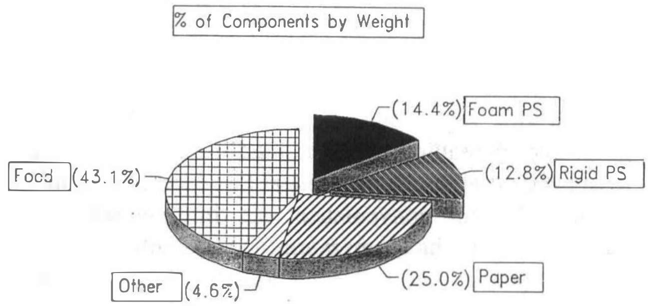

FIG. 2 POLYSTYRENE RECYCLING (Analysis of Recycling Bins)

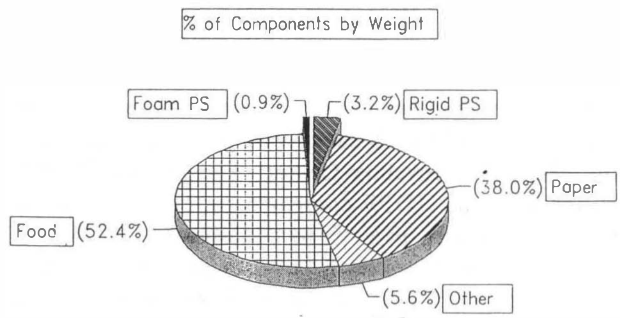

FIG. 3 ANALYSIS OF WASTE BINS

rene. Collection costs are even lower as residents now put used PS into ordinary used plastic grocery bags.

WASTE CHARACTERIZATION

Three bales of the Fitchburg polystyrene (442 lb total) were sorted and weighed. The PS had been baled and stored outside for 2–3 months before it was analyzed. Although most residents rinsed their polystyrene, some mold developed; pieces heavily contaminated with mold were considered reject PS (Gruder-Adams, 1990). Table 1 shows the percentage by weight of the various components in those three bales of PS. The collection bags, weighing 67 lb, were not included in the analysis. (However, these bags were recycled, as were all of the pilot program collection bags).

Contamination was 17% of the total. It appears from Fitchburg that residential PS collected in an established recycling program comes in clean with a minimum of food waste—especially when compared to post-consumer polystyrene separated into special bins at two McDonalds restaurants in Madison (see below).

Food Service Collection

Results from a waste study conducted by the Recycling Economics group in January, 1991 at two fast-food restaurants indicate that customers did a very poor job of sorting their waste (see Figs. 2 and 3). Bins plainly marked for polystyrene contained only 14.4% by weight of foam polystyrene, plus 12.8% rigid PS. Food waste and waste paper predominated in the recycling bins as well as in the waste bins.[6] Customers got one thing right; the adjacent bins for waste received little polystyrene; foam PS was 0.9% by weight, and rigid PS was 3.2%. Although customers placed the bulk of the PS in the correct bins, they put even more food and paper waste into the PS bins.

Additional education may enable restaurant customers to more effectively separate recyclable PS from waste. In longer running recycling programs on the East Coast, McDonalds staff were stationed at the recycling and waste bins to show patrons how to sort their food service waste. In this case, however, the

[6] In addition to food, contaminants included other plastics or composites, such as polypropylene straws, cream containers, and catsup packages.

program had barely begun when McDonalds announced that it would soon switch from foam polystyrene to paper wrappings.[7]

With this high contamination rate, food service-generated PS requires different handling and processing than residential PS. Consumers at fast-food restaurants presumably seek convenience and time-savings; perhaps it is logical that contamination rates will be higher than for polystyrene waste separated and collected at a more leisurely pace in the home. Removal of the contaminants and disposal of the nonrecyclables wastes will increase the processing costs.

PROCESSING OPTIONS

Baling

In the Fitchburg program, the polystyrene collection bags were baled by a local private recycling operation, the Madison Recycling Center. The bagged PS was pulled from the HDPE compartment of the collection trailer and stored in gaylord containers (3 ft × 3 ft corrugated cardboard boxes) until enough had accumulated to bale (25 gaylords/bale). A 60 in. horizontal ram baler with manual feed was used to bale the polystyrene; the firm also bales high density polyethylene (HDPE) and polyethylene teraphthalate (PET) with this baler. The polystyrene bales varied from 70–160 lb. (Using a dual ram paper baler as an experiment, they produced one PS bale weighing more than 200 lb.)

The memory or shape-retaining ability of polystyrene foam increases the time in the baler considerably. It took approximately 2 hr per bale; some bales were left in the baler overnight. The same baler could do four bales of HDPE plastic at 500 lb/bale in 1 hr. Using an average weight of 150 lb per PS bale[8], we would get 75 lb/hr for polystyrene versus 2000 lb/hr for the HDPE—a significant difference in processing rate.

The bales of polystyrene were shipped to Landfill Alternatives, Inc., in Elburn, Illinois where they were debagged, sorted, washed, dried, and granulated. The recycled polystyrene was marketed as granules or else extruded into pellets (Gruder-Adams, 1990).

The Madison processor no longer bales Fitchburg's polystyrene, deeming this too expensive.[9] He stores the bags in gaylords and ships them to another processing center, Wisconsin Intercounty Nonprofit Recycling, Inc. (WINR), where it is washed, dried and ground into flake.[10]

Washer/Dryer/Grinder

Because food contaminants can cause odor and vector problems, specialized equipment has been developed to wash and dry post-consumer polystyrene. As part of our research, we have been tracking the development of a specific washer/dryer/grinder system initially designed by engineers at Amoco Foam Products Co., and now in commercial production by PlastiCycle, Inc., of Eau Claire, Wisconsin.

Description of Machine

The PlastiCycle Washer/Dryer is a continuous feed system using three separate rotating chambers to wash, dewater and dry the PS. An auger feed system meters and distorts the material to minimize "nesting" of containers. Washing takes place in a rotary chamber equipped with stationary nozzles which spray high-velocity hot water.

After washing, the polystyrene passes the dewatering section, and then an evaporative dryer removes the remaining moisture. The hot water and the hot air are recycled to conserve energy. An off-the-shelf plastics grinder produces flake PS, which is then blown directly into gaylord boxes for storage and shipment. The process is similar to that used by the National Polystyrene Recycling Company, except that the small scale equipment washes the PS whole, which reduces the drying time.

The capacity is rated at 200 lb/hr for foam PS and 300 lb/hr for other thermoplastics. The cost of the Washer/Dryer is $35,000. Depending on the size, grinder prices range from $8000 to $15,000.[11]

The Minnesota State Fair

In August 1991, we gathered data on the first commercial operation of the continuous-feed washer/dryer/grinder system. This machine was installed in a building on the State Fairgrounds in St. Paul, Minnesota. During the 12 days of the fair, polystyrene cups were collected, processed on site, and shipped to market.

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[7] McDonalds and the Environmental Defense Fund, making a joint announcement, did not promise to recycle paper wrappers. Rather, they promised continuing research, including the possibility of composting the paper and food waste.

[8] The bales were not weighed until they arrived at market. Using the three bales from the waste sample gives a rounded average of 150 lb per bale.

[9] Telephone interview, Glen Myers, Manager, on July 30, 1991.

[10] WINR received a prototype washer/grinder for PS in September, 1991, and its operating cost data will be available before the end of the year.

[11] Correspondence and telephone interviews with Dave Bergstrom, General Manager, PlastiCycle, Eau Claire, WI in June and July 1991.

The Fair Board felt they could reduce their waste collection and disposal costs by using a recyclable beverage cup. They required that all food vendors (350) sell their hot and cold beverages in extruded foam polystyrene cups. The Fair Board purchased 4.3 million cups of different sizes from a single source, Amoco Foam Products. Twelve hundred collection bins (55 gal) for polystyrene cups and an equivalent number of waste bins were scattered throughout the 310 acre Fairgrounds. The collection bins were placed 15–20 ft apart and usually paired with a smaller waste bin (30 gal). Fairgoers were expected to sort their waste into the appropriate bins.[12]

With 1.5 million people expected to attend the Fair, educating the public about the cup recycling was critical. There were printed instructions on all the polystyrene cups as well as on the collection bins. All daily event schedules contained recycling instructions. Signs were posted around the fairgrounds and news releases were placed in the local media. For most fairgoers, their "polystyrene source separation training" began when they purchased their first beverage.

Using a flat bed trailer which held approximately 50 barrels, a collection crew of 4–5 people replaced full bins with empties several times a day. The full bins were emptied onto a concrete floor, in a large mound next to the washer/dryer. Liquid waste flowed into floor drains. A bobcat loader pushed the pile up to a belt conveyor. Turning the pile helped to drain liquids; it also allowed the lighter PS to rise to the top while the heavier contaminants stayed on the floor.

Two workers raked the cups onto an incline conveyer belt. The materials fell to a horizontal conveyer where four workers separated nested cups and removed food wastes and other plastics. The PS cups then dropped into the feed hopper where they were augered into the drum washer. The polystyrene was processed at a rate of 120–180 lb/hr with an average of 150 lb. The line was frequently stopped because the grinder was not working well. It was finally discovered that the voltage coming into the building was less than 440 V. Once the voltage was corrected the grinder performed well and the throughput rate reached as high as 250 lb/hr.

To determine how well the public was sorting out the polystyrene cups, a waste characterization was performed on nine randomly selected 55-gal polystyrene collection bins. The contents were sorted into seven categories and weighed. A full 55-gal bin contained 16–24 lb of material, of which 4–8 lb were polystyrene cups. Food waste and ice comprised 8–18 lb of the total. As only cups were collected, the bulk of the food waste was liquid—water from ice cubes and residual beverages. Lemon rinds from lemonade stands were the most common solid food waste with an occasional french fry or corn cob.

TABLE 2 CONTENTS OF POLYSTYRENE RECYCLING BINS AT THE 1991 MINNESOTA STATE FAIR

Components	*% By Wt.*
PS Cups	32.3%
Food Waste (Liquid & Solid)	60.1%
Paper	5.3%
Plastic Cutlery	.3%
Plastic Lids	.3%
Other Plastics	.9%
Other	.8%

A 55-gal bin holds approximately 500 loosely packed cups of assorted sizes. By weight, liquid and food waste was the main contaminant. By volume, the PS cups predominated with the liquid wastes comprising 1–2 gal per bin. Other contaminants were minimal. The fairgoers did a good job of "preprocessing" the polystyrene for recycling. Even with a good education program and an interested public, a sizable amount of food waste contamination will still need to be dealt when recycling food service PS.

Amoco reported that 30,855 lb of the recycled flake or an estimated 2.25 million cups were shipped back to their plant for use as recycled resin. This gives a capture rate of 50%.

Fair Costs

The recycling costs from collection through to extrusion are summarized in Tables 3–5. Table 3 represents the actual costs incurred in this project. Several assumptions were made to develop the adjusted costs in Table 4. Throughput was increased to 200 lb/hr to reflect the correct voltage of 440 V. With the added experience, it was assumed that the Minnesota State Fair will cut their labor costs by 25%.

[12] Telephone interview with Ken Giannini, Minnesota State Fair Board, on July 10, 1991. The official attendance turned out to be 1,488,810.

TABLE 3 MINNESOTA STATE FAIR AUGUST 22–SEPTEMBER 2, 1991
(Actual Polystyrene Recycling Costs+)

	FAIR Cost	Cost/lb	Cost/yr	Capital Costs
Collection Costs:++				
Equipment	$3,899.66		$4,104.91	$37,478.00 Barrel tops, trailer
O & M	$4,263.41		$4,450.80	Barrels=7 yr life, other = 10 yr life
Labor $	$13,270.57			$12,184.00 Barrel Preparation
Net Collection Costs	$21,433.64	$0.69		
Sorting Costs:++				
Equipment	$232.88		$245.14	$2,884.00 2 conveyors
O & M	$273.98		$288.40	10 yr life
Lbs/hr/8 hr day/5 day wk	150			
Sorting rate lbs/hr	25			
Labor $	$11,530.00			
Net Sorting Costs	$12,036.86	$0.39		
Washing/Drying Costs:*				
Equipment	$588.42		$2,975.00	$35,000.00 Washer/Dryer
O & M	$1,038.39		$5,250.00	10 yr life
Lbs/hr/8 hr day/5 day wk	150			
Machine Utilities $.035/lb	$1,079.93			
Labor $/hr	$1,230.00			
Net Washing/Drying Costs	$3,936.74	$0.13		
Grinding Costs:*				
Equipment	$50.44		$255.00	$3,000.00 Grinder
O & M	$59.34		$300.00	10 yr life
Lbs/hr/8 hr day/5 day wk	150			
Machine Utilities $.01/lb	$308.55			
Labor $/hr	$1,230.00			
Net Grinding Costs	$1,648.32	$0.05		
Transportation Costs:**				
Truck Rental- $50/day	$600.00			
Fuel-$.10/mile x 180 miles	$216.00			
Labor-$12/hr; 4hr/trip	$576.00			
Meals/ entry fees	$72.00			
Net Transportation Costs	$1,464.00	$0.05		
Extruding Costs:#				
Equipment	$749.34		$11,050.00	$130,000.00 Extruder
O & M	$1,322.36		$19,500.00	10 yr life
Lbs/hr/8 hr day/5 day wk	218.75			
Machine Utilities $.08/lb	$2,468.40			
Labor $12/hr(2 people)	$3,385.23			
Net Extruding Costs	$7,925.33	$0.26		
Revenues @ $.35/lb	($10,259.29)	($0.35)		
Avoided Costs @ $67.50/ton	($1,041.36)	($0.03)		
TOTAL NET COSTS	$37,144.25	$1.20		

Note: Annual depreciation: capital cost minus 15% divided by project life of equipment.
+ Assumes 150 lbs/hour processing rate; 6 people sorting and 1 person on washer/dryer and grinder.
++ Fair usage is .95 x annual costs; equipment used mainly for 12 days of Minnesota State Fair.
* Washer/dryer and grinder usage is job hours divided by 1040 hours/year times annual costs.
** 12 trips with partial loads.
# Extruder usage calculated as job hours divided by 2080 hours/year times annual costs.
Due to contamination rate and resulting screen changes 2 people required to operate extruder.

Table 5 compares Projected Costs with the costs from Tables 3 and 4.[13] The collection and sorting costs were high. This partially reflects the premium price paid to collect waste at such an event. Large collection vehicles can not be used in the midst of heavy pedestrian traffic. For pedestrian safety, small, slow-moving tractors with narrow wagons are used.

This collection process is very labor intensive. It cost the Minnesota State Fair Board over $900/ton or approximately $0.45/lb to collect and dispose of the solid waste generated at the 1991 Fair. Since the recycling

[13] The projected costs were supplied by PlastiCycle. These costs were calculated for a plant operation and not special events.

TABLE 4 MINNESOTA STATE FAIR AUGUST 22-SEPTEMBER 2, 1991
(Adjusted Polystyrene Recycling Costs+)

	Adjust. Costs	Cost/lb	Cost/yr	Capital Costs
Collection Costs:++				
Equipment	$3,899.66		$4,104.91	$37,478.00 Barrel tops, trailer
O & M	$4,263.41		$4,450.80	Barrels=7 yr life, other = 10 yr life
Labor $	$10,388.07			$12,184.00 Barrel Preparation
Net Collection Costs	$18,738.53	$0.61		
Sorting Costs:++				
Equipment	$232.88		$245.14	$2,884.00 2 conveyors
O & M	$273.98		$288.40	10 yr life
Lbs/hr/8 hr day/5 day wk	200			
Sorting rate lbs/hr	44			
Labor $	$6,485.63			
Net Sorting Costs	$6,992.49	$0.23		
Washing/Drying Costs:*				
Equipment	$441.32		$2,975.00	$35,000.00 Washer/Dryer
O & M	$778.79		$5,250.00	10 yr life
Lbs/hr/8 hr day/5 day wk	200			
Machine Utilties $.035	$1,079.93			
Labor $/hr	$615.00			
Net Washing/Drying Costs	$2,915.03	$0.09		
Grinding Costs:*				
Equipment	$37.83		$255.00	$3,000.00 Grinder
O & M	$44.50		$300.00	10 yr life
Lbs/hr/8 hr day/5 day wk	200			
Machine Utilties $.01/lb	$308.55			
Labor $/hr	$615.00			
Net Grinding Costs	$1,005.88	$0.03		
Transportation Costs:**				
Truck Rental- $50/day	$400.00			
Fuel-$.10/mile x 180 miles	$144.00			
Labor-$12/hr; 4hr/trip	$384.00			
Meals/ entry fees	$48.00			
Net Transportation Costs	$976.00	$0.03		
Extruding Costs:#				
Equipment	$749.34		$11,050.00	$130,000.00 Extruder
O & M	$1,322.36		$19,500.00	10 yr life
Lbs/hr/8 hr day/5 day wk	218.75			
Machine Utilities $.08/lb	$2,468.40			
Labor $12/hr (2 people)	$3,385.23			
Net Extruding Costs	$7,925.33	$0.26		
Revenues @ $.35/lb	($10,259.29)	($0.35)		
Avoided Costs @ $67.50/ton	($1,041.36)	($0.03)		
TOTAL NET COSTS	$27,252.61	$0.88		

Note: Annual depreciation: capital cost minus 15% divided by project life of equipement.
+ Assumes a 25% increase in labor efficiency, except for extruder, and a 200 lbs/hour processing rate.
++ Fair usage is .95 x annual costs; equipment used mainly for 12 days of Minnesota State Fair.
* Washer/dryer and grinder usage is job hours divided by 1040 hours/year times annual costs.
** Assumes full loads of 24 gaylords per truck per trip.
# Extruder usage calculated as job hours divided by 2080 hours/year times annual costs.
Due to contaminaion rate and resulting screen changes 2 people required to operate extruder.

collection and sorting equipment is used for basically 12 days/year, 95% of annual equipment and O & M costs were allocated to this project. This type of accounting is used for other capital costs at the Fairgrounds as well; many fair activities cost more than they would in a continuous year round operation. This fact does increase the real cost of recycling polystyrene or other materials at special events.

The washing, drying and grinding costs were not unreasonable considering this was the first field test of

TABLE 5 MINNESOTA STATE FAIR AUGUST 22–SEPTEMBER 2, 1991
(Cost Comparison)

	Projected Cost	Costs/lb	FAIR Cost	Cost/lb	Adjust. Costs	Cost/lb
Materials Input	10,000 lbs/wk		30,855 lbs		30,855 lbs	
Collection Costs:++						
Equipment	n.a.		$3,899.66		$3,899.66	
O & M	n.a.		$4,263.41		$4,263.41	
Labor $	n.a.		$13,270.57		$10,388.07	
Net Collection Costs	n.a.	n.a.	$21,433.64	$0.69	$18,738.53	$0.61
Sorting Costs:++						
Equipment	n.a.		$232.88		$232.88	
O & M	n.a.		$273.98		$273.98	
Lbs/hr/8 hr day/5 day wk	250		150		200	
Sorting rate lbs/hr	100		25		44	
Labor	$400.00		$11,530.00		$6,485.63	
Net Sorting Costs	$400.00	$0.04	$12,036.86	$0.39	$6,992.49	$0.23
Washing/Drying Costs:*						
Equipment	$67.31		$588.42		$441.32	
O & M	$100.96		$1,038.39		$778.79	
Lbs/hr/8 hr day/5 day wk	250		150		200	
Machine Utilities $.035/lb	$350.00		$1,079.93		$1,079.93	
Labor $/hr	$125.00		$1,230.00		$615.00	
Net Washing/Drying Costs	$643.27	$0.06	$3,936.74	$0.13	$2,915.03	$0.09
Grinding Costs:*						
Equipment	$9.62		$50.44		$37.83	
O & M	$14.42		$59.34		$44.50	
Lbs/hr/8 hr day/5 day wk	250		150		200	
Machine Utilities $.01/lb	$100.00		$308.55		$308.55	
Labor $/hr	$150.00		$1,230.00		$615.00	
Net Grinding Costs	$274.04	$0.03	$1,648.32	$0.05	$1,005.88	$0.03
Transportation Costs:**						
Truck Rental- $50/day	n.a.		$600.00		$400.00	
Fuel-$.10/mile x 180 miles	n.a.		$216.00		$144.00	
Labor-$12/hr; 4hr/trip	n.a.		$576.00		$384.00	
Meals/ entry fees	n.a.		$72.00		$48.00	
Net Transportation Costs	n.a.	n.a.	$1,464.00	$0.05	$976.00	$0.03
Extruding Costs:#						
Equipment	$355.77		$749.34		$749.34	
O & M	$533.65		$1,322.36		$1,322.36	
Lbs/hr/8 hr day/5 day wk	250		218.75		218.75	
Machine Utilities $.08/lb	$800.00		$2,468.40		$2,468.40	
Labor	$350.00		$3,385.23		$3,385.23	
Net Extruding Costs	$2,039.42	$0.20	$7,925.33	$0.26	$7,925.33	$0.26
Revenues @ $.35/lb	($3,395.00)	($0.34)	($10,259.29)	($0.35)	($10,259.29)	($0.35)
Avoided Costs @ $67.50/ton	($337.50)	($0.03)	($1,041.36)	($0.03)	($1,041.36)	($0.03)
TOTAL NET COSTS	$3,019.23	$0.30	$37,144.25	$1.20	$27,252.61	$0.88

a newly designed machine. It is assumed that these costs will be reduced further. The pelletizing costs are described in the next section.

Pelletizing

Some post-consumer polystyrene markets, including Amoco, prefer to purchase pellets rather than bales or flakes. Amoco tested recycled flake for their industrial line in early 1991 but found it unsuitable for their specifications (see Table 6).[14] They are also concerned about possible contamination problems with flake PS. When flakes are extruded into pellets, the polystyrene is heated to 400 °F, which sterilizes the plastic and removes any leftover blowing agents. Also, industry is used to purchasing virgin plastic resins in a pellet form; this is the normal way to handle the material.

[14] Correspondence from Ray Peterson, General Manager, Amoco Foam Products Co., Chippewa Falls, Wisconsin on February 20, 1991.

TABLE 6 QUALITY ASSURANCE SPECIFICATIONS FOR PURCHASED POST-CONSUMER RECYCLED POLYSTYRENE (Amoco Foam Products Co.)

Melt Flow Rate	G/10 Mins	8.5 Max
Styrene Monomer	PPM	900 Max
Bulk Density	lbs/Ft^3	15 Min
Moisture	Wt. %	2% Max
Benzene	PPB	20 Non Detectable
Toluene Insolubles	Wt. %	7.4% Max
Color		Wide Range Acceptable
Fines		Try to Minimize

Note: Amoco Foam Products will only accept material that has been processed in an extruder at 400º F minimum to ensure that the material has been sterilized.

In mid-1991, Amoco bought a 3.5-in. vented reclaim extruder to pelletize post-consumer polystyrene flake at their Chippewa Falls plant. A stuffer ensures the proper feed rate for the flake polystyrene. The line costs $130,000 and has a rated capacity of 400 lb/hr. In an early test run with PS flake, the extruder operated at 370 lb/hr.[15]

In October, batches of the Minnesota State Fair polystyrene were extruded. The equipment produced acceptable pellets provided the moisture content was below 5%. Some of the boxes of flake had higher moisture contents and the resulting steam deformed the pellets. Once this was discovered, all remaining PS was given additional venting as it was blown into the storage silos. This solved the moisture problem.

Contaminants in the flaked PS reduced the throughput rate and increased costs. Small particles of paper fiber, cigarette filters and aluminum rapidly plugged the screens in the extruder at about 5 sq. in./min. This rate required screen changes every 2 min on the 10 sq. in. screen. Polystyrene food service containers washed, dried and ground in a similar small scale recycling machine in operation at the Amoco extruder facility required a screen change once every 20 min or ½ sq. in./min. Labor costs doubled as a result of the more frequent screen changes for the State Fair materials.

The extruder project manager felt that a regular schedule of cleaning the dryer drum and more careful manual sorting would bring the contamination rate within the ½ sq. in./min range.[16]

TABLE 7 EXTRUDER COSTS ADJUSTED FOR LOWER CONTAMINATION RATE

Equipment	$749.43	
O & M	$1,322.36	
Lbs/hr/8 hr day/5 day wk	$218.75	
Machine utilities $.08/lb	$2,468.40	
Labor $12 hr (1 person)	$1,692.62	
Net Extruding Costs	$6,232.71	$0.20 per lb

At $0.20/lb, this adjusted cost is same as the projected extruding costs. Both are higher than the going rate of $0.08–$0.10/lb for extruding scrap plastics.

MARKETS

From an economic perspective, there is little point in collecting and cleaning polystyrene if it cannot be done and marketed for the same net cost or less than the cost of collecting and disposing in landfill or by incineration.[17] Revenue from the sale of the material, as well as the avoided costs of high collection and tipping fees, means that a community can accept a higher collection and processing cost for recycled materials provided there is no net loss to the community.[18] More communities are recognizing the value of the avoided costs.

Until very recently, known markets for recycled polystyrene were few and thin, and their future was uncertain. The main industry effort, known as the National Polystyrene Recycling Company (NPRC), has built four plants each with capacities of 13 million lb/year. It inaugurated a new plant in Chicago in the fall of 1991.

The Chicago plant is now buying baled polystyrene waste—post-consumer as well post-industrial PS. They produce several grades of recycled crystal polystyrene pellets. NPRC pays an average of $0.07/lb for baled

[15] Telephone interview with Carl Loff, Engineer, PlastiCycle, Eau Claire, Wisconsin on July 31, 1991.

[16] Telephone conversation with Pete Butler, extruder project manager, on December 10, 1991.

[17] The cost of landfilling, of course, should include the cost of finding and building a future landfill, not just the historic cost of existing facilities that could not be replaced at the same cost because of higher technical requirements and the need to compensate neighbors at a new site.

[18] Preliminary figures from our analysis of the Wisconsin Department of Natural Resources data on community recycling programs indicate that the avoided disposal costs average four times as much money as the revenue from the sale of recyclables.

post-consumer PS and $0.10 for block and shape molded foam PS; $0.02/lb of this price is called a transportation allowance. This is up from the pre-opening price, in February, 1991, when they paid a flat $0.05/lb for both post-consumer and post-industrial polystyrene, baled and delivered to their site. NPRC pays less for the post-consumer polystyrene because the dirty baled food service PS requires three separate washings to remove contaminants. If these bales have been stored for any length of time, there will be considerable mold contamination as well.

If it is collected in bags, the PS must be debagged before baling. This allows the liquid waste to drain away. The NPRC wants the waste to be "reasonably clean" in visual inspection and prefers baled post-consumer waste over flake. They feel they have more control over the final quality of the pellets by doing their own sorting, washing, drying, grinding and extruding. They want less than 5% by weight of other plastics in their final product.[19]

The Amoco Foam Products plant in Chippewa Falls, Wisconsin, has been buying clean flaked PS for $0.10–$0.20/lb based on quantity and quality, and they pay shipping costs. They are paying $0.35–0.40/lb for pellets. The recycled material is used in the core of a polystyrene foam protection insulation board which is co-extruded with virgin PS outer layers; the recycled content is around 30%. As previously mentioned, they would prefer to buy the material already pelletized, and have offered to work with recycling programs to help them develop that stage of processing.

The Traex Company, of Dane, Wisconsin, is buying extruded and pelletized post-consumer polystyrene from various sources, paying in the range of $0.35–0.40/lb. The recycled resin is blended with virgin polymer and used in a variety of trays and other food service products.

NPRC sells their post-consumer polystyrene pellets to several types of end-users: extruded board for construction industry, household products, and office supply products. They sell a recycled crystal polystyrene pellet and are thinking of producing high impact polystyrene (HIPS).[20] Depending on the grade, they sell their pellets from $0.20–0.45/lb.

Forty cents per pound is close to the current price for the virgin polymer (see Table 8), and in our judgment, represents in part a perceived marketing advantage of

TABLE 8 MIDWEST PRICES FOR POST-CONSUMER FOAM POLYSTYRENE

Virgin PS	$ .46-52[a]
Clean baled PS	$ .07[b]
Clean flaked PS	$ .10-20[c]
Clean pelletized PS	$ .35 -.40[d]

Actual prices paid unless other wise noted as of July 1991.

[a] and [b] Source: National Polystyrene Recycling Co. (NPRC) Chicago, IL

[c] Source: Amoco Foam Products, Chippewa Falls, WI.

[d] Source: Amoco Foam Products

being able to offer insulation panels and other end products with significant post-consumer recycled content. However, the price of virgin polystyrene has been dropping. A potential marketing advantage for recycled PS is its lower price. Recycled PS probably needs an 8–10% price margin, as it is perceived to be of lesser quality than virgin even when it meets the physical specifications for the application.[21]

Baled PS would sell for $140/ton and flaked PS would range from $200–$400/ton. This is comparable with other post-consumer plastics being sold to processors. The Great Lakes Recycling Price Market recently quoted clear HDPE at $160–240/ton and clear PET at $120–200 (Kohrell, 1991).

CONCLUSIONS

Post-consumer polystyrene presents unique recycling challenges. The light weight, rigid, high memory characteristics that make it an ideal packing or food serving item translate into a bulky, low density material when recycled. This means higher transportation, processing and marketing costs per pound than for HDPE and PET plastics recycling.

Based on the Fitchburg, McDonald and Minnesota State Fair waste studies, there is a significant difference in the contamination rate between residential and food service generated polystyrene which translates into different processing needs, options and costs.

[19] Telephone interview and correspondence from Bill Matthei, Source Development Manager, National Polystyrene Recycling Company, Lincolnshire, IL on July 31, 1991.

[20] Telephone conversation with Bill Matthei of NPRC on July 31, 1991.

[21] *Ibid.*

Public events generate large volumes of single serving cups, plates and other containers. Early results indicate that it is technically and logistically feasible to collect polystyrene at these types of events. Fairgoers at the 1991 Minnesota State Fair did well in recycling polystyrene cups. The Fair Board is considering recycling other types of polystyrene food service containers in future years.

Polystyrene recycling still needs more efficient compacting and processing equipment. Residential collection costs can be kept low if PS is added to existing source-separated collection programs, but baling and grinding costs must be brought down. If the secondary markets for post-consumer polystyrene want a more highly processed material than they demand for HDPE or PET, the costs of recycling PS increase. Although there are opportunities to reduce the costs of recycling polystyrene, it is also reasonable to assume that the various processors will expect to be paid for the services they provide.

Recycling programs do produce savings in avoided collection and disposal fees. Currently, post-consumer PS recycling is driven by legislative requirements or environmental considerations. However, unless landfill disposal is extremely expensive, further reductions in intermediate processing costs are needed before most communities would consider it economically feasible to recycle post-consumer polystyrene.

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