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1.0 INTRODUCTION

The Department of Environmental Engineering Sciences (DEES, University of Florida) was contracted by the Duval County Department of Solid Waste and Resource Management to provide technical assistance in regard to their innovative recycling grant on polystyrene food trays. Awarded by the Florida Department of Environmental Protection (FDEP), the innovative grant examined various stages, including the collection, processing, and recycling of polystyrene food trays from Duval County schools. The grant investigated the use of ground polystyrene as a substitute for perlite, a common compost amendment in horticulture applications. Additionally, the grant also sought to develop markets for alternative uses of polystyrene.

The DEES was contracted to perform the following services:

- **Task 1**: Conduct a market analysis of shredded polystyrene collected from school cafeterias. A general market analysis for recycling polystyrene, as well as a specific investigation of local markets for the materials generated within Duval County was conducted. As part of this task, contact was made with Florida Rock Industries, who became involved on the project as an independent party.

- **Task 2**: Assist the County in evaluating the size reduction equipment selected by its contracted party (Moriah Industries) for shredding polystyrene. The evaluation was conducted with regard to the applicability of the equipment to the specific waste stream, ease of use, future use, and economics.

- **Task 3**: Conduct analytical testing of the materials to further investigate other local recycling options. The specific analytical tests performed included physical characterization for the athletic field application and microbiological tests related to use in concrete and the RASTRA product. The task also included facilitating and reporting the results from Florida Rock Industries.

The document presented here is a summary of the results of the tasks listed above. Two previous versions of this report have been submitted, Version I on March 23, 1999 and Version II on June 23, 1999. This report is submitted as Version III. Duval County's innovative recycling grant project involved many participants, and only information pertaining to the UF tasks are presented here (with the exception of the Florida Rock data).

The following sections are included within this report. Section 2 presents background information regarding polystyrene properties and recycling (Task 1). Section 3 discusses information found regarding application of shredded polystyrene in horticultural compost (Task 1). Section 4 presents results of tests evaluating the incorporation of ground polystyrene into material used for athletic fields (Tasks 1 and 3). Section 5 presents results related to the use of ground polystyrene as a lightweight aggregate in concrete (Task 1 and 3). Section 6 includes the grinder analysis presented in previous report versions (Task 2). Finally, section 7 provides a bibliography of information related to polystyrene recycling (Task 1).

2.0 Background

2.1 Polystyrene Properties

Polystyrene is the common name for the alkene polymer styrene, a petroleum by-product with the repeating formula $H_2C{=}CHC_6H_5$. C_6H_5 is a phenyl group, which is comprised of a benzene ring with one hydrogen atom removed[1]. Although first produced in the 1930s, styrene's first significant role was in the production of synthetic rubber during the Second World War. It was not until after the war that the commercial use of polystyrene became prominent[2].

There are several forms of polystyrene. The first is made without any additives and is considered general-purpose polystyrene. In this form, polystyrene is a brittle, clear material that can be easily colored. This material is used for injection molding to make such things as CD cases, boxes, and ballpoint pens[2].

Polystyrene can also be blended with rubber to produce another useful material. While this material has reduced tensile strength and modulus, it displays an increased toughness that sustains high impact. This type of blended polystyrene is used for such applications as television and radio cases[2].

The forms of polystyrene most identifiable to the public are the extruded and expanded foams. The extruded foams are used in the making of food service containers, meat trays, plates, and cups. The expanded foams are used as packing material for the protection of fragile goods during shipping. Pentane and carbon dioxide are used in the manufacturing of these types of polystyrene foams[2].

Polystyrene is best known for its efficiency, cost-effectiveness, and sanitation. The material is lightweight, cushioning, and easily conforms to any shape. Therefore, it is ideal for protecting packaged goods during shipping. Polystyrene's efficiency begins with the initial low cost of styrene. In most cases, only five percent of the final product is comprised of polystyrene while air makes up the other ninety five percent. Thus, a cost savings is demonstrated for industries using polystyrene products[2].

The exceptional insulating capabilities of polystyrene help prevent the spoilage and waste of food by maintaining the temperature of cold and hot food. Polystyrene packaging meets all of the U.S. FDA standards for food industry use. Service-ware made from polystyrene has been proven to be more sanitary than reusable service ware. Additionally, polystyrene service-ware products reduce water usage. To promote food safety, health officials advocate the use of single-use food service ware. And, in the food industry, cost efficient polystyrene utensils and containers have replaced reusable, as well as paper, food utensils[2].

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[1] Massachusetts Institute of Technology. "Polystyrene." Retrieved March 9, 1999 from the World Wide Web: www.dmse.mit.edu

[2] Polystyrene Facts." Retrieved March 25, 1999 from the World Wide Web: www.polystyrene.org

2.2 Polystyrene Recycling

Before beginning any discussion on polystyrene recycling, it is important to understand the appropriate terminology related to solid waste recycling. Source reduction is the minimization of waste generation. Reusing an item means to use the product for it's original or a similar purpose without altering the product's material properties. Recycling refers to collecting a product and altering its properties in order to make a new product.

The most common reused and recycled polystyrene is the loose-fill packing material. This product can be repeatedly reused for its original purpose. Molded packing foams can be ground in mills and also used as loose-fill. Other post consumer polystyrene is collected cleaned and repelletized for reuse as moldable bead, which is often mixed with virgin stock to meet manufacturer's requirements.

As with all recycled materials, economic considerations are often the determining factors of success. The same properties that make polystyrene a good packing material, also make it expensive to recycle. Polystyrene's density (1 lb/ft^3) makes it expensive to ship to a recycling plant. Balers are used to compact the polystyrene food trays into a more transportable form. By using balers that increase the density to thirty pounds per cubic foot, without degrading the polystyrene, trucks can be loaded to near weight capacity. Another issue is the surplus of virgin polystyrene, which has led to a decline in the price to approximately forty to fifty cents per pound. At this rate, virgin materials are cheaper, and thus, more attractive to businesses[3].

Another method of polystyrene waste reduction is combustion in a waste-to-energy (WTE) facility. Instead of landfilling this material, it is taken to a WTE plant to produce electricity. Since polystyrene is a petroleum-based product, it is combusted to produce a substantial amount of energy, which generates steam for electricity. When burned, the volume of the polystyrene is reduced by at least ninety-nine percent. It then contains water vapor and carbon dioxide along with a small amount of non-toxic ash as by-products[4]. The recycling of polystyrene in a waste-to-energy plant is probably the most economically feasible of the traditional methods at this time. Nonetheless, economics depends heavily on transportation and incineration costs -- both of which could easily nullify any potential energy gain.

2.3 Markets For Polystyrene

This report discusses three potential markets for recycled polystyrene. These markets include addition of ground polystyrene to compost as an amendment, incorporation to athletic field material, and the utilization as a light weight aggregate in concrete and insulated concrete forms. Basic information on these applications is presented in this section, followed by specific discussion of applicability for Duval County in sections 3, 4, and 5.

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[3] Ehrlich, Raymond J. "The Economics Realities of Recycling." *Polystyrene News* II, No. 4 (Fall 1997): n.p. Retrieved May 26, 1999 from the World Wide Web: www.polystyrene.org

[4] Polystyrene Packaging Council. "Polystyrene and the Environment." Retrieved April 11, 1999 from the World Wide Web: www.polystyrene.org

2.3.1 Ground Polystyrene in Horticultural Applications

Ground polystyrene has been proposed as an amendment to soil or compost. It has been suggested that ground polystyrene could serve as a substitute for perlite, a common additive to potting soils. Perlite is the common name for siliceous rock formed by rapidly cooling volcanic lava. When reheated to above 1600 degrees Fahrenheit [871 degrees Celsius (C)], the rock quickly expands up to twenty times its size. This is due to the water content of the crude perlite rock. In its crude state, the rock contains between two and six percent water. Once reheated and expanded, perlite can weigh as little as two pounds per cubic foot. Perlite in its final stage has a white color; the crude form may be transparent light gray to glossy black[5].

Horticultural uses of perlite include seed cultivation, the propagation of plant cuttings, interior and exterior planter growth, and exterior landscaping. Perlite is advantageous as a soil additive, because it improves drainage and aeration in the growing media. It also insulates plant root systems from wide temperature fluctuations. The tiny voids formed by the air cells increase the surface area of the perlite and serve to store moisture and nutrients that can be utilized by plants. These voids also provide perlite with excellent capillary attraction that provides water to plants at a rate that equals their uptake[6]. Another favorable feature of perlite is its sterility. This enables it to be free of disease and insects. It is also inorganic, therefore, it will not degrade in the ground[7,8].

Polystyrene particles could serve some of the functions of perlite, but not all. Ground polystyrene would reduce the overall density of the soil or compost and would promote drainage and aerate the root system. Polystyrene does not, however, retain moisture. Some studies compared polystyrene to perlite with some success. This reuse option is discussed in more detail in section 3. Substituting polystyrene for perlite has also proved advantageous when used on golf greens. By increasing the drainage, greens dried quicker and were playable quicker after heavy rains. Additionally, there was no damage that foot traffic can cause to soggy golf greens[9].

2.3.2 Ground Polystyrene in Geomaterial Applications

Perlite has been used successfully as a soil fill to minimize compaction of park and stadium turf. Because perlite increases soil drainage and provides a softer surface, the material has been proven to reduce sports-related injuries[8].

Since polystyrene exhibits many of the same characteristics that perlite has, ground polystyrene could be added to soil fill to minimize compaction of parks and stadiums turf. The Innovative Grant investigated the incorporation of ground polystyrene with compost and

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[5] The Schundler Company. "Basic Perlite Information and Data." Retrieved May 26, 1999 from the World Wide Web: www.schundler.com

[6] Horticultural Uses of Perlite and Vermiculite." Retrieved May 27, 1999 from the World Wide Web: www.schundler.com

[7] Brentlinger, Dan. "Tomatoes in Perlite A Simplified Hydroponic System." *AVG,* February 1992, 50-52.

[8] "Horticultural Perlite Solves Compaction Problem at New Stadium." Retrieved May 27, 1999 from the World Wide Web: www.perlite.org

[9] "Renovating Golf Greens with Horticulture Perlite." Retrieved May 27, 1999 from the World Wide Web: www.perlite.org

shredded tires (a commercial product called REBOUND) at several athletic fields in Duval County. The University of Florida performed a number of laboratory tests to evaluate this reuse option. The results are presented in Section 4.

2.3.3 Ground Polystyrene in Construction Applications

There are numerous companies that use perlite in cement and gypsum. For example, Redco II in California and the Schundler Company in New Jersey, incorporate perlite aggregate into their lightweight cement blocks, concrete, plaster, and gypsum. These materials are used when a lightweight, fire resistant material is desired[10]. Perlite is also used as loose fill insulation in the cavities of block walls. By doing so, heat transmission is reduced up to fifty percent[11]. Thus in a manner as similar to replacement of perlite in compost applications, ground polystyrene may also have the ability to replace other lightweight aggregates such as kiln dried clay.

RASTRA is a company that uses a mixture of styrofoam beads, Portland cement, and water to manufacture ICF's. RASTRA ICF's display good insulating properties, lends structural integrity to the building, are fire retardant, and are resistant to insects and vermin. The product was originally designed for its user-friendly properties in do-it-yourself construction. RASTRA is a concrete form system made of a lightweight material called THASTYRON, which provides a framework for a grid of reinforced concrete. RASTRA mixes the ground polystyrene with concrete to provide insulation for the pre-cast walls. Recycled post-consumer polystyrene waste makes up 85% of its volume, keeping this material from being landfilled and taking up valuable disposal space. This type of panel is used in Europe and the Western United States, but is relatively unknown in the Southeast.

RASTRA has incorporated the ground polystyrene product as a substitute for one-half of the styrofoam beads in the ICF mixture for the panels, with favorable results. The altered panels will be composed of one-third Portland cement powder, one-third recycled styrofoam beads and one-third recycled polystyrene. RASTRA has committed to manufacturing and providing wall panels using the ground product for a structure or structures on school property. Labor will also be provided by RASTRA to "dry in" the building(s). Negotiations were initiated by Moriah Industries.

As part of this project, work was conducted on the addition of ground polystyrene as an aggregate in Portland cement to concrete. This information is presented in section 5. Section 5 also addresses concerns commonly expressed such as microbial contamination by using food tray polystyrene.

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[10] Seung Bum Park, Eui Sik Yoon, Burtrand I. Lee. "Effects of processing and materials variations on mechanical properties of lightweight cement composites". *Cement and Concrete Research* 29 (1999) 193–200.

[11] "Perlite Block and Cavity Fill Masonry Loose Fill Insulation." Retrieved May 27, 1999 from the World Wide Web: www.schundler.com

3.0 Market Analysis
Substitute for Perlite in Horticultural Applications

3.1 Use of Ground Polystyrene in Compost

Ground polystyrene was collected during the visit to Jacksonville on February 25, 1999 for the purpose of conducting analytical tests on the material. At that time, the properties of the ground polystyrene mixed with composted yard waste from the Enviro-Comp Services facility were evaluated. The testing included appropriate environmental tests in compliance with the Florida Department of Environmental Protection's policies toward beneficial reuse of solid wastes in the environment. Previous laboratory work contracted by the County, as well as available information in the literature, indicated that State policies could be met. Even so, additional testing is prudent.

With its shape and texture similar to that of perlite, expanded polystyrene (EPS) is commonly used for horticultural applications. Polystyrene as a soil amendment achieves many of the same benefits as perlite; it increases the drainage and aeration, and maintains the thermal properties of the soil. It does not degrade over time; hence, it is durable and effective without serving as disease or insect vector. In fact, it is estimated that the amount of polystyrene in the plastics waste stream will double over the next 25 years[12].

Figure 1. Polystyrene-Compost Mixture

3.1.1 Physical Properties

It appears that the use of polystyrene as a soil amendment will achieve many of the same benefits as perlite. Polystyrene is analogous to perlite in that it increases the drainage, aeration and thermal properties of the soil. It does not biodegrade or act as a disease or insect vector.

Polystyrene falls short of perlite in two areas; the first is in its capillary attraction, second is its ability to retain water. There is very little capillary movement of water in polystyrene, but there is some ability to hold water in the soil. In a comparison of the retention properties of the

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[12] M.K. Patel, E. Jochem, P. Radgen, and E. Worrell. "Plastics streams in Germany—an analysis of production, consumption and waste generation". *Resources, Conservation and Recycling* 24 (1998) 191–215.

two in their pure forms, the volume of water retained by polystyrene was approximately thirteen percent of that held by perlite. In a study carried out by the Perlite Institute, researchers found that by using a mixture of two parts peat to one part amendment, polystyrene retained forty to fifty percent as much water as perlite. This percentage increases slightly as the amount of peat in the mix is increased[13].

3.1.2 Pathogen Control

One of the criteria for compost is pathogen control. To address this criterion, polystyrene should be added to any compost mixture prior to the composting process. This is due to the fact that food residue, possible bacterial contaminants, could still be present on the polystyrene. Any bacterial residue would be killed during the actual composting process as temperatures rise. This would lead to compost that is free of pathogens and odor.

3.1.3 Trace Pollutants

Another criteria that must be addressed is the presence of trace pollutants (heavy metals and organic compounds). Food-grade polystyrene should not present a problem in regard to trace pollutants. It will be the compost itself that may cause limitations, if any. Routine testing, the same as any compost, should be performed.

3.2 Summary and Conclusion

Over all, because of its properties, the addition of polystyrene to compost is a potential benefit. As mentioned before, polystyrene is as effective as perlite for some properties when added to compost. It increases the drainage, thermal properties and aeration of the soil. However, it does not retain water as well as perlite. Since the amount of polystyrene waste generated is so great, addition to compost does not offer the best solution for diverting this waste. If this option is chosen, state regulations require consistent testing of the final product, which includes pathogens and trace pollutant content. In this case, it is the properties of the compost itself that will dictate potential reuse. Testing should be conducted the same as with any compost application.

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[13] Matkin, O. A. “Comparative Growth Studies Perlite vs. Polystyrene Media.” Retrieved May 27, 1999 from the World Wide Web: www.perlite.org

4.0 Market Analysis
Polystyrene in Athletic Fields

Expanded polystyrene (EPS) has been used as an alternative geomaterial in Europe for over twenty years. It was chosen due to its ability to insulate and absorb energy. Another favorable characteristic, already mentioned, is that it is very lightweight. Most applications use EPS sheets or blocks that contain only a fraction of post-consumer recycled polystyrene. For example, De Page County in Illinois has used EPS in their bike paths for quite some time[14].

4.1 Potential Reuse in REBOUND

REBOUND[15] is a product consisting of ground tire rubber and compost. It is used in athletic fields to provide cushion to the soil. As part of this Innovative Recycling Grant, ground polystyrene was blended into the REBOUND mix at two high schools. A variety of mixes were tested in the laboratory at the University of Florida to assess applicability of this reuse option.

Figure 2. Athletic Field with Polystyrene Mixture

4.2 Analytical Tests Performed

To demonstrate the advantages of using polystyrene as a shock absorbent, ground polystyrene was collected during the visit to Jacksonville on February 25, 1999, and analytical tests were conducted. The testing included appropriate environmental tests in compliance with the Florida Department of Environmental Protection's policies toward beneficial reuse of solid wastes in the environment. Previous laboratory work contracted by the County, as well as available information in the literature, indicated that State policies could be met. Even so, additional testing is prudent.

There were three analytical tests conducted, each using the polystyrene-crumb rubber mixture. These were size distribution, bulk density, and soil impact value, which are detailed in the following sections.

4.2.1 Size Distribution

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[14] "Bike Trail Gets Lift." *Civil Engineering News*, November 1996, 23-24.

Size distribution was determined in accordance with the American Society for Testing and Materials (ASTM) standard C 136. This testing method determines the particle size distribution by taking a sample of dried material of known mass and passing it through a series of sieves with progressively smaller grid openings. The materials tested were: Crumb rubber supplied by American Rubber Technologies, Inc., and shredded polystyrene food trays. In each case the material was separated into three portions of 700 milliliters and massed on an electronic balance accurate to 0.1 grams. Each material was then tested three times through sieves of decreasing sizes of 0.5”, 0.25”, 0.185”, 0.0787”, 0.055”, 0.0394”, 0.0234”, and 0.0059” that were placed in a W. S. Tyler Inc. mechanical sieve shaker model # RX-86.

The size distribution as presented in Table 1 was determined by calculating the average percentages of material by weight that passed through each successive sieve for all three trials per material. These values are presented in figures 3 and 4 respectively. These figures demonstrate the % of polystyrene that would pass through a sieve of a given size. For example, 50% of the ground polystyrene would pass through a sieve with an approximate size of 0.07 inches. Although that particular sieve was not used in the experiment, we are able to extrapolate the information from the graph. These graphs also provide a good indication of how well the grinder is operating and if additional grinding is needed to reach the appropriate particle size.

Table 1. Sieve Analysis for Crumb Rubber.

Sieve Size (inches)	**Average Passing (percent weight)**	
	Crumb Rubber	**Polystyrene**
0.5000	98.3	100
0.2500	6.50	100
0.1850	1.40	97.3
0.0787	0.00	53.4
0.0550		34.0
0.0394		23.4
0.0234		13.9
0.0059		0.90

Table 2. Polystyrene Amendment Ratios for Bulk Density.

Test Number	Control Sample to Amendment Ratio	
	Polystyrene	Perlite
1	10:1	N/A
2	10:2	N/A
3	10:3	N/A
4	10:4	10:4
5	10:5	10:5
6	10:6	10:6
7	10:7	10:7
8	10:8	N/A
9	10:9	N/A
10	1:1	N/A

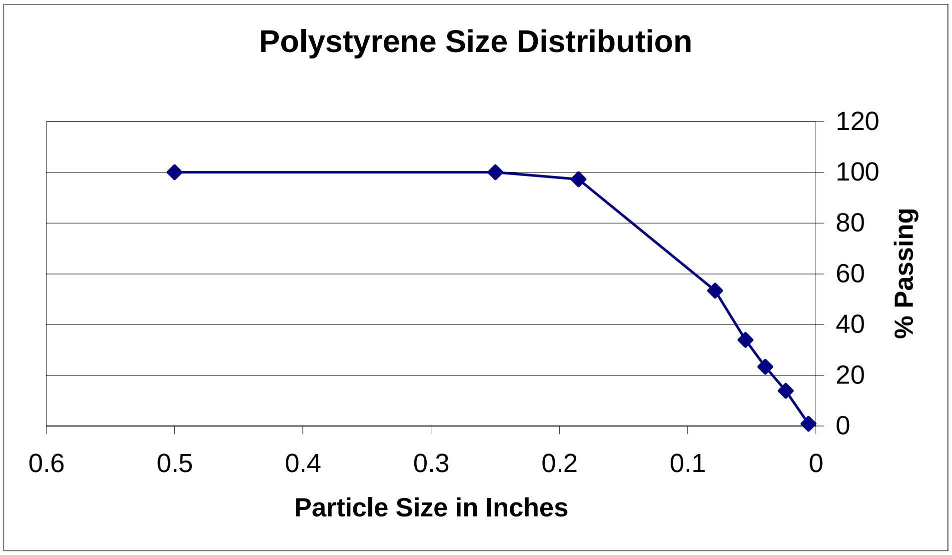

Figure 3. Polystyrene Size Distribution

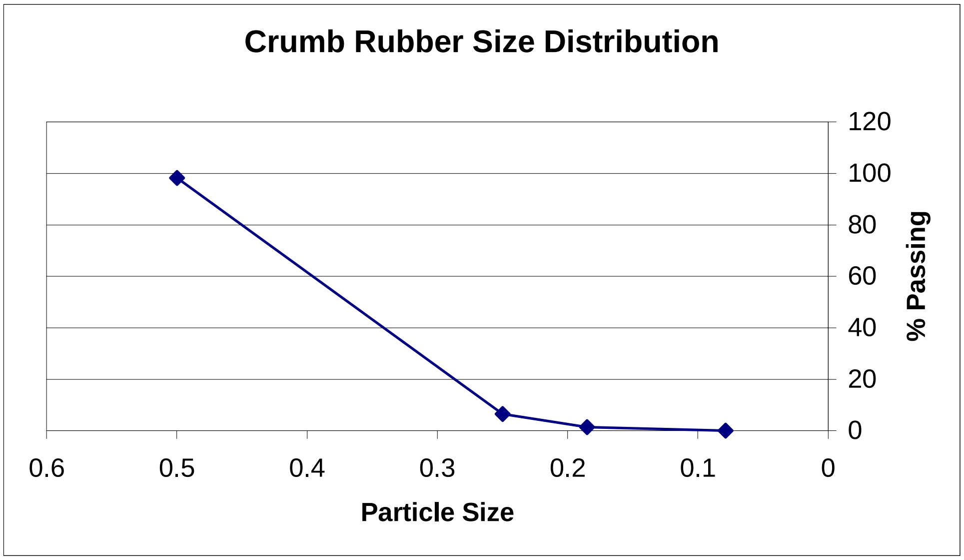

Figure 4. Compost Size Distribution

4.2.2 Bulk Density

The bulk density tests were completed on the individual materials of crumb rubber, polystyrene, and perlite. The bulk density was also determined on the mixtures of materials that will be impact tested. The control sample used an equal mixture of compost and crumb rubber. Table 2 displays the polystyrene amendment ratios for these tests. It should be noted that tests four, five, six, and seven were duplicated with perlite as the amendment in place of shredded polystyrene.

The bulk density was measured in accordance with standard ASTM D 1556 for determination of the density of sand. The tested material was placed in a 1000 milliliter graduated cylinder with a known mass. The cylinder was tapped lightly to close up any large voids but not in a manner as to cause compaction. The cylinder and material were weighed. The bulk density was calculated by dividing the total mass minus the cylinder mass by the volume of the material (1000 mL).

Three-bulk density determinations were completed for each material and mixture, as presented in Table 2,and the average was calculated. To verify that the samples were not compacted, the maximum variation between any one determination and the average could not exceed one percent as specified in the ASTM standard. Table 3 displays the Bulk Density test results.

Table 3. Bulk Density Results.

Material	Mixture Ratio	Mean Weight (g)	Mean Volume (cm^3)	Bulk Density (g/cm^3)
Ground Polystyrene	No Mixture	33.5	468.3	0.071
Perlite	No Mixture	90.9	553.3	0.164
Crumb Rubber	No Mixture	196.2	486.7	0.403
Dry Compost	No Mixture	76.4	310.0	0.247
Base Mix	No Mixture	148.5	300.0	0.495
Base: Polystyrene	10:1	155.7	350.0	0.445
	10:2	142.5	326.7	0.436
	10:3	143.6	333.3	0.431
	10:4	139.1	336.7	0.413
	10:5	134.0	336.7	0.398
	10:6	130.4	346.7	0.376
	10:7	126.0	365.0	0.345
	10:8	104.8	326.7	0.321
	10:9	109.5	348.3	0.314
	1:1	102.9	331.7	0.310
Base:Perlite	10:4	141.8	366.7	0.387
	10:5	130.9	350.0	0.374
	10:6	134.5	376.7	0.357
	10:7	122.2	360.0	0.339

4.2.3 Soil Impact Value

A standard method, ASTM #D 5874, was followed to measure soil impact values. The material was placed in a mold fixed at the bottom of a five pound impact hammer. The hammer was raised to a set height and allowed to free fall onto the sample. The impact value was derived from the peak deceleration measured, and presented in terms of acceleration of gravity (g) by an accelerometer that has been attached to the hammerhead. The results are then displayed on an oscilloscope and printed.

Standard method ASTM #D 5874 with the Clegg Impact Soil Tester was used to evaluate mixture hardness following the test procedure. As before, an equal mixture of crumb rubber and compost was used as the control. Table 4 displays the polystyrene amendment ratios for this test.

Table 4. Polystyrene Amendment Ratios for Soil Impact Value.

Test Number	Ratio Control Sample to Amendment
11	10:1
12	10:2
13	10:3
14	10:4
15	10:5
16	10:6
17	10:7
18	10:8
19	10:9
20	10:10

Table 5 displays the results of the impact value (IV) of the Soil Samples. Appendix B contains representations of the raw data that was generated by the accelerometer. The accelerometer measured force of impact at ten millivolts per gravity. IV values are measured in tens of gravities (g). [IV = (milli volts/10)/10]

Table 5. Impact Value of the Soil Samples.

Material	Ratios	IV (g)
Control	N/A	3.25
Polystyrene	10:1	3.09
	10:2	3.06
	10:3	2.97
	10:4	2.97
	10:5	2.88
	10:6	3.13
	10:7	3.28
	10:8	3.41
	10:9	3.53
	1:1	3.44
Perlite	10:4	2.88
	10:5	3.22
	10:6	3.38
	10:7	3.38

4.3 Summary and Conclusion

The results of these tests showed that the impact value decreased with the addition of the shredded polystyrene to the control mix. This effect only seemed to be valid until the mix ratio reached ten parts control mix to six parts polystyrene. From this point on the test results would indicate that any additional polystyrene actually allowed the sample to compress to a greater degree. Perlite offered the same effect with using less material.

5.0 Market Analysis
Polystyrene as Lightweight Aggregate in Concrete

One reuse option of polystyrene is addition to concrete. Florida Rock Industries, a concrete manufacturer in Florida, agreed to add polystyrene to cement and conduct a series of tests to determine compatibility of using ground polystyrene in cement mixtures. Two control batches were analyzed along with seven batches of polystyrene concrete mixture at the Florida Rock Industries Gainesville plant. The different mixtures of polystyrene and concrete are outlined in Table 6. The concrete mixture consisted of 700 lbs of type I cement, 1200 lbs of silica sand, 1700 lbs of #57 limestone and 283 lbs water. The concrete was mixed using ASTM method 192. The different mixtures were exposed to a series of tests as outlined in Table 7.

Table 6. % mass of polystyrene in each batch of concrete

Batch Number	% Polystyrene
1 (Control)	0
2 (Control)	0
3	3
4	6
5	9
6	9
7	12
8	15
9	18

Table 7. Tests Methods

Method Number	Method Name
ASTM 29	Unit Weight and Voids in Aggregate
ASTM 31	Making and Curing Test Specimens in Field
ASTM 39	Compressive Strength
ASTM 143	Slump of Hydraulic Cement Concrete
ASTM 173	Air Content of Freshly Mixed Concrete

5.1 Unit Weight and Voids in Aggregate (ASTM Method 29)

This test method outlines the procedure to determine unit weight in a compacted or loose condition and calculate voids in aggregates. A container with a known volume was weighed and its weight was recorded. The container was then filled with concrete in three approximately equal layers and each layer was compacted, respectively. The container (including the concrete) was weighed. The unit weight was calculated using the following equation:

$$M = \frac{(G - T)}{V}$$

Where :

M is the unit weight of the aggregate (lb/ft^3)
G is the mass of the aggregate plus the container (lbs)
T is the mass of the container (lbs)
V is the volume of the container (ft^3)

The design unit weight was measured by diving the total weight of the concrete's components by the total volume of the concrete. The results of this test are presented in Table 8. As shown in the table the addition of the polystyrene to the concrete mixture did not affect the unit weight of the concrete considerably. Thus, additional transportation costs are negligible. These results were expected since the density of polystyrene is small (1 lb/ft^3).

Table 8. Concrete Unit Weight.

% Polystyrene in Concrete	Design Unit Weight (lb/ft^3)	Actual Unit Weight (lb/ft^3)
0	142.9	143.8
0	142.3	143.5
3	142.0	139.2
6	140.9	142.8
9	139.8	141.8
9	142.0	142.7
12	140.2	142.1
15	139.9	142.1
18	139.6	142.0

5.2 Compressive Strength (ASTM Method 39)

This method is used to determine the compressive strength of cylindrical concrete specimens. This method is used for concrete with unit weight in excess of 50 lb/ft^3. Specimens were collected and poured into cylinders using ASTM method 31. After pouring the concrete into cylinders, they were placed in a water bath and tested at 3, 7, 14, 28 and 56 days. The results of the tests are tabulated in table 15. The compressive strength of the specimen is calculated by dividing the maximum load carried by the average cross-sectional area.

Table 9. Concrete Compressive Strength.

% Polystyrene	Compressive Strength (psi)				
	3 days	7 days	14 days	28 days	56 days
0 (Control)	5150	6930	-	7170	7330
0 (Control)	5710	6740	7130	7530	-
3	5150	6890	-	7030	7330
6	5310	6540	-	6930	6930
9	5310	6380	-	6830	7130
9	5710	6340	6740	7330	-
12	5150	5940	6340	7030	-
15	4910	5900	6340	6620	-
18	4750	5350	5740	6440	-

From the previous table it is apparent that the addition of polystyrene to concrete would reduce its compressive strength. However, the compressive strength would increase to that of the control batch for low concentrations of polystyrene if the mixture was allowed to cure for a longer period of time (more than 14 days).

5.3 Slump of Hydraulic Cement Concrete (ASTM Method 143)

This test determines the slump of concrete. The slump is the distance between the original and displaced positions of the center of the top surface of the concrete. This distance is measured in inches and is presented in Table 10.

Table 10. Slump Test Results

% Polystyrene	Slump (inches)
0 (Control)	5.5
0 (Control)	4.5
3	5.5
6	5.5
9	5.5
9	4.5
12	4.25
15	4.0
18	3.5

It is evident from the results that polystyrene at low concentrations does not affect the slump of the concrete. However, as the % polystyrene increases to above 9%, the slump decreases from 5.5 inches to 3.5 inches.

5.4 Air Content of Freshly Mixed Concrete (ASTM Method 173)

This test method determines the air content of freshly mixed concrete. An air meter consisting of a bowl and a top section (Figure 5) conforming to the ASTM requirements for this method is used. The results of this test are presented in Table 11.

Table 11. Air Content Results.

% Polystyrene	Air content by volume (ft^3)
0 (Control)	0.54
0 (Control)	0.67
3	0.54
6	0.54
9	0.54
9	0.54
12	0.81
15	0.81
18	0.81

Figure 5. Air Content Testing Apparatus.

At low concentrations, polystyrene addition to concrete does not have an effect on the air content of the mixture. But at higher concentrations, greater than 9%, it is evident that the addition of polystyrene leads to an increase of air content within the concrete/polystyrene mixture.

It is also important to address the potential microbial growth caused by food contamination on the polystyrene. Tests conducted at the University of Florida Environmental Toxicology labs (Appendix A) showed that bacteria grew profusely on all plates, control (concrete only) and mixed (polystyrene/concrete). Thus, the data did not show any inhibition of growth due to the presence of polystyrene. However, any enhancement of growth due to the presence of polystyrene was not shown either.

Figure 6. Concrete/Polystyrene Mixture for Bacterial Growth Testing

5.5 Summary and Conclusion

From all the tests presented previously it is clear that polystyrene, at concentrations less than 9%, does not affect the physical characteristics of concrete. The samples tested performed at the same level as the control samples for these mixtures. However, it is evident that at concentrations greater than 9%, the mixture loses some of its strength. Knowing this, it is still important to discuss the ultimate uses of the polystyrene/concrete mixture (sidewalks vs. bridges). Toxicological tests show that there was no evidence that microbial growth occurred due to the addition of polystyrene to concrete.

6.0 Evaluation of Grinder

Duval County made the decision to have a grinder built by Moriah Industries of Rome, Georgia. The University of Florida DEES evaluated the grinder during the Spring. Team members were able to observe the grinder in use and speak with operating personnel. The information in this section was presented in previous versions of this report and are included here as a summary of results relating to Task 2.

6.1 Evaluation of Grinder Properties

The grinder from Moriah Industries is a portable, shredder system with a 125 cubic foot storage capacity. It has a 50 horsepower drive motor with a 500 pound per hour minimum capacity. The grinder system has two screening mechanisms and a bar magnet. A picture of this grinder system is shown below.

Figure 7. Moriah Industries Portable Grinder
Model MI0902JAX/A

The grinder by Moriah adequately size reduces the polystyrene food trays. After an initial investigation of the grinder by the UF team, a few concerns remain regarding personnel safety of the feeding and conveyance system. Additionally, appropriate methods for breaking down the trays prior to entrance into the conveyance system were suggested to be explored. In subsequent visits, the grinder did appear to adequately process polystyrene for the intended purposes. Further evaluation and testing will resolve these issues.

6.2 The Gehl Feed Mixer

Information was presented to the County by the UF team early in the project regarding the base model that the grinder was apparently constructed from. The base model was apparently a GEHL agricultural feed mixer. Information on the device is presented in Appendix D. Contacting agricultural vendors revealed that the typical retail cost for the machine was between $10,000 and $15,000.

6.3 Additional Models

There are other types of grinders that meet the needs for this particular application. Three additional vendors were contacted to obtain cost and product information. Stacy Botte from Crigler Enterprises in Atlanta provided information regarding a Hammermill model. This model is “complete with 30 HP, 1800 RPM, 230/460 volt, 3 phase, 60 cycle motor”. The model can also be equipped with a “high efficiency 48 [inch] cyclone air separator with stand to mount over container, anti-emission screen and discharge damper”[15].

Don Groppe from Williams Patent Crusher and Pulverizer Co., Inc. in St. Louis provided information on a heavy duty industrial Hammermill grinder. This model is equipped with a 10 HP, 1200 RPM motor with V-Belt drive, a drive guard, structural steel base and feed hopper[16]. Finally, Kent West from the Tryco/Untha Company in Decatur, Illinois provided information regarding their UNTHA Single Shaft Shredder. This model is “equipped with a dual cylinder hydraulic ram feeding system, reversible and replaceable cutting teeth mounted on a replaceable teeth holder, siemens SPS speed and pressure control, foreign substance recognition and automatic reversal system”[17]. The price quotes ranged from $14,000 to $30,000. This additional grinder information is provided as a reference for the price of this type of equipment. It is not a recommendation for one particular vendor.

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APPENDIX A

Toxicology Report

UNIVERSITY OF
FLORIDA

Marnie Ward
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P.O. Box 116450
381 NEB
Department of Environmental Engineering Sciences
Gainesville, FL 32611-6450

Report #1001-SW

Date: 12-2-99

Re: Recycled polystyrene (RP) and
Concrete polystyrene (CP) aggregate

Sample	Total coliform (9221B)*	Fecal coliform (9221C)*
RP	130000	1700
CP	**	**

*Standard Methods, 17th edition
** not tested due to sample interference from sample matrix

Conclusions:
The recycled polystyrene contained both total and fecal coliforms, but it is important to note that the polystyrene material was stored outside on the ground and total coliforms include many of the soil bacteria, e.g. *Klebsiella sp*. As a result of being stored out of doors, the material was subject to various animal species, which would contribute feces and hence fecal coliforms to the polystyrene. When mixed with the concrete and heated the coliform bacteria would be inactivated.

Isolation of polystyrene-utilizing bacteria

Flasks were prepared with minimal salts and autoclaved polystyrene material. Aliquots of an endemic bacterial species from a local lake were added to the flasks. The flasks were continuously agitated at room temperature and turbidity was monitored. The flask cultures were plated on heterotrophic count agar for enumeration of bacterial colonies.

Bacteria grew profusely on all plates. The data did not show any inhibition of growth due to the presence of polystyrene, but we also could not show any enhancement of growth due to the presence of polystyrene.

APPENDIX A (CONT.)

Conclusions:

Our laboratory was presented with the question of whether or not a pathogenic bacterial species could colonize and thrive on a construction material composed of a concrete/polystyrene aggregate. Our lab facilities preclude us from being able to definitively answer that question. The proper sterilization of the polystyrene material would require a sterilization chamber with a controlled environment. The identification of bacterial species is a labor-intensive procedure, which requires a highly skilled technician and specialized equipment.

There is a form of bacteria, which will grow in any environment. If a secondary cover, e.g. sheet rock, plaster or paint is going to be applied over the concrete/polystyrene material then any bacteria on the material will be isolated.

Marnie Ward

Figure A.1. Flasks prepared with salts, autoclaved polystyrene material and endemic bacterial species from a local lake on the agitator.

Appendix B

Impact Values for Polystyrene

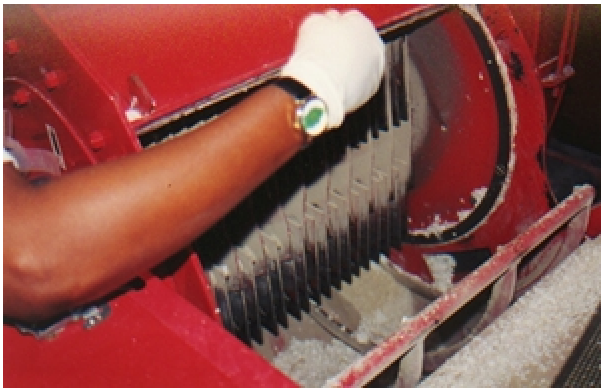
Appendix C

Spent food service polystyrene lunch trays.

Used food service polystyrene trays collected from a school cafeteria.

Polystyrene food trays being prepared for grinding.

Polystyrene food trays being fed into the grinder.



Close up of grinder.

Ground polystyrene food tray material.

REBOUND project at Englewood High School's football field in Jacksonville, Florida.

Pouring polystyrene/concrete mixture into the air apparatus.

Addition of water to concrete/polystyrene mixture in the air apparatus.

Florida Rock air content test apparatus.

Ground polystyrene being added to compost pile.

Mixing of polystyrene/compost.

Compost/Polystyrene product after mixing.

Appendix D
Information from the Gehl Web site

http://www.gehl.com/ag/Feedmaking/mix_all/index.htm

Model 125 - with proven hydraulic drives

Now you can have all the advantages of hydraulically operated feedmaking right on your farm with the Gehl 125 Mix-All. A full 100-bushels (125 cu. ft capacity) big, this portable grinder-mixer is the combination of all the advancements made on past Gehl mixers, plus hydraulics. Hydraulics designed in, not added on! The result to you is smooth feeding, fingertip control, and fast 3½- minute unloading. Check the features: proven, 21" wide mill with 66 reversible hammers; wide variety of screens that can be changed faster than ever before; self-contained hydraulic system with infinitely variable speeds to reduce grinding time; continuous recirculation action to thoroughly mix your ration; side-mounted concentrate hopper so supplements don't have to go through the mill; full-length, graduated windows; and more!

Plus, you can use remote controls for the unloading auger, giving you tractor-seat control over positioning of the auger. You can also mount the remote controls on the rear of the mixer near the conveyor.

And, you get hydraulically operated attachments, like the swinging auger feeder for feeding grains and shelled or ear corn, a gravity feeder, and feed roll for ear corn and baled hay. There are also new electronic scales and unloading conveyor extensions to fit operations like yours. The 125 is hard to match when it comes to unloading! The big, 8" unloading auger is hydraulically powered for smooth, fast unloading -- no surges, unloads a full tank in only 3½ minutes! Twelve-foot unloading conveyor is standard, with 3-, 4-, and 7½-foot extensions available. The unloading conveyor swivels a full 270 degrees to get you into the toughest-to-reach bins. And a new top-mounted winch simplifies operation.

See your Gehl dealer for the full story on the new generation of Mix-AIls. For over 137 years the Gehl Company has been serving North American agriculture. Gehl company will continue it's commitment by providing the finest products and service available today, and in the future.


GEHL
mix-all


GEHL