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RP-CRP3-41

Worcester Polytechnic Institute
Interactive Qualifying Project
Costa Rica Project Center E'00

Recycling Post-Consumer Plastics in Santa Ana, Costa Rica

Janelle Arthur
Elizabeth Caswell
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Sponsored by el Centro de Investigaciones en Contaminación Ambiental

CICA

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100 Institute Road
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July 3, 2000

Dr. Ronald Arrieta Calvo
Dr. Milton Alvarez
Centro de Investigaciones en Contaminación Ambiental
Universidad de Costa Rica
San Pedro de Montes de Oca
Costa Rica

Dear Dr. Arrieta and Dr. Alvarez:

Enclosed is our report entitled *Recycling Post-Consumer Plastics in Santa Ana, Costa Rica*. The report was written in Costa Rica during the period of May 15 through July 3, 2000. Preliminary background work was completed in Worcester, Massachusetts, prior to our arrival in Costa Rica. Copies of this report are simultaneously being submitted to Professors Pietroforte and Rivera for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We appreciate the time that you both, as well as your organization, have devoted to us.

Sincerely,

Janelle Arthur

Janelle Arthur

Elizabeth Caswell

Elizabeth Caswell

Katherine Wheeler

Katherine Wheeler

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Janelle Arthur
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WPI
100 Institute Road
Worcester, MA 01609

el 3 de julio, 2000

Dr. Ronald Arrieta Calvo
Dr. Milton Alvarez
Centro de Investigación en Contaminación Ambiental
Universidad de Costa Rica
San Pedro de Montes de Oca
Costa Rica

Estimados Dr. Arrieta y Dr. Alvarez:

Junto con esta carta es nuestro proyecto titulado *El reciclaje de los plásticos pos-consumidores en Santa Ana, Costa Rica.* El proyecto fue escrito en Costa Rica durante el período del 15 de mayo hasta el 3 de julio, 2000. Investigaciones preliminaries fueron acabadas en Worcester, Massachusetts, antes de nuestra llegada en Costa Rica. A la vez, se presentan unas copias de este proyecto a Profesores Pietroforte y Rivera para evaluación. Después de la revision de la facultad, la copia original de nuestro proyecto será catalogado en la biblioteca de Gordon de Worcester Polytechnic Institute. Nos agradecemos el tiempo que Uds. dos, además de su organización, nos han dedicados.

Atentamente,

Janelle Arthur

Elizabeth Caswell

Katherine Wheeler

Report Submitted to:

Professor Ángel Rivera
Professor Roberto Pietroforte

Costa Rica, Project Center

By

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In Cooperation With

Dr. Ronald Arrieta Calvo, Director of Solid Waste Program
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Centro de Investigaciones en Contaminación Ambiental

RECYCLING POST-CONSUMER PLASTICS IN SANTA ANA, COSTA RICA

July 3, 2000

This Project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of Centro de Investigaciones en Contaminación Ambiental or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

Costa Rica currently lacks post-consumer plastic recycling, due primarily to the fact that there is no washing process in practice; thus dirt and contaminants adhered to the plastics cannot be removed and will damage processing equipment and devalue the resulting secondary plastics. This project, submitted to el Centro de Investigaciones en Contaminación Ambiental (CICA), analyzes each phase of the recycling process and provides recommendations for the implementation of a pilot post-consumer plastics recycling program in Santa Ana, Costa Rica.

Acknowledgements

In the completion of this Interactive Qualifying Project, we would like to thank our liaison, Dr. Ronald Arrieta, as well as our advisors, Professor Ángel Rivera and Professor Roberto Pietroforte, for their guidance throughout our project. Additionally, we would like to thank Dr. Milton Alvarez, Dr. Maria Laura Arías, Professor Berghandahl, Professor Clifford Bruell, Professor Rudolph Deanin, Professor Robert Malloy, Professor Steven McCarthy, Ms. Charlene Music, Professor Plummer, Professor Kent Rissmiller, Dr. Elias Rosales, Professor Nicholas Schott, and Ms. Liliana Umaña. Special thanks to Jonathon Molina and Adriana Soto of *Gente Reciclando* for their enthusiasm, support and guidance during our stay in Costa Rica.

Authorship Page

This report entitled, *Recycling Post-Consumer Plastics in Santa Ana, Costa Rica*, has been completed on July 3, 2000 with equal contributions from Janelle Arthur, Elizabeth Caswell and Katherine Wheeler. Although some sections were written individually, they were collectively edited and revised.

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Executive Summary

Plastic technology offers today's consumers an ever-expanding array of choices, from shatter-resistant ketchup bottles to squeezable jelly jars. Innovation has allowed for increased versatility and the development of new applications for plastics in the United States, as well as in less-industrialized nations including Costa Rica. At the same time, plastic waste is also on the rise, in landfills, incineration plants, even in rivers or on the streets – and its recovery poses many problems.

Costa Rica currently lacks a post-consumer plastics recycling program, due in part to the fact that plastics arrive at collection facilities often with dirt and contaminants adhered to their surfaces. This presents a problem, as there is no process for cleaning these contaminants currently in practice. Without a cleaning method, contaminants cannot be removed, and will in turn damage processing equipment and devalue the resulting secondary plastics. A number of companies do recycle post-industrial plastics, which are unused and inherently clean. One small business in the San José region, *Gente Reciclando*, shreds post-industrial plastics, and enthusiastically notes the strong demand for high-quality recycled plastics in Costa Rica and international markets. Together with el Centro de Investigaciones en Contaminación Ambiental (CICA), a pollution research division of the University of Costa Rica for which this project was completed, *Gente Reciclando* hopes for a solution to the post-consumer plastics dilemma, so that these too may be recycled.

This report investigates each aspect of the recycling process as it relates to the issue at hand and provides recommendations for the implementation of a pilot recycling program, which includes post-consumer plastics, for the city of Santa Ana. Dr. Ronald

Arrieta of CICA is working in close partnership with the Santa Ana municipality and will use the recommendations contained within this report to aid in the implementation of this recycling program. The report's findings include a survey of public recycling awareness, a study of available recycling technology and current methods of collection, separation and processing, research of washing techniques including biodegradable detergents and microorganisms, and lastly, the discussion of options for wastewater treatment. Ultimately, this report connects the collection center with secondary purchasers, such as *Gente Reciclando,* which will further process and market the cleaned post-consumer plastics. The results of this analysis are presented to both CICA and the Santa Ana municipality in the form of a recommendations manual, which has been further supplemented by a workshop that outlined the proper techniques for identifying and cleaning post-consumer plastics.

While the pilot program has been designed with the center's specific needs and resources in mind, it nonetheless serves as a model for establishing successful community recycling programs in Costa Rica. Moreover, this project illustrates the complexity of recycling plastics in addressing not only technological, but social challenges as well. By mirroring the methods this project proposes to overcome these challenges in a sustainable manner, future recycling programs in Costa Rica will allow for the successful recovery and recycling of post-consumer plastics.

Resumen Ejecutivo

La tecnología de plásticos le ofrece a los consumidores de hoy en día una gran variedad de alternativas, desde botellas inquebrables para salsa de tomate hasta tarros para jaleas que se pueden estripar. La inovación ha llevado a una creciente versatilidad y al desarrollo de nuevos usos para plásticos en los Estados Unidos, así como en países menos industrializados como Costa Rica. Al mismo tiempo, los desechos plásticos también se han incrementado en botaderos, plantas de incineración, y hasta en los ríos y en las calles – y recuperarlos trae muchos problemas.

Actualmente, a Costa Rica le hace falta un programa de reciclaje de plásticos, y esto en parte se debe a que los plásticos llegan sucios y contaminados a los lugares de recolección. Esto presenta un problema, ya que no hay un proceso para limpiar estos contaminantes. Sin un método de limpieza, es imposible deshacerse de los contaminantes, y estos más bien dañan el equipo para procesar los materiales y devalúan los plásticos secundarios que son producto de este proceso. Varias compañías sí reciclan sus materiales post-industriales, los cuales están limpios ya que no han sido usados por consumidores. *Gente Reciclando,* una pequeña compañía en San José, hace trizas los plásticos post-industriales, y es conciente de la gran demanda para plásticos reciclados de buenas calidades que hay en Costa Rica y en el mercado internacional. Junto con el Centro de Investigaciones en Contaminación Ambiental (CICA), una división de investigaciones en contaminación de la Universidad de Costa Rica para la cual se llevó a cabo este proyecto, *Gente Reciclando* espera encontrar una solución para el problema que traen los plásticos usados por los consumidores, para que estos también puedan ser reciclados.

Este informe investiga cada aspecto del proceso de reciclaje en cuanto a este problema y proporciona recomendaciones para la implementación de un programa piloto de reciclaje, el cual incluye plásticos usados, en la ciudad de Santa Ana. El Dr. Ronal Arrieta de CICA trabaja en asociación con la municipalidad de Santa Ana y usará estas recomendaciones para mejorar y hacer posible la implementación de este programa de reciclaje. Los hallazgos de este informe incluyen una encuesta del conocimiento público de reciclaje, un estudio de la tecnología disponible para el reciclaje y de los métodos de recolección actuales, una investigación de técnicas de lavado incluyendo detergentes biodegradables y microorganismos, y finalmente, una discusión de las opciones para el tratamiento de las aguas. Fundamentalmente, este informe conecta al centro de recolección con los compradores secundarios, como *Gente Reciclando*, quienes llevarán más allá el procesamiento y el mercadeo de los plásticos limpios ya usados por consumidores. Los resultados serán presentados a CICA y a la municipalidad de Santa Ana en forma de un manual de recomendaciones, el cual ha sido aumentado con un taller que delínie las técnicas adecuadas para identificar y limpiar los plásticos usados.

Aunque que el programa ha sido diseñado tomando en cuenta las necesidades y recursos específicos del centro, también sirve como un modelo para establecer programas exitosos de reciclaje en las comunidades de Costa Rica. Además, este proyecto ilustra las complejidad del reciclaje de plásticos al mencionar no solo los desafíos tecnológicos, sino también los sociales. Tomando en consideración los métodos que use este proyecto para sobrellevar los desafíos de una manera sostenible, futuros programas de reciclaje en Costa Rica permitirán la recuperación y el reciclaje de plásticos usados.

Chapter 1. **INTRODUCTION**

This Interactive Qualifying Project (IQP) provides guidelines to facilitate the implementation of a pilot program for the recycling of post-consumer plastics in Santa Ana, Costa Rica. The project was completed in conjunction with the Centro de Investigaciones en Contaminación Ambiental (CICA), an environmental research branch of the University of Costa Rica. The organization is seeking to promote plastics recycling in Costa Rica, in part through their collaboration with the Santa Ana community.

> The following report was prepared by members of the Worcester Polytechnic Institute Costa Rican project center. The relationship of the center to the Centro de Investigación en Contaminación Ambiental (CICA) and the relevance of the topic to CICA are presented in Appendix A.

Plastics recycling has become increasingly important in both industrialized and developing nations throughout the world. The growing and widespread usage of plastics, along with new developments in plastics technology, has led to an increase in plastic waste. Since most plastics are recyclable, the bulk of waste, which is presently incinerated or dumped into landfills, can be greatly reduced. Plastics recycling technology is continually improving; yet, along with these improvements come many challenges.

Currently, Costa Rica recycles industrial plastic waste, which is inherently clean because it is composed of unused scrap that is not exposed to sources of contamination. Household and consumer plastics, however, are often dirty upon their arrival at waste management facilities. This creates two main problems. First, the various contaminants on plastics may damage equipment used during the recycling process. Second, the eventual disposal of wastewater containing these contaminants poses environmental hazards. To date, Costa Rica has not developed an effective technique for cleaning post-consumer plastics. For this reason, the extent of recovery is presently limited to the collection and processing of soiled polyethylene, commonly known as PET or type #1 plastic, by only one facility for the entire country. These plastics are then marketed overseas after only minimal processing and without cleaning. Environmental organizations such as CICA hope to expand plastics recycling in Costa Rica by developing a sustainable cleaning procedure.

Although detergents are familiar and effective cleaning agents, their use has historically necessitated secondary treatment of the wastewater in order to remove the byproducts of their application. Nonetheless, detergent residues, such as phosphates and nitrates, often remain in treated wastewater that is released into the environment, triggering a series of undesirable environmental consequences.

Since the current lack of cleaning technology accounts for the greatest limiting factor in the processing of post-consumer plastics, one fundamental focus of this project thus lies in the examination of alternative washing procedures to the use of conventional detergents. CICA has proposed the investigation of the use of microorganisms as a possible, alternative cleaning agent. One focus of this project, therefore, is the study of the nature and feasibility of cleaning post-consumer plastics with microorganisms.

At the same time, the solutions to these technological challenges must be considered in terms of their realization at the municipal collection center in Santa Ana. Indeed, we discovered it was impractical to consider the washing process alone. The following report therefore provides a well-rounded evaluation of plastics recycling, as it specifically pertains to Santa Ana. Accordingly, our methodology outlines each step taken in our investigation, which effectively traces the logical sequence of the processing of post-consumer plastics that are derived from Santa Ana's public waste stream. Specifically, our study begins with an analysis of the use and disposal of plastics from the home, progressing to an evaluation of the city's plans for curbside collection, then a familiarization with the collection center's employees and resources, followed by an ascertainment of the current state of recycling technology available in Costa Rica, to the investigation of microorganism and other conventional detergent alternatives, and then the study of appropriate treatment for the center's wastewater. Finally, we conclude with the consideration of secondary markets for Santa Ana's semi-processed post-consumer plastics.

The results from our investigation ultimately allowed us to create a recommendations manual for the implementation of the pilot-recycling program, which accounts for the collection, sorting, washing, and distribution of post-consumer plastics from the collection center. As a supplement to the manual, we developed and conducted a small workshop to demonstrate proper sorting and processing techniques found in our recommendations manual. Together, the workshop and manual will help to facilitate and ensure the success of this program, which may serve as a model for future plastics recycling projects in Costa Rica.

Chapter 2. BACKGROUND INFORMATION

2.1 Introduction

The rapid advancement and growth of technology in today's modern society offers unforeseen benefits to the populations of the world, but along with these benefits come equally unexpected complications. Technological development has created the need for increased production of synthetic materials. In order to maximize their utility, these compounds have been specifically devised to be both non-reactive with chemicals typically found in the environment and perseverant "in the field" in which they are used. These same two attributes consequently inhibit the degradation of synthetic materials, leading to an increase in waste (Gealt, 1993). Wastewater and solid waste pose another waste management problem (US EPA, 2000). As the world's population continues to rise, landfills and water treatment plants are operating at their limits. Recycling efforts have significantly helped to reduce waste worldwide; however, recycling itself can lead to further waste complications. For example, many of the detergents commonly used in the process of cleaning the materials to be recycled are detrimental to the environment. Furthermore, detergents, which contain surfactants, do not break down contaminants, but instead merely facilitate their removal from plastic surfaces. The water used in the cleaning process must then be treated in a secondary process before being released into natural bodies of water.

The Centro de Investigaciones en Contaminación Ambiental (CICA) in San Pedro, Costa Rica is seeking an effective and environmentally sound technique for the cleaning of post-consumer plastics, as this is a critical aspect for the success of their pilot recycling program. Additionally, CICA realizes the importance of designing a well-rounded and effective system that accounts for the collection, sorting, processing and distribution of post-consumer plastics.

By means of library and Internet research, personal interviews and facility visits, we have gained an understanding of the most current information and ideas regarding the problem at hand. This knowledge, presented in the following review of relevant literature and background information, includes a discussion of plastics' properties and plastic waste, the various steps involved in the process of plastics recycling, and the perception of plastics as commodities in Latin America, as these topics clarify the current plastics situation. The cleaning process and the wastewater generated by this process are integral, yet complicated, components of the plastics recycling process. Thus, we investigated and summarized the use of detergents and other cleaning alternatives, the environmental impact of wastewater, and the applications of microorganisms in waste management as well. The vast majority of the research, interviews and visits that this chapter is based upon were conducted in the United States where recycling technology is highly developed and readily available. Though an important aspect of Costa Rican culture is a great concern for environmental conservation, waste management technology is primarily small-scale and in developmental stages. Another characteristic of Costa Rica is a pronounced emphasis on manual, rather than mechanical labor. For these reasons, many of the processes originally reviewed in the United States would not be feasible to implement in the Santa Ana program. This factor is therefore taken into consideration in the subsequent methodology, data and data analysis, conclusions and final recommendations.

2.2 Plastics Overview

In conjunction with the rise of modern technology, the synthesis of plastics has grown steadily and considerably in the past forty years since their invention. Thus, current data (Table 2-1) also show a measurable increase in plastic waste, beginning in 1960, as a percentage of total municipal solid waste (MSW) in the United States (Subramanian, 2000). Shent, Pugh, and Forssberg, in their review of current recycling technology, agree that "plastic waste has become a larger area of MSW, particularly in industrialized countries" (1999, p. 87). In accordance, statistics further indicate that between the years of 1975 and 1984, the percentage of plastic waste, as a fraction of aggregate US MSW, essentially doubled (Powelson, 1992). Carol Neugent writes that the usage of polyvinylchloride (PVC) alone, a common durable plastic found in children's toys, has increased one hundred times since during the same time period (2000).

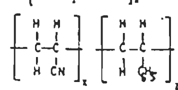
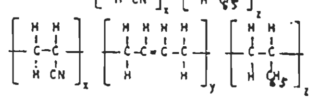
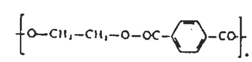
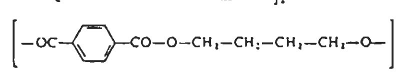
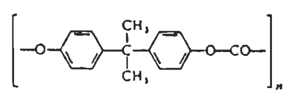
Table 2-1. Growth of Plastics in MSW

Year	Plastics in MSW (%)
1960	0.5
1970	2.6
1980	5.0
1990	9.8
1992	10.6
1994	11.2
1995	11.5
1996	12.3

(Subramanian, 2000, p. 256)

Defined simply, primary plastics are resins composed of polymers of various combinations of organic monomers. These monomers are simple molecules derived from carbon, hydrogen, oxygen, and nitrogen that become linked together during polymerization (Table 2-2). The resulting plastic products, called resins, are then divided into two categories: thermoplastics, which have the ability to be remolded; and heat resistant thermosets, which are composed of long, cross-linked polymers that resist reformation once fused. The variation of the polymers accounts for roughly one hundred and fifty different types of resins, each with a unique chemical formula (Powelson, 1992).

Table 2-2. Structural Formula of Some Plastics

Polymer	Abbreviation	Molecular Category	Formula
Polyethylene	PE	Polyolefin	$[-CH_2-CH_2-]_n$
Polypropylene	PP	---------	$[-CH_2-CH(CH_3)-]_n$
Polystyrene	PS	Polystyrene	$[-CH_2-CH(C_6H_5)-]_n$
Polystyrene-acrylonitrile	SAN	Copolymer	
Acrylonitrile-butadiene-styrene	ABS	----------	
Polyvinylchloride	PVC	Vinylchloride	$[-CH_2-CCl_2-]_n$
Polymethyl-methacrylate	PMMA	Polyacrylate	$[-CH_2-C(CH_3)(COOCH_3)-]_n$
Polyoxymethylene	POM	Polyether	$-[-CH_2-O-]_n-$
Nylon 6	PA6	Polyamide	$[-(CH_2)_5-CO-NH-]_n$
Polyethylene-terephthalate	PET	Polyester	
Polybutylene-terephthalate	PBT	-----------	
Polycarbonate	PC	Aromatic polymer	

(Shent, 1999, p. 93)

Considering the many plastic varieties, Subramanian points to increasing waste simply as the tangible indicator of plastic's ever-developing role in technologically advanced societies - including its applications in medical technology, packaging, food preservation, household appliances, as well as computer and electrical technology (2000). CICA's mission in Costa Rica serves to illustrate that plastics have become significantly integrated into less-industrialized nations as well. The utility and diversity of plastics are based upon their unique aforementioned chemical and resulting physical properties. While each resin boasts individual characteristics, plastics as a whole are esteemed for their relatively low cost of production and sturdy yet lightweight construction (Subramanian, 2000). Many consumer plastics are of the thermoplastic variety. The two widely known as polyethylene (PET) and high-density polyethylene (HDPE) constitute a significant portion of MSW and are commonly used to manufacture beverage bottles. Durable consumer goods, on the other hand, such as children's toys, electronics, furniture, car and other vehicular plastics are thermosets, which create a problem as secondary goods due to the difficulty inherent in their breakdown and recovery (Powelson, 1992).

According to the most recent figures presented by *S.P.M Industries*, there is indeed an increase in the percentage of MSW now entering the recovery, recycling, or composting cycle, an improvement from twenty one percent in 1991 to twenty seven percent in 1996 (Subramanian, 2000). Table 2-3 shows, however, that the current rate of plastic recycling is now leveling off, which Subramanian attributes to what he believes to be its high costs of production in comparison to the costs incurred through the production of virgin materials (2000). Other authors note that the prices of post-consumer plastics are determined by their purity (Powelson, 1992) and the cost required to reprocess post-consumer products to such a marketable value. The *S.P.M Industries'* findings therefore illustrate the culpability of the free-market economy in allowing for the market failure of recycled plastics. The article later explains that recycling may increase once again through future regulation or simply as a result of continual public concern for less wasteful and more environmentally sound technology (Subramanian, 2000).

Table 2-3. Municipal Solid Waste in the U.S.

	1993	1994	1995	1996
Total MSW (million tons)	206	209	211.5	209.7
Per capita generation (kg)	2.0	2.0	2.0	1.95
Per capita discards (kg)	1.59	1.54	1.49	1.45
Recovery–recycling, composting (%)	21	24	26	27

(Subramanian, 2000, p. 254)

2.3 Recyclables as Commodities

In a mission statement that clearly addresses the aforementioned economic problem, Dr. Ronald Arrieta Calvo of CICA likewise notes that in general, the promotion of traditional free-market economies has caused respective societies to overlook their accountability in exploiting natural resources (i.e. fossil fuels necessary for the synthesis of plastics). Dr. Arrieta further criticizes incineration practices and landfill usage for their environmentally destructive solid waste disposal methods (Arrieta, 2000). Neugent also explains that the incineration of PVC plastics, for example, causes the release of the toxic compound dioxin into the environment. In determining why ecological and health conscious waste management is not more widely practiced, Powelson and Powelson argue: "the biggest obstacle currently facing recycling is economics"(1992, p. 13).

Recalling a visit to a Managuan junkyard in *Life is Hard*, Roger Lancaster contrasts US and Nicaraguan attitudes toward waste management through an economic and social analysis. Lancaster asserts that in Nicaragua, "no one throws anything away" (1992). He examines the resulting intricate chain of product redistribution and reuse after noting one local woman's disbelief in learning that broken television sets are commonly thrown away in the United States. In the book's chapter, entitled "The New Dependency," the author applies Argentine-educated Raul Prebisch's economic theory of the 1930's to analyze these different attitudes toward waste. The Prebisch theory states that hegemony and subsequent economic dependency will naturally occur between two trading partners (for example, the US and Latin America) in a free-market system (Love, 1995). The two partners assume so-called center and periphery roles, where the center uses the periphery to gain wealth. This is illustrated by the agricultural export-led economies of Latin American countries that provide the US, for example, with primary goods. Love explains that the center countries become self-sufficient and able to maintain wages within their countries, regardless of prices and other pressures. The wages of workers in periphery nations, however, are affected by economic fluctuations and prices resulting from the demand for their goods (or lack thereof) by a given center nation (Love, 1995).

Lancaster's experience and conclusion correlate strongly with the Prebisch theory. He remarks that the value of labor in Latin America, as a result of these nations' dependency roles, is generally quite low while the cost of store-bought manufactured goods is comparably high, while the reverse is true in the US. Therefore, rather than immediately disposing of salvageable wastes, the market for repair and reuse predominates in Nicaragua (Lancaster, 1992). This theory and example additionally explain both the prevalence of manual labor in waste management and the contrasting scarcity of manufactured recycling equipment in Costa Rica.

2.4 The Process of Recycling

To promote the post-consumer plastics market, the magazine *Biocycle* suggests some companies are finding creative ways to sell recycled products, while others are looking into making the entire process less wasteful, from synthesis to disposal ("Plastics in the Spotlight," 1990). Subramanian suggests that the critical analysis of a plastic's lifetime can lead to better-integrated waste management as a whole (2000). Other authors carefully delineate the post-consumer plastic separation process and explore the effectiveness of separation technology in producing a more marketable, high quality product. It is their belief that post-consumer plastics have the potential to compete with the production of virgin resins (Shent, 1999). For example, Gente Reciclando of San José asserts that cleaned post-industrial plastic waste is in very high demand from their facility. Clients from various industries are satisfied with the high quality of Gente Reciclando's recycled products, of which they are able to purchase at fifty-percent of virgin plastic prices (Gente Reciclando, personal communication, May 31, 2000).

Looking further into the recycling process, Powelson and Powelson explain that, financial obstacles aside, the greatest technical problem is resin incompatibility (1992). In creating a secondary product from scrap plastics, it is simply not feasible to mix the vast majority of the one hundred and fifty different types of resins due to their unique chemical properties. For example, HDPE and low-density polyethylene (LDPE) are desirable because their low melting temperature makes them easy to work with, but they cannot be mixed with PET, another desirable type, because it has a higher melting point. Polypropylene and polystyrene, however, have low melting points and do mix with HDPE and LDPE. Additionally though, while HDPE and LDPE are both type #2 plastics, they differ in physical properties and cannot be processed in the same manner (Malloy, 2000).

Though techniques vary between companies and facilities, and a good number of private companies do not disclose their methods to the public, a review of recycling literature nonetheless indicates threads of commonality in the individual protocols for plastic reprocessing.

According to a plastics flotation research group, the four general phases of plastic recycling can be viewed as collection, separation, processing/manufacturing, and marketing (Shent, 1999). The utmost concern at various stages of the process is decontamination, for objects such as metal lids, labels and soil will damage the machines that reprocess and manufacture secondary plastics (Powelson, 1992). It is critical to separate these items that tend to remain in one piece when plastics are melted. Plastics, on the other hand, assuming compatibility and thermoplasticity, will easily lose their rigidity at certain temperatures where compositional polymers begin to flow again (Powelson, 1992). Other scholars explore the ability of plastics to be separated from one another based upon density analysis in water flotation once they have been shredded, due to their hydrophobic properties (Shent, 1999).

There is, however, a clear disagreement in the literature regarding the order of each stage. Depending on the facility, the wash process may occur either prior to or following (or both) the act of shredding and separating plastic wastes into small, flake-like substances. In addition, Powelson and Powelson (1992) note that differing processing plants carry out the wash process in a variety of ways - some use detergents while others simply use a cold water spray, and some even filter the resulting wastewater. At some point in all cases, the shredded flakes are then heated, melted, perhaps filtered once more to remove the last of the contaminants before they are inserted into a die that will process strands of "new" plastic to be later chopped into pellets and marketed.

Enviroplastics, a private recycling company located in Auburn, Massachusetts, is responsible for the shredding, cleaning and pellet formation of post-consumer plastics. Upon arrival to the *Enviroplastics* facility, the post-consumer plastics have been sorted by plastic type, compressed and baled. The plastics within the bales may still have labels and contaminants attached, for they have not yet been cleaned in any way.

First, *Enviroplastics* shreds each bale into tiny flakes of plastic and label paper. The mixture of flakes is then submerged in water, which allows the plastic and paper to separate due to density. Once separated, the paper waste is transported to a landfill, since it is biodegradable, and the plastic flakes are washed in order to rid them of any contaminants. Due to the competitive nature of recycling companies, the washing process and solvents used are proprietary. However, it is known that a detergent is used as a plastics cleaning agent.

Following the cleaning process, the flakes are then melted down to form pellets. These pellets are packaged and marketed to companies, such as *Recycline*, one of

Enviroplastics customers, which incorporates the recycled plastic into future products (Enviroplastics, 2000).

2.4.1 Collection of Recyclables

Concurrent with Subramanian's (2000) belief that one must examine a plastic's lifetime as a whole, experts agree that the degree of effectiveness of any recycling program begins not with the washing and crushing, but with the collection process from the household (Glenn, 1992). In managing any type of solid waste, including recyclables, the collection process is the most costly - accounting for sixty-five percent of the total recycling cost (Biddle, 1998b). Therefore, improving upon the collection method is critical in improving the waste management program overall. Since the industry is based on the cost per ton of refuse, increasing the recycling rate reduces the tonnage of MSW, and therefore also reduces the disposal costs (Biddle, 1998a). This can be done in numerous ways, including gaining public participation through education, restructuring collection times and methods to be more convenient for the public, and improving upon equipment and processes for greater efficiency.

Stimulating public participation is the first and possibly most effective method of increasing the amount of recyclables collected in a given area. Waste management facilities must educate the citizens they serve with information regarding the importance of recycling and regulations to be complied with, so that cleaning and separating recyclables becomes a daily habit. Additionally, workers must be trained to demand customers' adherence to regulations, for example, by not collecting dirty or unsorted materials. Collectors in Palm Beach County combine education with strict policies by leaving such "unwanted materials" in the consumers' bins along with an explanatory sticker (Glenn, 1992, p. 31). The director of the Santa Ana collection center further agrees that in Costa Rica, the best method of increasing compliance is to provide adequate education (Umaña, 2000).

In determining why recycling is not more widely or habitually practiced, a frequent complaint is that recycling is simply not convenient. In response to such complaints, cities have begun regular curbside collection schedules and/or have distributed bins to each household specifically for recyclables. Some experts in the US have found that weekly, co-collection of garbage and recyclables is the most convenient schedule for homeowners. While this reduces route flexibility and time efficiency for the collector, Moore asserts that the benefits of public participation outweigh this disadvantage (1992). Another solution involves the distribution of containers for recyclables or recyclables and trash in order to make curbside recycling more convenient. In Austin, Texas, this plan increased participation so greatly that before distribution was completed, one employee was added per collection truck to handle the extensive increases in recyclables left at the curbside (Glenn, 1992).

In Austin, Texas, like many cities, modifications in manpower and equipment as well were necessary to support the results of public participation. For one, waste management facilities have employed vehicles with a split body design, some of which are equipped with semiautomatic loading machinery that have reduced manpower, the number of vehicles necessary, workers' injuries, and dumping time (Farrell, 1999). New York City cited efficiency gains of twenty two percent after employing these vehicles (Biddle, 1998c). The split body design allows the vehicle to transport both recyclables and refuse, reducing the need for separate transportation. The compartments of these trucks are divided half or three-quarters lengthwise to avoid contamination, with one side being a standard compactor for MSW and the other for recyclables (Grogan, 1992). They usually have a smaller compartment for glass behind the cabin and vary in design depending upon whether they side-, rear-, or front-load. Drivers of side-loaders work as a one-man crew, sitting in the right side of the cabin and stepping out onto the curb to empty trash into the right compartment and recyclables into the left. This design reduces workers' injuries because they must only lean over the truck to dispose of recyclables, which usually weigh less than trash. One disadvantage of this design is that when full, the trash side usually weighs more than the recyclable side. To correct for this imbalance, however, trucks use a suspension system of rubber blocks rather than springs. Semiautomatic front end loaders, although more expensive (costing approximately $170,000 versus $145,000 for a side-loader), further reduce the number of vehicles, manpower and injuries by hydraulically lifting over the cabin and dumping into the split compartment. This takes more time than manual loading, but significantly reduces the number of workers' injuries. Peter Guttchen, Olympia, Washington's recycling coordinator, notes that in eight months of using these vehicles, he has not seen a shoulder or back injury associated with garbage collecting and dumping (Farrell, 1999).

Cities like Milwaukee and New York City have experimented with these split-bodied trucks, pairing them with large, and oftentimes covered, split containers to further facilitate collection. When used in conjunction with a truck with corresponding split compartments, the semiautomatic lifting and dumping reduces workers' injuries and the lids prevent paper and other recyclables from blowing out of the bins while dumping.

Once people become accustomed to using these bins, there is less contamination among the recyclables, and due to their larger size, it is often unnecessary to collect more than once a month. There are obviously drawbacks to using these bins, however. One is that it is difficult to determine the ideal size. When bins are too small and pick-up is infrequent, residents often remove the divider and fill the bins only with garbage, thus defeating their purpose. Likewise, if bins are too large and only half filled, the system becomes less efficient (Biddle, 1998c).

Another efficient alternative to using split bins is to employ a bagged collection program. Chicago's blue bag collection program consists of a four bag system: one for assorted paper, one bag for commingled recyclables (plastics, metal cans, glass, etc.), one for yard clippings, and a standard garbage bag for MSW. All bags are collected concurrently in a standard packer truck that is dumped only when full, unlike split body trucks that may be dumped when only half-full of recyclables. Increased participation is further attributed to the convenience of bagging all recyclables together, with the exception of paper, with the simultaneous pick-up of yard trimmings (Biddle, 1998c). Chicago's Department of the Environment hopes to promote the program through education, including radio and television ads, as well as a website design that allows visitors to "point and click" through processing facilities (Biddle, 1998c, p. 78).

2.4.2 Separation of Recyclables

Clearly, there is no single, most effective way to collect recyclables and other waste. One must realize, however, that when the collection process is simplified, the separation process often becomes more complex. Commingling recyclables in one container is more convenient for the consumer, but requires more work for separating and processing facilities. In cities with high collection costs and lower participation due to the "inconvenience" of sorting recyclables, simplified collection processes may be optimal.

An article in a 1998 issue of *Biocycle* states that single-stream collection (where one truck is used to transport combinations of MSW, commingled recyclables including paper, and yard trimmings) is "the wave of the future" (Biddle, 1998c, p. 78). Materials recovery facilities (MRF's) receive this collected waste and sort it using conveyor belts in conjunction with various screening systems, boasting over a ninety percent efficiency rate. While separation costs may be higher, collection costs have been reduced by twenty percent using single-stream collection (Biddle, 1998b). Mr. Steve Changris, of the National Solid Waste Management Association, Northeast division in Natick, MA, explains that many private companies assist MRF's in lowering costs by supporting the processing of recyclable materials other than those pertinent to their needs. In Massachusetts, for example, *Veryfine* provides for the recycling of paper in addition to glass and plastic bottles at a local MRF (Changris, 2000).

As with any process, there are pros and cons to using a single-stream collection process. On a positive note, specialized, more expensive trucks are not necessary, participation of the public increases due to greater convenience, and collection routes and dumping can be simplified. At the same time, separation processes become more complex, broken glass may contaminate other recyclables, and greater skilled laborers are needed. Organizations such as the American Forest and Paper Association are worried that by commingling recyclables, producing quality paper from recycled materials will become more difficult. However, *RRT Design and Construction* president Nathiel Egosi attests that the "screening, fluffing, and shaking" action forces glass out of the fiber in the case of contamination with broken glass. As waste management facilities continue to improve upon collection processes, separation processes will improve as well (Biddle, 1998b, p. 49).

Ongoing improvements in automatic sorting techniques are taking place in many MRF's. In general, magnets and air jets are used to separate metals from plastics and light transmission is used to separate different colored glass. Automation has become necessary for various reasons including high labor costs, an increase in recyclables collected, and greater diversity in size and shape of material. Especially with plastics, diversity in size and shape makes separation far more difficult than determining whether a container was a Coke bottle or a milk jug. New techniques at three different levels, macro, micro, and molecular, are being tested and improved upon (Dinger, 1992).

Currently, macro separation is the only form in practice in the US. Working with *Asoma Instruments*, Professor Henry Frankel developed a plastics separation system that uses computer software to track light transmission properties of the resins of PET, unpigmented HDPE, and pigmented containers. After an instrument analyzes the bottle (located in a single file array), it is identified and sent into the correct separation container. Accurate sorting of plastics is necessary because some types are contaminants to others - such as PET and PVC. In this technique, the plastics are subject to "low-level radiation" and software identifies the type of plastic based on the chlorine peaks in the x-ray spectrum. Not only is this system more technologically advanced than using manual labor, it is faster and more accurate, with conveyor belts that operate at ten feet per second and have an error rate of only one in one hundred thousand (Dinger, 1992, p. 80).

Another available separation technique, called *VinylCycle*, uses air jets to identify plastics. Containers (that need not be in single file) are passed over a row of detectors located beneath the conveyor belt. As it passes a detector, the system notes the position of the PVC bottle and as the bottle moves further, it is ejected from the belt by a blast of air. This is done continuously so that the system receives a stream of information and ultimately can determine, based on change in position, the difference between PVC and vinyl containers (Dinger, 1992).

In an ideal world, all plastic products would be marked with some sort of easily detectable invisible ink to facilitate sorting. This is not feasible because it would require the full cooperation of every manufacturer of plastic products. It is feasible, however, for resin producers to put molecular markers in all of their resins. While similarly, the full cooperation of resin producers would be necessary, this is a far easier task to accomplish (Dinger, 1992). It also illustrates the point that for recycling to be most efficient, it must begin at the birth of the plastic. Before the bottle is even formed, the resin should contain a molecular marker that, while unimportant in the usage of the bottle and the collection process, will facilitate and accelerate the separation process.

Professor Rudolf Deanin of UMASS, Lowell explained that density separation by water was a fairly simple and common method of sorting plastic types, which is also effective in separating other contaminants such as glass. Professor Deanin was also able to describe the other aforementioned highly technological methods, but suggested that hand separation would be most appropriate in nations such as Costa Rica where manual labor is most cost-effective (Deanin, 2000).

2.4.3 General Mechanical and Chemical Washing Procedures

According to Professor Deanin, the difficulty that is often encountered in cleaning post-consumer plastics stems from two main causes. Firstly, adhesives that hold paper or plastic labels to the plastic containers are generally quite difficult to remove. Some adhesives are softened with soap and water, others with organic solvents. Starch adhesives can be removed with water alone. Secondly, contaminants that were held within the containers often are not easily eliminated and can sometimes have adverse effects when in contact with one another or particular plastic types (Deanin, 2000).

In their review of the different technical aspects of post-consumer plastics cleaning, Bittner and Michaeli divide the washing process into three general phases: soaking/softening, circulation for the release of dirt bound to plastic surfaces, and the removal of and separation of this dirt from clean plastic surfaces. Their research stresses the importance of understanding the composition of contaminants arriving on plastics in order to ensure that the washing procedure will itself attract dirt particles to a larger degree than the plastic surfaces. They recommend, for all plastic particles, a slow speed conveyer mechanism for heavy-duty soaking to ensure equal "residence time" (1995, p. 257), followed by a separate circulation stage. Frictional, or turbo, washers strategically aligned as a cascade system of high-speed stirring vessels during the circulation phase may further allow for wastewater counterflow and recirculation within the facility where post-consumer plastics are washed. A final fresh water spray following the preceding circulation step will ensure the separation of virtually all sediments from clean plastics. Such sediments may ultimately be removed through their precipitation during wash water recirculation (Bittner and Michaeli, 1995).

As other areas of the literature review show, the quality of recycled post-consumer plastics depends largely on the degree to which they are cleaned. Theoretically, the most desirable outcome for plastics recycling is a closed-loop system whereby discarded plastic soft-drink bottles, for example, may be recovered, recycled, and used to create new soft-drink containers. The US FDA approved of several chemical procedures developed by *DuPont*, *Eastman Kodak*, *KoSa/Hoechst Celanese and Shell* during the early 1990's to clean and recycle post-consumer PET plastic (RECOUP, 2000) for secondary uses in the food industry. The general chemical processes these companies carried out are known as methanolysis and glycolysis. The first involves the depolymerization of PET into dimethyl terephthalate (DMT) and ethylene glycol (EG) from the addition of methanol at 200°C in a pressurized system. Both DMT and EG may then be used to regenerate new PET plastic (RECOUP, 2000).

Glycolysis, though less expensive, was also found to be less efficient. When ethylene glycol is added to PET under the same conditions as the methanol treatment, the product, bishydroxyethylterephtalate (BHET) must be further filtered to remove remaining contaminants. At the present, neither methanolysis nor glycolysis is widely practiced due to their costs (RECOUP, 2000). Closed-loop recycling, in fact, is not mandated nor carried out in the United States today, though the technology exists to do so (Deanin, 2000).

2.4.4 Processing/Manufacturing of Post-Consumer Plastics

The degree of cleanliness necessary and the methods of processing and manufacturing depend on the future market of the specific plastic. Once separated and cleaned, plastics are usually melted and shaped into pellets for future markets. Whether they are cleaned then separated, or separated then cleaned depends on the specific facility's processes.

The one significant difficulty in processing and manufacturing the plastics lies in their original composition. Many types of plastics cannot be recycled and end up incinerated or dumped in landfills. Others are composed of many kinds of resins, which makes them less "pure," and therefore, less desirable to manufacturers (Ecology America, Inc., 2000a). *Coca-Cola* refuses to use recycled plastics because they are "unsustainable and not economically viable." The company also cites that it is "very costly to the company" to use recycled plastics, however, with forty-four percent of overall soft-drink market shares, *Coke* may be exaggerating about the costs required (Ecology America, Inc., 2000c).

Since producing easily recyclable products can be difficult, companies such as bottle manufacturers have been working with recycling facilities in a manner of concurrent engineering. One problem in the recycling of plastics is to remove adhesives before processing. Companies are looking toward standardized adhesives by analyzing their composition as well as how they are applied, overall or in one strip (Malloy, 2000).

A product of concurrent engineering between recyclers and manufacturers is *Welch*'s new fully recyclable juice concentrate containers. They are made completely of HDPE plastic with a label printed directly on the container. There is no paper or adhesive. Disposable cameras, as well, are becoming more "recyclable" than disposable. Once the film is removed, the cameras are 95% recyclable. They are made of high impact polystyrene mixed with rubber, and the adhesive for the labeling is compatible with the resin so the two can be melted together.

2.4.5 Secondary Markets for Post-Consumer Plastics

There are numerous companies that incorporate recycled plastics into their products. However, different markets depend on different levels of cleanliness. The most successfully recycled plastic is PET, which is both widely available and need not always be cleaned to the degree of virgin plastics. The lesser degree of cleanliness required is acceptable because the recycled PET is used for secondary products such as fiberfill for mattresses, pillows and sleeping bags (Deanin, personal communication, April 18, 2000). Recycled plastics can also be found in some clothing types, floor coverings, toothbrushes, jewelry, plastic lumber, and of course, bottles and containers.

Recycline, a company based in Somerville, Massachusetts, has found that in the United States alone, toothbrushes account for fifty million pounds of plastic waste per year. Therefore, the company has created the first "environmentally friendly" *Preserve* toothbrush. This toothbrush is made with both post-consumer and pre-consumer recycled plastic, sold in a clear plastic container (also recyclable), and accompanied by a postage-paid return envelope so that consumers can send back the toothbrush for further recycling (Ecology America, Inc., 2000b).

The *Preserve* toothbrush's handle is composed of at least ninety percent polypropylene (PP), also known as plastic type #2, with twenty to thirty percent of that amount post-consumer plastic. This type of plastic was chosen for its strength and flexibility, which are not altered in the recycling process, as well as for its abundance among pre- and post- consumer recycled plastics. The degree of cleanliness necessary for this market is the same as that of virgin plastics. A "foreign elements reading" test assures that the cleaned and processed plastics are, in fact, at this degree of cleanliness (Recycline, 2000). Additionally, when the toothbrush is sent back after use, *Recycline* recycles the entire *Preserve* toothbrush and uses it to make plastic lumber. The blend of nylon bristles and polypropylene handle produces strong, weatherproof "lumber" that can be used in outdoor products like park benches, bridges and decks (Recycline, 2000).

Plastic lumber is possibly the most common product made from recycled post-consumer plastics. *Durawood, SmartDeck* and other brands of plastic lumber are usually composed of one-third plastic and two-thirds wood or fifty percent plastic and fifty percent wood, with the plastic portion containing between ninety and one hundred percent HDPE (U.S. Plastic Lumber, Ltd., 2000). This product, also known as type #2 plastic, is found in milk jugs, yogurt containers, grocery bags, detergent bottles, and other less common items (Plastic Recycling of Iowa Falls, 2000). In *Durawood* lumber, the recycled plastic is cleaned to a level of "over ninety-nine percent HDPE." (US Plastic Lumber, Ltd., 1999a) *TriMax Structural Lumber* is similar and is composed of recycled plastic reinforced with fiberglass (US Plastic Lumber, Ltd., 1999b). Using recycled plastics in such lumber not only encourages recycling and preserves the environment, but also produces quality lumber that is more durable than wood alone, does not need paint or stain, does not rot or crack, and is impermeable to insects, mold, and mildew (US Plastics Lumber, Ltd., 2000).

Another industry that has promoted a growing use of recycled plastics is the carpet manufacturing industry, specifically *Mohawk Industries Inc*. The desired plastic type is type #1, also known as PET. This type commonly holds beverages, peanut butter, salad dressing, household cleaners, and cosmetics. It is one of the easiest to recycle and is used in carpeting, polyester clothing including T-shirts and sweaters, and as filling for sleeping bags and winter coats. Sally Shepard, director of the Kanawha County Solid Waste Authority, explains that before 1995, there was a shortage of cotton in China, so recyclable plastic was in high demand to produce clothing. When the demand for plastics rose, plastic recycling facilities were built to accommodate the influx of recyclables. Soon, however, the demand for plastics decreased, and recycling facilities went out of business (Charleston Newspapers, 2000).

Recently there has been an increased demand for plastics, due in part to companies like *Mohawk Industries* that use plastics for carpeting, as well as from Asian countries like China and Japan that are making an extensive amount of products from recycled plastics. With this high demand for recycled plastics, Shepard states, "my biggest problem [now] is deciding who gets the load, not how do I get rid of it" (Charleston Newspapers, 2000). Since the polyester fibers in their carpets are made with one hundred percent recycled PET, each week *Mohawk Industries* needs approximately one hundred and fifteen to one hundred and twenty tractor-trailer loads of this plastic, simply to keep its factory in operation. Therefore, recycling facilities have been importing bottles from places within the United States, as well as parts of Canada and Mexico to keep up with the high demand (Charleston Newspapers, 2000).

As the demand for plastics increases and new markets are created, the degree of cleanliness necessary for various markets most likely will differ. Additionally, various markets have different tests and standards for cleanliness. Unfortunately, like the cleaning process itself, this proprietary information is generally unavailable to the public.

2.5 Water Resource Management

With the implementation of a washing procedure comes the responsibility of carrying out effective wastewater treatment. Daniel P. Loucks, Eugene Z. Stakhiv, and Lynn R. Martin explain that the promotion of a sustainable water resource involves the careful consideration of its long-term management. According to the authors, sustainability is the ability of a resource, in this case, water, to fully meet the objectives of both present and future societies while upholding its "ecological, environmental, and hydrological integrity" (Loucks, et al., 2000). Their paper recognizes that sustainability is not a new idea, but has recently come under scrutiny due to increasing awareness of and concern for human impact on ecological systems. They suggest that the most difficult question raised in developing a sustainable water resource model is determining what the needs and desires of future societies will be. In understanding the change in a given society over time, they contrast the historical promotion of engineered water control in the United States (i.e. large-scale dams, locks in rivers, canals), as opposed to current movements to restore water supplies to their natural states. Several examples include The Columbia River Salmon Project, the National Estuary Program, and the Florida Everglades Project (Loucks, et al., 2000).

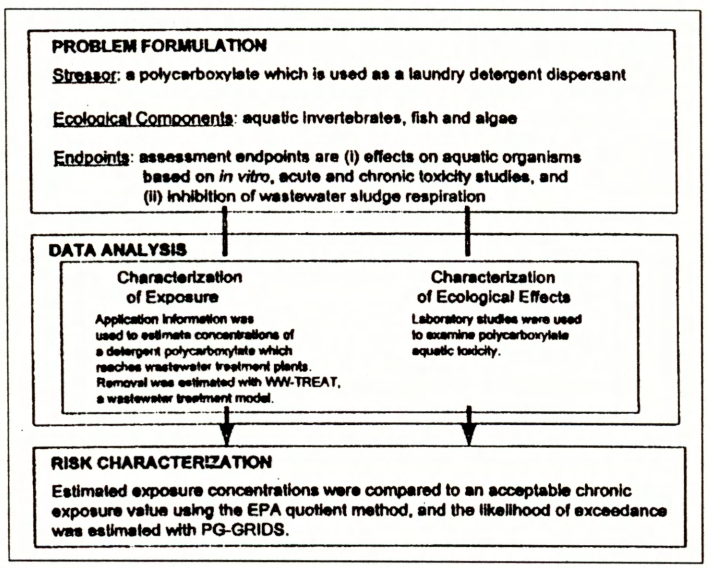
The authors further delve into the issue of sustainability by examining the mechanisms by which such a system may be facilitated. The first task is to examine "economic, environmental, ecological, social, and physical goals." When considering tradeoffs, the authors deem it necessary to account for differing opinions on how concepts such as economic justice, poverty elimination and resource usage are defined. They ask the question "who has a better vision of sustainability?" (2000, p. 44). In reaching a conclusion, the paper suggests that an effective sustainability plan is one that should not be delegated solely to professionals, such as engineers. Furthermore, the authors suggest that individuals making sustainability decisions must be aware of the role stresses and pressures play on the regulatory institutions governing water resource management. They propose, consequently, that water resource management need also involve an informed public sector, as social objectives cannot truly be met without community consensus on the formulation of these objectives (2000).

2.6 Aquatic Risk Assessment

Two factors of contamination that need be considered in the treatment of wastewater from cleaned plastics are product residues washed from plastic containers as well as the detergents or cleaning agents used to facilitate the washing process. The current scientific methods used to determine water quality and sustainability, however, generally do not follow the guidelines suggested above. The following model is more typical of today's research. Polycarboxylate polymers, which prevent calcium salt buildup on fabrics and disperse soil in wash water, are used to replace phosphates as builders in detergents (see following section). J.D. Hamilton, Michael B. Freeman and

Kevin H. Reinert use the US EPA problem formulation flowchart as a model to plan and define the purposes of ecological risk assessment in the polycarboxylate example (see Table 2-4). The risk value for a chemical agent released into an aquatic environment can be calculated using a mathematical equation. An acceptable concentration of chronic exposure is determined for the most sensitive species through toxicity experimentation with a variety of marine-life. The so-named chronic value is often divided by ten to better account for experimental error. In this model, the authors suggest it is important to account for the effects of a chemical's removal from these environments through wastewater treatment. The polycarboxylate calculations allow the authors to assert that its usage presented no "unreasonable risk to aquatic species" (Freeman, et al., 1996).

Table 2-4. US EPA Problem Flow Chart



(Freeman et al., 1996, p. 69)

2.7 Detergent Chemistry

The use of soaps and detergents has been implemented since about 600 BC (McMurry, 2000) in order to facilitate contaminant removal. Despite the variety of their chemical properties, all soaps function similarly because all are both hydrophilic and hydrophobic. The hydrophilic anionic end, a carboxylate group, is attracted to water, while the hydrophobic hydrocarbon backbone of the molecule is non-polar and therefore attracted to contaminants such as grease. Upon application in water, the hydrophobic portion of the soap molecule attaches to contaminants, while its hydrophilic properties simultaneously allow for these contaminants to be rinsed away into the water supply (McMurry, 2000).

Examining the environmental impact of detergents involves a more in-depth analysis of their specific compositions. According to the US EPA, companies manufacture billions of pounds of chemicals per year to be used in the laundering process, all of which are eventually released into the wastewater stream (US EPA, 1999b). To better monitor environmental and health-related consequences derived from detergent usage, the US EPA founded the DfE Industrial/Institutional Laundry Partnership. This organization promotes better design and usage of detergent products while confidentially recording each partner company's detergent formulations. Companies are then officially recognized for their achievements in creating and marketing environmentally oriented products. Ultimately, the goals of the partnership include pollution prevention, resource conservation, energy efficiency and overall simulation of innovation (US EPA, 1999b).

To this extent, the US EPA also provides an easily accessible guideline that charts general detergent characteristics. It cites and describes seven main chemical factors found in laundry detergents: surfactants, builders, bleaches, colorants, brighteners, solvents, and wash water properties (US EPA, 1999a). The US EPA laundry detergent guideline additionally comments on the aspects of resource efficiency (i.e. the reduction of temperature and number of rinse cycles) and packaging. However, these latter variables, in addition to several previously mentioned detergent features, such as colorants, may not directly apply to the problem at hand.

2.7.1 Critical Environmental Studies of Detergents

One frequently studied detergent additive is the family of compounds known as surfactants. Like their name implies, these are chemicals that facilitate surface interactions during the cleansing process. An alkyl-benzene sulfonate (ABS) was the first chemical surfactant found in newly introduced synthetic detergents in 1948 (Schroeder and Tchobanoglous, 1985). Even in areas of low concentration, however, it was found to cause the accumulation of foam in the groundwater near sewage treatment plants since the surfactant biodegraded very slowly. Research therefore led to the replacement of this complex, ring-shaped molecule with its straight chain formulation, known as linear alkyl-benzene sulfonate (LAS), in the 1960s (1985). Additional sources provide evidence for the low toxicity of this compound that has been found to biodegrade rapidly, unlike its predecessor. It is, however, formed from alkyl benzenes, which are extremely toxic and may even exist as unreacted impurities in LAS samples (Chemicals Programme, 2000). The US EPA list suggests linear alcohol ethoxylates and betaine ethers as additional examples of quickly biodegrading surfactants. On this note, the US EPA likewise contrasts these chemicals with the high level of aquatic toxicity and environmental persistence shown in studies of ring shaped alkyl phenol ethoxylates (US EPA, 1999a).

The effects of surfactants on the environment are twofold. The first consequence is related to the chemical properties and usage of surfactants themselves. In 1983, scientists determined a disturbingly high concentration of surfactants in Spanish rivers. In this region, Tarazona and Nuñez conducted a study to measure the acute effects of sodium lauryl sulfate (SLS), one such surfactant, on the shells of *Linaea peregra*. Their findings demonstrate a decrease in the inorganic mass of these snails' shells with increasing concentrations of SLS in parts per million. They propose that the chelating properties of anionic surfactants may have both removed calcium from the shells (composed largely of calcium carbonate) and inhibited the animals' ability to form or maintain their shells in general (Tarazona, 1987).

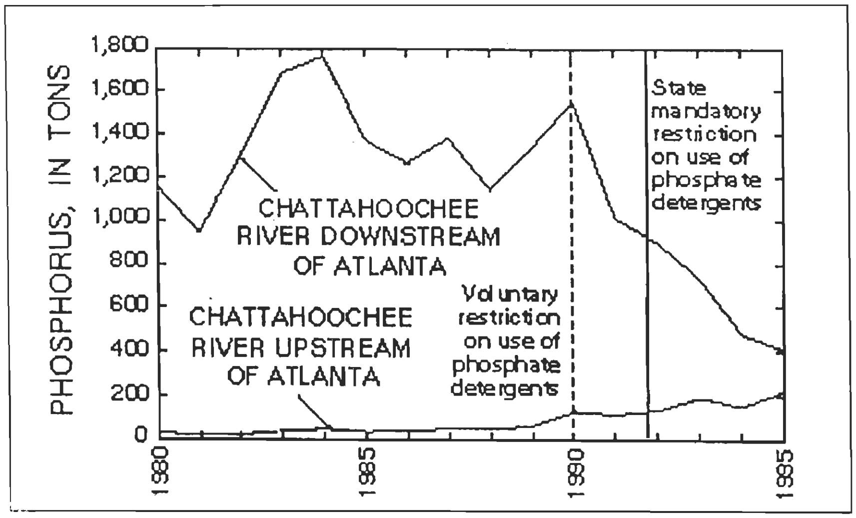
The approval of surfactant levels in the water supply result from the lack of significant acute toxicity to humans, as evidenced in the Screening Information Data Sheet (SIDS) report on LAS. In this publication the concentrations of LAS in influent and effluent waters at sewage treatment facilities are examined to serve as a model of the worst-case dilution levels in the environment. The results of the analysis show the following: undetectable to a concentration of 1 parts per billion (ppb) in effluent waters and undetectable to 0.66 parts per million (ppm) in influent receiving waters (Chemicals Programme, 2000). It is interesting to compare the effects of a 0.66 ppm concentration of SLS on snail shells in the Tarazona study, though the SIDS finding concludes that such

LAS concentrations (also a calcium chelating chemical) pose a very unlikely risk to humans or aquatic species because of its biodegredation factor. The findings also show that over ninety-eight percent of LAS remnants in the water supply may be removed through the use of activated sludge at treatment facilities (Chemicals Programme, 2000).

The second remaining consequence of the shift to LAS usage involves the implementation of phosphate builders in detergents and their well-studied environmental impact. Phosphorus is an essential nutrient in marine ecosystems, though it inhibits growth in very great quantities by catalyzing the process of eutrophication (USGS, 2000). This phenomenon occurs when oxygen levels decrease in a water supply as a result of the increase in richness of dissolved nutrients, such as phosphates (US EPA, 1999a). The evidence for eutrophication is the presence of excess algae in wastewater, or other affected point sources. The proposed solution for the reduction of phosphates in affected waters may include the elimination or reduction of phosphorus in synthetic detergents, the removal of phosphates from wastewater, or lastly, the diversion of discharged waters contaminated with phosphates to less sensitive points (Schroeder and Tchobanoglous, 1985).

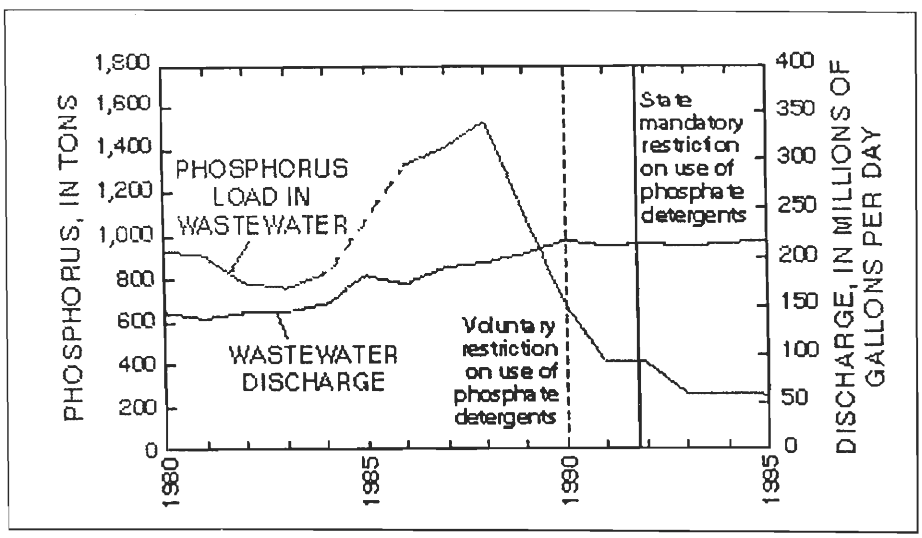
Two prime case studies serve as models of phosphate control and point to the shrinking problem of phosphate contamination as a result of detergent usage. The USGS studies provide two diagrams that illustrate effective public environmental regulation (see Figures 2-1 and 2-2 below). Figure 2-1 shows the level of phosphorus quantities in waters downstream of treatment plants, both before and after the implementation of state regulations to restrict the use of phosphorus in detergents and to reduce the amount of phosphorus from the wastewater treatment process. Figure 2-2 shows the diminishing quantity of phosphorus in wastewater regardless of the increase of wastewater itself (USGS, 2000).

Figure 2-1. Levels of Phosphorous with Regulations



(USGS, 2000)

Figure 2-2. Levels of Phosphorous with Increasing Wastewater Quantities



(USGS, 2000)

Possible substitutions for phosphates are quite limited thus far. In 1987, the compound nitriloacetic acid (NTA) had been distributed as a builder in Canadian, Finnish, and Swedish detergents, and was studied for its toxicity by Anderson, Bishop and Campbell. This substitute was another strong chelator of calcium and magnesium, which caused increasing alkalinity and pH stress of NTA-affected water supplies. Their studies show an inhibition of microorganism growth only in unrealistically high concentrations of NTA, such as eight hundred to ten thousand milligrams per liter. Findings on the levels of NTA showed no detectable concentrations in New York groundwater supplies during a 1.5-year marketing period, and an average concentration of 2.1 micrograms/liter NTA in New York rivers and reservoirs. Their more extensive Canadian database illustrates no detectable quantities of NTA in surface samples in about ninety-three percent of all samples. The overall conclusion asserted that NTA would not "constitute a health risk to man" during its "commerical use" (Anderson, et al., 1987, pg. 89). Nonetheless, the more current research in *Water Quality* cites NTA as a cause of infant brain damage (Schroeder and Tchobanoglous, 1985).

2.7.2 Changes in Detergent Formulation

Substitutes and modifications continue to be made in the detergent industry in order to meet growing environmental concerns. Zeolites (aluminosilicates) for example, have been found by the US EPA to pose low toxicity and low general impact on the environments and may be used as builders in detergents (US EPA, 1999a). The US EPA further recommends hydrogen peroxide or ozone bleaches as low toxic substitutes for highly toxic bleaches like sodium hypochlorite, sodium perchlorate, and dichloroisocyanurate. The data sheet also suggests that colorants, such as Rhodamine B, a known carcinogen, should be eliminated from laundry detergents. The organization explains that further testing needs to be completed on the environmental impact of brighteners, such as amintriazine- and stilbene-based whiteners. Again, these latter two detergent additives should not factor into the cleaning of plastics.

In the United States, stricter regulations have forced the detergent industry to amend its products. A 1994 study, which took place in the San Francisco bay area, monitored the increase of heavy-metals in water supplies due to the use of household detergents between 1988 and 1989 (Jenkins, 1996). The study contains data about the recent change seen in the quantities of most of these heavy metals. Table 2-5 below illustrates the specific chemical concentration data. At the same time, the percentage of heavy-metal contributions by household detergents appears to rise as a percentage of influent/effluent heavy-metal quantities at wastewater treatment facilities. This is due to the fact that regulations have diminished certain heavy-metal output at the industrial level. Jenkins concludes that the overall result is, nonetheless, a measurable improvement from earlier water quality statistics taken from the same region.

Table 2-5. Average Heavy Metals Concentrations in Laundry Detergent

	Heavy metals concentrations, mg/kg (except where noted)								
Detergent form	As	Cd	Cr	Cu	Pb	Ni	Hg	Ag	Zn
Reformulated product	0.30	<0.20	<1.0	1.6	0.19	<1.0	<0.025	1.0	4.1
Product prior to reformulation	13.8	0.26	<1.0	0.49	<0.20	<0.50	<0.025	<0.5	7.3
Change in concentration resulting from reformulation, %	−98	>−23	~0	+230	~0	~0	~0	>+50	−44

[a] Hazleton Laboratories, 1995.

(Jenkins, 1998, p. 981)

2.8 Alternatives to Using Traditional Detergents

Due to the numerous downfalls of using common detergents, many companies have sought out alternative cleaning methods such as: biodegradable detergents and bioremediation. These alternatives are conceived as non-toxic, environmentally safe and, at the same time, as effective as common detergents or better.

2.8.1 Biodegradable Detergents

In 1965 Senator Gaylord Nelson introduced a new bill to the United States Congress. This bill declared that LAS, a supposed biodegradable surfactant, proved to be a suitable replacement for ABS in detergents; therefore the detergent pollution predicament had been solved. Later that year, Senator Nelson presented a second bill to amend the Federal Water Pollution Control Act, which would result in the addition of a section on detergents (McGucken, 1991). Furthermore, this amendment ordered the Secretary of Health, Education, and Welfare (HEW) to assemble a committee to assess the development of a biodegradable detergent. This committee was also responsible for obtaining scientific data that assured the biodegradability of LAS, since the previous data had not been gathered by an official Government agency and therefore was not entirely reliable. Upon completion, the committee's study had proven LAS to have an average removal of ninety-five percent, an adequate removal rate to be classified as biodegradable at that time (McGucken, 1991).

Yet, in the many years since this study, scientists and environmental specialists have discovered that LAS is not entirely environmentally sound. LAS is a petroleum based surfactant, which, contrary to the findings, is known to accrue and pose a lasting threat to the environment. Today's biodegradable detergents do not contain petroleum surfactants for this reason (CleanSafe, 2000).

A second consideration involved in the formulation of a biodegradable detergent is that of foam. A common public belief is that foam represents the effectiveness of a cleaner. Contrary to this belief, foaming agents, which inhibit the cleaning process and require additional rinsing, must be added to cleaners since they do not naturally produce foam. Once in the water supply these foaming agents continue to cause problems. Foam buildup is an imposing problem for many water treatment plants, as well as dams, rivers and creeks (CleanSafe, 2000).

In November of 1953, the upper Ohio River experienced first hand the effects of foaming agents, once they have been released into the environment. After several days of rain, the creeks that had been dried up for the summer began to flow once again. Soon, the creeks were filled with suds and froth reaching levels of four feet high and two feet deep. Further downstream, twenty-four inches of foam spanned the seven hundred foot width of the river for a stretch of more than one mile. Following an analysis, the foam was determined to be composed purely of synthetic detergent (McGucken, 1991).

The true biodegradable detergents of today lack bio-stimulants and foaming agents and almost completely biodegrade within the ideal time of seven days in the environment. To ensure their environmental safety, biodegradable detergents do not contain alkalis, hydrocarbon solvents, acids, terpines, or chemicals that are irritants, carcinogenic, flammable, toxic, poisonous, or can cause genetic mutations (CleanSafe, 2000). Professor McCarthy of UMASS, Lowell specifically suggested the use of polyaspartic acid, a biodegradable chemical produced by *Rohmanhass* (McCarthy, 2000).

2.8.2 Bioremediating Washers

The little known market of bioremediating washers is steadily gaining attention and acclaim. The invention of the bioremediating washer has proven to be a breakthrough in the search for environmentally sound industrial cleaning techniques and there are now several companies marketing their own version of the washer. Presently, bioremediating washers are mainly used to remove oil, grease and other contaminants from automotive parts (ChemFree, 2000).

Typical bioremediating washers consist of three main components. The first component is the washing bin, in which the contaminated automotive part is placed. In the washing bin an aqueous degreasing solution removes hydrocarbons from the surface of the part. The hydrocarbons then settle to the bottom of the washing bin and drain into the reservoir, the second component of the washer (Ecology Warbugs, Inc., 1998). The reservoir, also called the biochamber, contains a precisely selected and usually proprietary mixture of microorganisms for which the hydrocarbons provide a source of nourishment. Within the biochamber, the microorganisms break the hydrocarbons down into carbon dioxide and water, two innocuous by-products (Ecology Warbugs, Inc., 1998). In most bioremediating washers the microorganisms used are capable of remediating crude oil, oils, solvents, benzene toluene ethylene and xylene (BTEX), greases, amines, creosote, phenols, polychlorinated phenols (PCP), fats and polynuclear aromatics (PNA) (ChemFree, 2000). The third component is the filtration system that is usually located within the washing basin. The purpose of this system is to remove the inorganic and suspended solids that end up in the aqueous cleaning solution and cannot be consumed by microorganisms (Ecology Warbugs, Inc., 1998).

Bioremediating washers are specifically designed to comply with, even surpass, today's strict environmental regulations as well as to clean equally well or better than the common, hazardous solvents (ChemFree, 2000). Other benefits of these systems include cost effectiveness, the lack of associated health concerns, safety factors and environmental friendliness. Since bioremediating washers do not use or produce any hazardous materials, there are no disposal costs and the environment is not polluted. The aqueous cleaner used is biodegradable and kept within the closed system of the washer instead of being disposed of after each use. Each of the solutions used in a bioremediating washer are safe for direct skin contact for they are non-toxic, non-volatile, non-flammable, non-pathogenic and at safe pH levels, including the microorganisms (PPEP, 2000).

An additional factor that makes bioremediating washers successful is that the solutions used only target hydrocarbons and other contaminants. Industrial grade metal, natural rubber, and plastic are left clean yet unaltered by the processing.

2.9 Applications of Microorganisms in Waste Treatment

The many problems caused by waste and waste treatment in our present day society have launched a vigorous search for alternative methods. One possible alternative is the process of natural degradation, also commonly known as biodeterioration or biodegradation.

2.9.1 The Process of Natural Degradation

In the process of natural degradation, microorganisms (bacteria, algae or fungi) are used to breakdown toxic compounds into non-toxic derivatives (Gealt, 1993). The biodegradation process is effective in treating water and soil that has been contaminated with a wide range of compounds. These compounds include, but are not limited to, hydrocarbons, alcohols, cyanides, waxes, phenols, organic amines and nitrites (Global Spill Control Pty. Ltd., 2000). Upon introduction to the contaminants, there are two possible processes that can occur. In the first of the two processes, the natural extracellular enzymes found on the outer surface of the microorganism allow a chemical bond to form between the toxic compound and the microorganism. Once the microorganism has attached to individual molecules of the contaminant, oxygen is used to chemically break down each molecule in a step-by-step process. The alternative process requires that the contaminant enter within the cell membrane of the microorganism where it is degraded by internal enzymes (Global Spill Control Pty. Ltd., 2000). The most common resulting derivatives of either contaminant breakdown method are carbon dioxide and water, both of which are innocuous in the environment (US EPA, 2000). Figure 2-3 below illustrates this process in the form of an equation:

Figure 2-3. Contaminant Breakdown

$$\text{Hydrocarbon} + \text{Oxygen} \xrightarrow{\text{Bacterial Attack}} \text{Carbon Dioxide} + \text{Water}$$

(Global Spill Control Pty. Ltd., 2000)

2.9.2 Advantages of Natural Degradation

There are several advantages to the natural degradation process that set it apart from other common processes currently in use. Some of the more obvious advantages are as follows: microorganisms are inexpensive, the reactions that occur between the microorganisms and the compounds can easily be predicted, and in most cases on site degradation is possible resulting in a 33% reduction in transport costs (Gealt, 1993). Table 2-6 below provides a comparison of cost, time, additional expense factors and safety issues between natural degradation (biotreatment) and other waste treatment techniques.

Table 2-6. Comparison of Waste Treatment Techniques

Type of treatment	Cost per cubic yard ($)	Time required (months)	Additional factors/ expense	Safety issues
Incineration	250–800	6–9	Energy	Air pollution
Fixation	90–125	6–9	Transport; long-term monitoring	Leaching
Landfill	150–250	6–9	Long-term monitoring	Leaching
Biotreatment	40–100	18–60	Time commitment of land	Intermediary metabolites and polymerization

(Gealt, 1993, p. 4)

As can be seen in Table 2-6, the cost of using biotreatment is significantly less than that of most other techniques displayed. However, the time required for this process to fully progress contributes to the overall expense (Gealt, 1993). Nonetheless, these data are from a source published in 1993 and the required time for this process has greatly decreased in recent years. Current sources show that in some cases biodegradation can take place in as few as six hours, yet the cost relationship between biotreatment and the other techniques remains unchanged from that in Table 2-6 (US EPA, 2000).

A further benefit of the natural degradation process is the continual reproduction and growth of the microbial population that occurs as the microorganisms breakdown the contaminants. As this degradation proceeds, some components of the toxic compounds provide the nutrients necessary for microbial reproduction. This increase in the microbial population makes the degradation process more efficient and progressively increases the process rate (Global Spill Control Pty. Ltd., 2000). Conversely, once all of the toxins have been degraded the microorganisms no longer have a source of nutrients and the population steadily decreases. The mixture of dead microorganisms and any small population that has survived does not present any hazard to the environment (US EPA, 2000).

Global Spill Control Pty. Ltd. is a company that specializes in the production of a variety of resources to be used in the clean up of chemical and oil spills. One of their products, *Biocare*, is a biodegradation kit composed of natural microorganisms. The initial application of *Biocare* contains approximately one million microorganisms per gram of soil. However, as the microorganisms degrade the toxic compounds this concentration can increase up to one thousand times the original concentration (Global Spill Control Pty. Ltd., 2000). The *Biocare* system clearly exemplifies the extent to which a microbial population can simultaneously grow and enhance its own utility.

Yet another advantage of biodegradation is its versatility. There is a wide range of applications for which this process can be used. As previously described, this process is effective in the treatment of contaminated soil and water as well as in separation pits, industrial waste systems, sewage treatment, oil and water interceptors and waste lagoons (US EPA, 2000).

Regarding the use of microorganisms as a direct cleaning agent for post-consumer plastics, Clifford Bruell, a professor of chemistry at UMASS, Lowell, explains that without the assistance of a secondary process, this technique is not feasible. He believes that the main reason microorganisms alone will not work is because, although they will clean contaminants from the plastics, they will leave a biological film that is difficult and costly to remove (Bruell, 2000). Despite his uncertainties, Professor Bruell was able to provide several suggestions regarding the use of microorganisms. He believes that one could grow a culture of microorganisms using an agar lacking a particular nutrient desired by, but not essential to, the growing microorganism. This absent nutrient could be the contaminant that needs to be removed from the plastic surface. Once in contact with the contaminated surface, the microorganisms would then eagerly attack and consume the contaminants. The plastics would then be left free from any contamination except for the biofilm left by the microorganisms. The solution containing microorganisms could then be boiled, in order to control their reproduction. This, however, is energy intensive and would incur great costs, both of time and capital (Bruell, 2000).

2.9.3 The Use of Microorganisms in Treating Wastewater

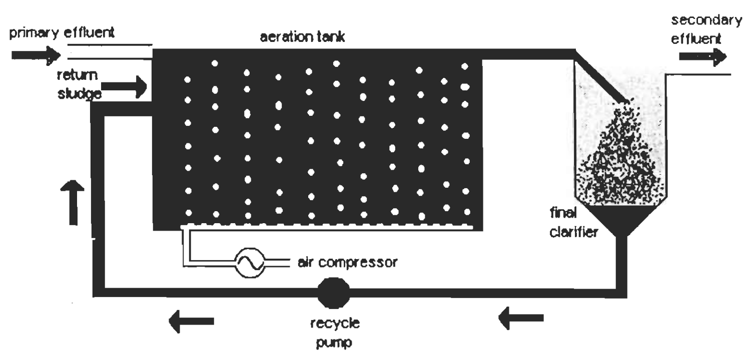
The biological treatment of wastewater involves the use of microorganisms. Domestic wastewater or a combination of municipal domestic and industrial wastewater are the primary types of water treated in a biological treatment facility (Gordon, 1999).

The wastewater treatment process occurs in a series of three main steps. Only the second stage of the water treatment process will be depicted in detail, due to its relevance to the topic at hand. The preliminary procedure involves the removal of large solids that are suspended in the wastewater using a succession of channels, filters and grinders. The tertiary process of wastewater treatment uses chlorine and other disinfectants to kill any pathogens that remain in the water before releasing it into the environment. Yet not all microorganisms in the water are killed, only those that pose a threat to the environment (Bitton, 1994).

The goal of the secondary process is to eliminate any dissolved organic matter that remains in the water and it is in this step that microorganisms are put to use. There are two possible techniques that can be used to accomplish this degradation (Gordon, 1999). The attached growth process is one of these possibilities. In this process microorganisms are cultured to grow on a rock or plastic surface. The wastewater is then poured over these surfaces and allowed to "trickle" into drains. Air is in plentiful supply throughout this process in order to facilitate the aerobic degradation of the microorganisms. Once the water enters the drainage system, the majority of dissolved matter has been deteriorated (Gordon, 1999).

The second possibility is commonly known as the suspended growth process. The system used in this process is comprised of two separate tanks: the aeration tank and the settling tank (see Figure 2-4 below). The bottom of the aeration tank is covered with a "mixed microbial culture", which is referred to as sludge (Bitton, 1994). Aerators along the bottom of the aeration tank continuously bubble air through the sludge mixture allowing for mixing and aeration of the sludge. The wastewater is also mixed into the sludge during this process and the microorganisms rapidly degrade the contaminants in the water. Once transferred to the settling tank, the sludge and water mixture is allowed to separate out, leaving a collection of "activated" sludge on the bottom of the tank and treated water on the top to be drained. "Activated" sludge is the terminology used to describe the sludge that separates from the water in the settling tank. Once separated, the "activated" sludge is then returned to the aeration tank to be reused. The microorganisms in the "activated" sludge are deprived of nutrients once the degradation has taken place and are fervent to begin the consumption cycle once again (Bitton, 1994).

Figure 2-4. Activated Sludge Process



(Gordon, 1999)

2.10 Wastewater Regulations in Costa Rica

Finally, the disposal of wastewater from Santa Ana or any other recycling facility in Costa Rica, must adhere to the regulations set forth by President José Maria Figueres Olsen and the national Department of Health in the executive decree on the regulation of dumping and reuse of wastewater published in June, 1998.

These regulations state that the parties responsible for dumping or reuse of wastewater must present periodic operational reports to the division of Environmental

Sanitation, in the case of wastewater directed to a receiving body of water, or to the Costa Rican Institute of Aqueducts and Sewers in the case of wastewater directed into public wastewater sewers. These reports must contain a register of water flow per unit time, lab analyses of water quality, the statement of any unusual accidents or situations involving the water in question, the evaluation of the current state of the system, and a plan for any necessary corrective actions. The water quality parameters that need be measured include biological demand of oxygen, pH, grease and oil, sedimentary waste, total suspended solids, and fecal coliform (bacteria) when wastewater is diverted to public recreation waters, or from hospitals. For this reason, the Santa Ana collection center would not need to analyze its wastewaters for coliform. The frequency of the reports is based upon the amount of water flow, according to Table 2 in the regulations manual (see Appendix B).

There are eight categories for reuse of wastewater: urban, restricted public access irrigation, non-commercial food crops, commercial food crops, non-food crops, recreation, public-restricted aesthetic water use, and construction purposes. All water that is to be reused, regardless of the nature of its origin, must conform to the contents of Tables 6 and 9, also found in Appendix B. When one or more of the given parameters is found to be in excess, an accredited lab may repeat the analysis on three different days in a period of no more than fifteen days after the date of the initial analysis, in the case of ordinary variations in a treatment system. In an unusual situation that cannot be explained by ordinary variations, the responsible party is given one month to present a correction plan focused on obtaining acceptable wastewater conditions. Operational reports must continue to be submitted in the appropriate frequencies, and sanctions may be imposed by the Department of Health if these corrections are not made. The Department also reserves the right to close the facility in question (Costa Rica Department of Health, 1998).

2.11 Conclusion

The topic of plastics recycling presents itself with the need for investigation in a number of areas, including the study of chemical and physical plastic properties, waste management, mechanisms of processing and washing, wastewater treatment, and secondary market availability. The findings of the literature and gathering of background information reflect an extensive consideration of each of these subjects, which together form an interdependent chain of events in the challenge of recycling post-consumer plastics. This knowledge has thus guided us in the development of the methodology, found in the following chapter, which essentially traces the lifetime of a piece of consumer plastic from its purchase, to its use in the home, its collection, processing and especially its washing process, the treatment of wastewater left by its contaminants, and finally, its marketing to secondary consumers. Understanding the relation between each phase has allowed us to adapt this knowledge for its application to the waste management situation in Latin America. We have learned that it is not sufficient to understand the technological and mechanical aspects of the problem alone in adapting an appropriate program for the Santa Ana community. This background therefore demonstrates the importance of understanding the ramifications of recycling plastics at cultural, scientific, economic, social, and environmental levels as well.

Chapter 3. METHODOLOGY

3.1 Introduction

The following methodology describes and justifies the steps we followed in the development of our recommendations to facilitate Santa Ana's pilot post-consumer plastics recycling program. Presently, the process of recycling post-consumer plastics is greatly inhibited in Costa Rica by the lack of an effective washing technique. Previous efforts in Santa Ana have also been hindered by inefficient guidelines for the processing of these plastics. Our methods therefore investigated each phase of the process, as well as the manner in which these phases affect one another, for the purpose of creating a well-planned program best suited to the Santa Ana community. Tracing the flow of plastics through these stages we began in the community itself, and conducted a public awareness survey with residents. Here we also toured the existing collection center and spoke with its manager to clarify her plans for the future. We next interviewed management and staff at local post-industrial plastic recycling facilities to evaluate current technology. Additionally, we analyzed the prevalence of different plastic types in Santa Ana and San Pedro, performed scientific experimentation with and researched the characteristics of microorganisms and other possible cleaning agents, studied wastewater treatment, analyzed the benefits of compacting the cleaned plastics in light of storage and transportation logistics, and finally, located potential secondary markets for Santa Ana's post-consumer plastics.

3.2 Meeting with Liaisons and Orientation to CICA and UCR

Upon arrival at CICA, our sponsoring organization, on May 15, 2000, we met our two liaisons, Dr. Ronald Arrieta Calvo and Dr. Milton Alvarez. We toured CICA's facilities for environmental research, as well as the chemistry and microbiology buildings of the University of Costa Rica (UCR), San Pedro.

During our orientation, we established initial faculty contacts on campus, including Dr. Maria-Laura Arias and Liliana Umaña. Dr. Arias, a professor in the microbiology department, aided us in performing experiments with microorganisms. Liliana Umaña, with whom we met the subsequent day, is an adult educator at UCR. She is also the manager of Santa Ana's municipal collection center.

3.3 Public Awareness of Recycling

To establish a general understanding of the public's level of education regarding recycling, as well as their willingness to participate in Santa Ana's pilot recycling program, we conducted brief oral surveys with thirty Santa Ana residents. Before our trip to Santa Ana, we developed a set of questions that were evaluated, tested, and revised by Dr. Arrieta (see the survey questions in Appendix C). Accompanied by two of Dr. Arrieta's students from UCR, we formed two groups and each surveyed fifteen residents within a designated area outlying the center of Santa Ana. The thirty survey participants were selected within a two-mile radius of the Santa Ana central district. All participants were adult residents above the age of eighteen, though we neither made nor recorded any further age bias in selecting respondents. Additionally, we chose participants without regard to gender, race, religion, physical appearance or disability, education level, employment status, personal financial status, or any other factor of bias.

The size of the survey sample was a limiting factor for the generalization of the responses, as it is not a complete representation of the entire city. Our survey, therefore, assessed the knowledge and opinions of the residents closest to the recycling center. Accuracy and fairness in representation to this district, however, were achieved by random distribution of surveys throughout streets, households and small businesses in the chosen two-mile radius. We conducted the surveys orally, and manually recorded the responses on thirty separate question sheets, at the time of each.

3.4 Collection of Post-Consumer Plastics

In determining the most convenient and the most efficient way to separate and store plastics in the home prior to collection, we compared recyclable storage in bags with that of recyclable storage in bins. Using data obtained from *RECOUP*, an organization located in the United Kingdom that investigate plastics recycling, as well as research presented in the background information chapter, we evaluated the cost, durability and convenience of either container, and recommended the most appropriate receptacle for the purpose of increasing public participation in the recycling program.

At the Santa Ana collection center, we interviewed Liliana Umaña to gather information regarding solid waste collection in Santa Ana (see interview questions in Appendix E). Specifically, we inquired about the collection schedule, type of collection receptacle presently in use and the type of collection truck that has been purchased. Knowledge of the current situation and analysis of the data has facilitated the development of our recommendations regarding an effective and convenient collection scheme.

3.5 The Santa Ana Collection Center

During our interview with Liliana Umaña, we additionally requested information about Santa Ana's current collection center, and that which they are planning to build in the near future. We intended to determine the dimensions of both facilities, the processes contained within them, the number of employees staffing each, the allotted budget for building and equipping the new facility, as well as its general location. These factors limit the nature of plastics recycling processes that may occur at the collection center, based upon the available spatial capacity and financial resources. For this reason, we have based our recommendations for the new collection center with these limitations in consideration.

3.6 Separation, Preparation and Processing of Plastics

Following our interview with Liliana Umaña, we visited *Palí* and *Auto Mercado*, local grocery stores within Santa Ana and San Pedro, respectively, to compile data regarding different plastic types, their prevalence and the nature of the contaminants found on their surfaces. From these data we verified the types of plastics that will be most likely to enter the recycling stream in Santa Ana and in what proportions these plastic types will be present. These data are important, as they have allowed us to determine the extent and specifics of the separation process that will occur at the new collection center.

We then toured *Gente Reciclando*, a recycling center that stores and processes post-industrial plastics. These plastics are processed in virtually the same manner as post-consumer plastics, however, they need not be washed because they are inherently clean. There, we observed the amount and variety of stored plastics to see what types of plastics are commonly accepted and recycled at the facility. In addition, we intended to observe the recycling processes themselves, specifically any sorting, shredding, or other treatments in use. These observations have helped us better evaluate the technological level at which Costa Rica currently stands with its recycling processes.

Next, we toured *Panamco*, a division of the *Coca-Cola* bottling company, which manufactures new plastic bottles and recycles unwashed post-consumer PET. There, we observed the plant's level of recycling technology as well as their process of recycling internal post-industrial plastic waste, which does not include any sort of washing process. We were specifically interested in the label removing, shredding and separation machinery. To this extent, we further sought to determine the order in which these processes are performed at their facility.

We additionally inquired about the nature of the PET plastic waste that is processed, the order in which recycling techniques occur, and the existence of any washing procedures used for post-consumer plastics at that facility. Since *Panamco* is very technologically advanced, information regarding their processing of plastics provides a basis for the availability of advanced technology in Costa Rica.

By visiting a local hardware store, *Capris Almacén Técnico*, as well as by conducting Internet research and contacting companies via e-mail, we were able to acquire information regarding several pieces of machinery and equipment that may be beneficial or necessary for the new collection center in Santa Ana. This machinery and equipment included a variety of saws for cutting the plastics, recyclable compacters to reduce the volume of the plastics, balers to bundle the plastics, conveyer belts to assist in the sorting of plastics, and large wheeled bins for the storage of recyclables. We investigated an assortment of products, varying in price and specifications, in order to gain well-rounded background information on which to base our recommendations.

Finally, on our own, we conducted a series of small-scale experiments to determine the most effective, yet simple, method for removing labels and adhesives from the plastics' surface. We first collected two plastic containers, each with a different type of label or adhesive: a water bottle and a salad dressing bottle. Next, we removed the paper label from the salad dressing bottle as much as possible, by hand, and used a knife to cut the plastic label from the water bottle. After soaking each bottle in hot water for approximately one minute, we then proceeded to scrape each label with a dull knife, but found that that they were not easily removed by these means. We subsequently mixed a solution of baking soda and warm water and, with an abrasive sponge, scrubbed the bottles with the mixture for a set duration of time.

3.7 Cleaning of Post-Consumer Plastics

3.7.1 Microorganism Investigation

As part of our investigation of an appropriate washing process, we performed research and experimentation with microorganisms. CICA suggested that microorganisms may be a more environmentally sound cleaning method than detergents.

However, it was necessary for us to investigate the implications of both methods in order to prove or disprove this suggestion.

During our first visit to Santa Ana, we collected three discarded plastic containers at the collection center: milk, vegetable oil and hand soap. Upon our return to San Pedro, we brought the three bottles to Dr. Arias' microbiology lab to culture the contents found inside each container. First, we took a culture from the inside wall of each bottle using a sterile inoculating loop. We then plated the three cultures on a blood agar in separate petri dishes. We were interested in what types of bacteria would grow from such cultures as these bacteria could potentially serve as cleaning agents for bottles contaminated with similar substances. We reasoned that if the bacteria had entered the bottle on their own, they must have been seeking a nutrient source, that which is provided by the contents of the bottles. Therefore, these organisms must naturally thrive on the contaminants within these bottles and could possibly eliminate all of the contaminants if given a suitable duration of time.

Next, we checked for bacterial colonies and found that while none grew from the vegetable oil or soap, two distinct colonies grew from the milk culture following three days of storage at room temperature. After a brief discussion with Dr. Arias, we concluded that this experimentation might have been inaccurate due to possible outside sources of contamination. This uncertainty with regard to contamination stems from the bottles' unknown origins and their exposure to the environment prior to our collection.

In response to this uncertainty in our experimentation, we consequently performed a revised experiment. In this second experiment, we purchased plastic bottles of milk, orange juice and soda, and then emptied the contents from the bottles. Soap and vegetable oil bottles were not cultured in this experiment since they produced no bacterial growth in the first. Orange juice and soda were chosen instead because unlike milk, they contain no fat and are slightly acidic. After recapping the bottles, we let them sit for four days at room temperature to allow for bacterial growth. We then took one culture from the inside wall of each bottle and plated them on blood agar, as in our first experiment. Following twenty-four hours of storage at room temperature, Dr. Arias assisted our experimentation by performing a gram-stain analysis to identify the species of bacteria that had grown.

Upon species identification, we performed additional research to highlight the characteristics of the cultured bacteria. With this research we sought to determine the nutrients necessary for the microorganisms' survival, the byproducts of their metabolism, their reproductive rate, their toxicology reports, the current applications of their usage, the cost of their implementation as a washing medium, and finally, the extent of their availability. From both research and experimentation, we have made recommendations regarding the feasibility of using these microorganisms to clean post-consumer plastics.

3.7.2 Detergent Investigation

Since the investigation of the most appropriate washing process is an integral part of our project, we furthermore investigated the feasibility of using conventional and biodegradable detergents. To gain information on this topic, we not only performed research, but also indirectly received information from Dr. Eduardo Obando through Dr. Arrieta. Dr. Obandois an expert in the field of biodegradable detergents as he is both a professor of chemistry at UCR as well as a research scientist for, *IREX*, a detergent manufacturing company in Costa Rica.

Unfortunately, Dr. Obando was unable to provide us with the exact name or chemical composition of the biodegradable detergent that he recommends we pursue. We had hoped to investigate the detergent's human and wastewater toxicology, cost, availability and physical attributes of its biodegradability, by means of its material safety data sheet (MSDS). Yet, due to the lack of details made available to us, we were unable to perform any additional research specific to this detergent, and therefore, have based our recommendations not only on this data, but especially on our research presented in the background information chapter.

3.8 Wastewater Treatment and Disposal Methods

After washing the plastics with any of the aforementioned cleaning agents, it will be necessary to find an appropriate way to treat and dispose of the wastewater that is generated. To determine the level of treatment that will be required, we have researched and read Costa Rican wastewater regulations. All of our recommendations concerning the washing process and the disposal of wastewater have been formulated in accordance with, and ensure adherence to these regulations.

In searching for appropriate means of wastewater treatment and disposal, we chose to investigate three methods: septic tanks, man-made treatment ponds and irrigation for agricultural fields. Each of these methods is relatively inexpensive and allows for the water to be released directly into the environment, either immediately or following a simple treatment process.

We first interviewed Dr. Elias Rosales Escalante, the manager of the wastewater treatment center at Instituto Tecnológico de Costa Rica in Cartago. Dr. Rosales showed us a series of man-made ponds, which are used to treat the Institute's wastewater, as well as septic tanks and their accompanying filters. As these two wastewater treatment techniques seemed appropriate for use at the Santa Ana collection center, we then further researched them on the Internet. Through the interview and our research we were able to compile a list of necessary considerations, such as the cost for each system, required space for the treatment, necessary size and capacity for each tank or pond, and the duration of time needed for the treatment process.

In a brief meeting with Dr. Arrieta, we learned of the third wastewater disposal possibility, that of using wastewater for irrigation of a nearby agricultural field. Due to the lack of background information and accessible research regarding this topic, we were unable to gain detailed data with which to base our recommendations. However, using our background information and other data we have created a summary of issues that must be considered when using this disposal technique.

3.9 Distribution and Future Markets for Recycled Plastics

To determine the most appropriate method of distribution from the Santa Ana collection center, it is necessary to distinguish the future destinations of the semi-processed plastics. Once the recycling program has been instated in Santa Ana, *Gente Reciclando* is looking to accept clean post-consumer plastics from the collection center, in order to expand their market. For this reason, we conducted a formal interview with Adriana Soto and Jonathon Molina, the owners of *Gente Reciclando*. During our interview we discussed the current capacity of their facility and its projected ability to accommodate the influx of post-consumer plastics. Among other topics, we asked about the plastic types they will accept, the physical state in which these plastics should arrive, the degree of separation and cleanliness demanded, and the means of transport for these plastics (see interview questions in Appendix F). The information provided regarding transport has allowed us to determine the most cost effective transportation method as well as the on Santa Ana's truck availability

We spoke with employees of *Gente Reciclando* and *Panamco* to determine the extent and nature of secondary markets for processed post-consumer plastics. We inquired about the location of such markets, the demand by and price paid by secondary purchasers, and the amount that *Gente Reciclando* will pay for semi-processed plastics from Santa Ana.

In concluding our interview with *Gente Reciclando*, we discussed the level of cleanliness demanded by various post-consumer plastic markets. This information was important in determining an appropriate washing process, for the process must achieve this standard level of cleanliness or higher.

Moreover, we contacted five hardware stores, both in Santa Ana and Escazu, as during our interview, *Gente Reciclando* informed us that hardware stores provide a market for clean, post-consumer plastic gallon jugs. In our communication with the five stores, we inquired about each store's demand, if any, for gallon jugs, the price it will pay for them, and the conditions under which it will accept these jugs.

3.10 Conclusion

In summary, the approach to our investigation clearly follows the lifetime of consumer plastics, beginning with their usage in the home and ending with their purchase by secondary plastics markets. The design of the methods illustrates the importance of the individual community in planning a recycling program, yet the logical sequence of our approach may be applied to any group or community beginning an introductory plastics recycling project. The investigation procedure that is illustrated in this chapter, in short, serves as a model for establishing future post-consumer plastics recycling programs in other local Costa Rican municipalities. As for Santa Ana, the analysis of data in the upcoming chapter will facilitate the understanding of the links between each recycling phase. This understanding will consequently provide justification for recommendations regarding sustainable processing and especially washing procedures.

Chapter 4. DATA PRESENTATION AND ANALYSIS

4.1 Introduction

This chapter presents the results we obtained from the application of the methods previously described in chapter three, together with analyses of these findings. Quantitative data are arranged in tables and graphs to support the text-based analysis of more qualitative findings.

We gathered all data for the purpose of designing a proposal for the implementation of post-consumer plastics recycling in the city of Santa Ana. To the best of our knowledge, this recycling program will serve as the first in Costa Rica to, in fact, recycle post-consumer plastics. With this in mind, our findings reflect the careful analysis of all phases required to collect, process, and market these plastics. The organization of the data, therefore, mirrors the sequence of the methodology, which traces a plastic's lifetime from its beginnings in the consumer's home to its eventual purchase by secondary markets.

Accordingly, the assessment of the recycling process includes the following areas of concern: public awareness of recycling, current methods of curbside collection in Santa Ana, the level of plastics recycling technology presently available in Costa Rica, resources allocated and available to the Santa Ana collection center itself, types of equipment to facilitate the preparation of plastics for washing, preliminary experimentation for the cleaning of post-consumer plastics, options for the treatment of wastewater, and finally, the investigation of secondary markets for Santa Ana's post-consumer plastics. The careful consideration of these areas of concern serves as the basis for the recommendations and conclusions found in Chapters Five and Six.

4.2 Public Awareness Survey

In Santa Ana, we conducted thirty short, standardized surveys using the predefined questions that are shown in Appendix C. We questioned residents in order to assess their knowledge of the forthcoming recycling program, to determine what plastics they will be likely to recycle, and to evaluate their willingness to clean plastic waste before it is collected from their home for recycling. Because several survey questions provided us only with background information and did not serve as a basis for recommendations, their analysis is included in Appendix D as supplemental information. The questions and responses that aided in forming our recommendations are analyzed below and recorded in Tables 4-1 through 4-7 and in Figure 4-1. Please note that one respondent was unable to complete the survey, as she departed for a bus midway through the interview. Therefore, questions 7 through 12 were left unanswered in this case.

Question 1: Is there a recycling project/program in Santa Ana?

Table 4-1. Knowledge of Program Existence

	Yes	No	Not Sure
% of Survey Respondants	30.0	43.3	26.7

As of June 2000, there was a collection schedule for recyclable wastes in Santa Ana (see collection schedule in Appendix G). However, we learned from Dr. Arrieta and Liliana Umaña that the collection truck broke down in 1998, and as a result, there have been no pick-ups since that date. Therefore, there is in fact a recycling program, but is inactive until the arrival of a new collection truck anticipated in late June (Umaña, 2000). This antecedent partially explains the negative and uncertain responses, which together account for the majority of responses to Question 1. Once the truck arrives and collections resume on a regular basis, a future short interview of residents using the same question could clarify this confusion and provide information on the number of residents truly unaware of the Santa Ana recycling program.

Due to a typographical error and consequent differences in interpretation, data from Question 2 and follow-up Questions 3 and 4 are further separated into two sets of fifteen responses. Group 1 asked residents if they are currently recycling, whereas Group 2 asked residents if they would recycle given the opportunity in the future.

Questions 2, 3, and 4, Group 1 Version: Do you recycle? If not, why? To what degree do you agree with the idea of recycling?

Table 4-2. Number of Interviewees Currently Recycling, and Degree of Agreement with the Idea of Recycling

Yes, I Recycle	Strongly Agree	Somewhat Agree	Don't Agree		No, I Don't Recycle	Strongly Agree	Somewhat Agree	Don't Agree		Sometimes I Recycle
8	8	0	0		7	4	1	0		0
	100%	0%	0%			57.10%	28.60%	14.30%		

Table 4-3. Rationale for Not Recycling Currently

Reasoning	Number of Negative Responses
I mainly just have cardboard waste in my business	1
I don't have enough time, I work too much	2
I am just not used to doing it	1
I don't have enough recyclable waste in my home to make it worthwhile	1
It is easier to just throw everything away	1
The truck stopped coming to pick up the recyclables	1

Table 4-2 shows that, while seven of fifteen interviewees do not currently recycle, four of the people who responded negatively actually strongly agree with the idea of recycling. Eight of these fifteen interviewees, however, claim to recycle and strongly agree with the idea of recycling. As evidenced in Table 4-3, there is a wide variety of rationale to explain why the seven non-recyclers currently do not comply. However, only one of the six different explanations relates to the present inactivity of Santa Ana's recycling program. The remaining five explanations listed in Table 4-3 above are based on factors of convenience, apathy, or shortage of disposable materials in the home. Only one of the fifteen interviewees does not presently recycle and does not care to do so for any reason in the future.

A UCR student-led campaign is scheduled for June 2000, which will concentrate, for one, on educating and familiarizing Santa Ana residents with the schedule of collection days for recyclable materials (Umaña, 2000). According to Liliana Umaña, public cooperation and participation in Costa Rica rises directly with education. The campaign is therefore one factor that will motivate those residents who are interested in recycling, but presently do not comply because they are unfamiliar or unaccustomed with recycling.

Our investigation of collection methods will lead to recommendations for the improvement of recycling convenience, a second factor that may increase public collaboration with Santa Ana's recycling efforts.

As with the responses to the Group 2 version of Questions 2, 3, and 4, the degree of interviewee honesty was influenced by the fact that the interviews were conducted orally, as opposed to written, more private interviews. Since recycling is commonly seen as a practice performed by "good" citizens, interviewees may have claimed to agree or comply with recycling in order to avoid portraying poor social commitment. Furthermore, the follow-up question for negative responses to Question 2 allowed for an analysis as to why those interviewees did not carry out recycling. However, there was no way to further probe the validity of the affirmative responses.

Questions 2, 3 and 4, Group 2 Version: Would you recycle? If not, why? To what degree do you agree with the idea of recycling?

Question 2: 100% of 15 responses - yes, I would recycle

Question 3: rationale for negative responses to Question 2 not applicable

Question 4: 100% of 15 responses - I strongly agree with the idea of recycling

These results indicate affirmative support for recycling from all fifteen respondents, which suggests 100% compliance with the forthcoming recycling program. However, the accuracy of this assumption is once again limited by the small sample size and the minimal degree of privacy during the interviews.

Please note that for questions 6, 7 and 8, cardboard was not originally one of the listed waste materials. It was added, however, to the list of materials when a number of residents mentioned it in their responses.

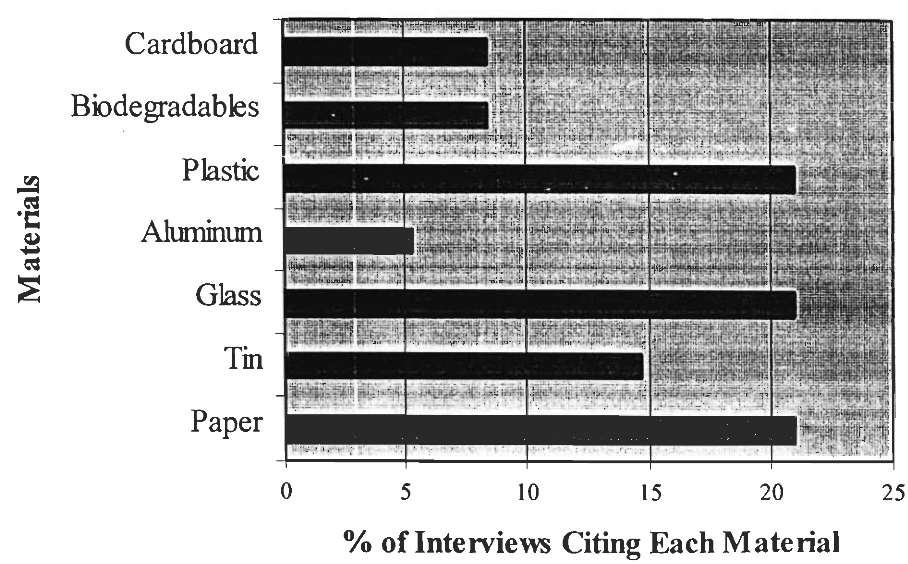
Question 5: See appendix D

Question 6: What types of waste material can be recovered from the trash?

Table 4-4. Summary of Responses to Question 6

Material	# of Times Material Was Named	% of Residents Citing Material as Recyclables
Paper	20	66.7
Tin cans	14	46.7
Glass	20	66.7
Aluminum	5	16.7
Plastic	20	66.7
Biodegradable	8	26.7
Cardboard	8	26.7

Figure 4-1. Materials That May Be Recovered From the Trash



For the purpose of our project, we were primarily interested in the number of interviewees who cited plastic as a type of waste that may be recovered from the trash for reuse or recycling. As shown in Table 4-4, plastic is mentioned by 66.7% of all respondents, showing they are aware that plastic is a recoverable material. Paper and glass, two commonly recycled materials, are also cited twenty times each. As Figure 4-1 illustrates, the majority of respondents noted all three of these materials in each case. These results suggest that residents of the Santa Ana central district should be recycling plastics as frequently as paper and glass. They also suggest that these residents are, for the most part, knowledgeable about the ability of plastics to be recycled.

Question 7: Which waste material is the most contaminating to the environment?

Table 4-5. Summary of Responses to Question 7

Material	# of Times Selected as Contaminating	% of All Responses
Paper	9	11.7
Tin	12	15.6
Glass	14	18.2
Aluminum	8	10.4
Plastic	16	20.8
Biodegradable	11	14.3
Cardboard	7	9.0

Question 8: Why do you feel this material is the most contaminating to the environment?

Table 4-6. Rationale for Contaminating Material Selections

Reason	% of Responses
None given	24
Material(s) will not degrade	20
Not thrown away properly	20
Contaminates water resources	12
Is dirty	4
Requires incineration	4
Causes disease	4
Smells bad	12

Tables 4-5 and 4-6 show that plastic is mentioned most often as an environmental contaminant. One problem arose with the question, however, when residents selected two or more, or in a number of cases, all materials from the given list. In this situation, the interviewees were unable to distinguish a single material as the most contaminating to the environment. Therefore, the results were tabulated as the total number of times the material was mentioned by all thirty respondents. These results show which materials are generally perceived as environmental contaminants, rather than isolating a single waste material as most contaminating. The unexpected manner in which survey participants responded to Question 7 partially accounts for twenty-four percent of the responses to question 8, which asked to explain why the particular selected material was most contaminating, being "none given." For the respondents who were able to specify a material or group of materials, the two most common explanations for their choices were "the material is unable to biodegrade" and "the material is not disposed of properly." The first of these two explanations correlates strongly with plastic wastes, as they indeed are non-biodegradable.

Question 9: See Appendix D

Questions 10 and 11: Knowing that plastics cannot be recycled when they are dirty, would you wash your plastic waste with soap and water at home before setting it aside for collection? Would you teach others to recycle?

Table 4-7. Percent of Interviewees Willing to Wash Post-Consumer Plastics at Home, and Percent Willing to Teach Others about Recycling

	Yes	No	Maybe
Would wash	75.0	7.1	17.9
Would teach	86.2	0	13.8

In general, the responses of Table 4-7 demonstrate a positive attitude towards assisting in recycling efforts. However, these results alone do not guarantee that 75% of the central district residents, or interviewees for that matter, will actually wash their plastics before their storage and collection. In retrospect, two alternative questions might have read: "How often do you rinse recyclables before they are thrown away?" and "Have you ever encouraged a friend or family member to recycle? If so, how?" Both of these questions would have induced more specific responses, rather than simple responses of yes, no, or maybe.

4.3 The Collection of Recyclables

To obtain data on the most effective collection schemes, we contacted *RECOUP*, a company located in the United Kingdom that researches post-consumer plastics recycling, and requested that they send us a copy of their literature. Also, we interviewed

Liliana Umaña of the collection center to gather information regarding the past, current and proposed collection schemes in Santa Ana. We reviewed the information and data from both *RECOUP* and Liliana Umaña, and developed an appropriate collection scheme for Santa Ana.

The city of Santa Ana first collected recyclable materials in 1996. This program, however, was short-lived, as over the period of two years it gradually faded from existence due to problems in its organization. The program was later carefully evaluated, and in 1998, reconstructed to follow a twice monthly collection schedule. Despite the success of the new recycling program, it was once again terminated when the collection truck broke down in that same year.

Since the truck's breakdown, recyclables, including post-consumer plastics, have been voluntarily brought to the collection center on an individual basis by residents. With the assistance of charitable funding from Holland, a new collection truck was purchased by the Santa Ana municipality and is scheduled to arrive in late June 2000. The truck will have a closed collection cab with rear access and minimal automated features. The same pick-up schedule, as was used in 1998, will be followed once the pilot program is running. Prior to the initiation of the pilot program, students from UCR will conduct an educational campaign to help re-familiarize Santa Ana residents with this collection schedule, as well as the nature of materials acceptable for collection. The collection program is slated to begin again in August 2000.

Liliana Umaña explained that in the future, plastic recyclables will be collected as commingled recyclables with tin, aluminum and glass, as they were in past programs. As evidenced by *RECOUP*'s data, the quantity of recovered plastics is increased when there is a greater variety of a recyclable material in a commingled collection scheme. Therefore, the Santa Ana collection center's plans to collect commingled recyclables will boost the quantity of plastics, as well as other materials, collected.

Currently in Santa Ana, as well as many other regions of Costa Rica, plastic bags are used to collect MSW. Recyclables are not separated from MSW, and therefore occupy space within these bags. If, in the future, these same bags are used for the collection of separated MSW and recyclables, there will be no additional cost to homeowners for separating recyclables. This is because the recyclables will still occupy the same amount of space, but simply within bags of their own.

Data from *RECOUP*, however, indicate that a far greater amount of recyclables is recovered when reusable plastic bins, rather than plastic bags, are distributed to homeowners. Specifically, *RECOUP*'s research shows that households provided with a collection box, such as the aforementioned plastic bins, collect an average of 3.5 kilograms of recyclable plastics per year. In contrast, households not supplied with a collection box, for example, households that use plastic bags, only collect an average of 1.5 kilograms of recyclable plastics per year.

The increased quantities of recovered recyclable plastics observed with the distribution of plastic bins, most likely stems from the convenience of their use. These bins are more durable, and therefore, easier to transport to and from the curbside. Additionally, these bins are reused for each collection period and can be easily stored in a visible location within the home; consequently serving as a constant reminder to recycle. While bags could just as easily be stored in a visible location, the open, rigid design of plastic bins allows for effortless depositing and storage of recyclables.

4.4 The Santa Ana Collection Center

The current collection facility is approximately one hundred square meters in size, and is located on a residential side street in the Santa Ana central district. With the remaining funds from Holland, the municipality plans to construct a new collection facility that will be approximately two hundred square meters, that is, twice the size of the current facility. The new collection center will be relocated to a rural plot of land, elevated above a canyon and a river. It will be built in close proximity to a commercial agricultural center.

Fifteen young adults, all of whom work without salaries, currently staff the collection center. These workers, the majority of whom have a physical or learning disability, are provided with a small commission whenever possible, but work primarily for the activity provided by a full day of work at the center. Each workday consists of an eight-hour shift, with a one-hour lunch break and two shorter breaks in both the morning and afternoon. Liliana Umaña manages these fifteen workers, and explains that they work most efficiently in small groups. Umaña also points out that on average, their relative productivity level is approximately half of that of a non-disabled worker.

Due to the scarcity of funding and abundance of manual labor at the Santa Ana collection center, most recycling processes, both now and in the future, will be manually performed. Currently, the center owns a dolly, a scale, several wheelbarrows and ladders. For the new collection center, the municipality also hopes to obtain a used compacter from a nearby cement plant.

4.5 The Separation of Plastics

In order to estimate the frequency of plastics, by type, that will enter the waste stream and arrive at the collection center, we gathered data from two grocery stores, *Palí* and *Automercado*. We learned that in Massachusetts, only type #1 and #2 are recycled due to the economic inefficiency of storing other types (types #3-#7), which individually appear less frequently in the waste stream. Liliana Umaña noted that the most common plastic containers currently found at the collection center include shampoo bottles, butter tubs, sauce containers, plastic bags, as well as juice, water and soda bottles.

At *Palí,* we counted each type of product contained in plastic by brand. We selected *Palí* as it is the largest supermarket in the central district, where the collection center is located. In our tally, we divided the products into categories (see Table 4-8) and noted the number of brands within each category. These were further categorized by plastic type, including non-plastics. This method was limited, however, in that the total number of plastic containers within each brand was unaccounted for.

Table 4-8. Percentage of Products in Plastic Containers at *Palí* Supermarket, Santa Ana

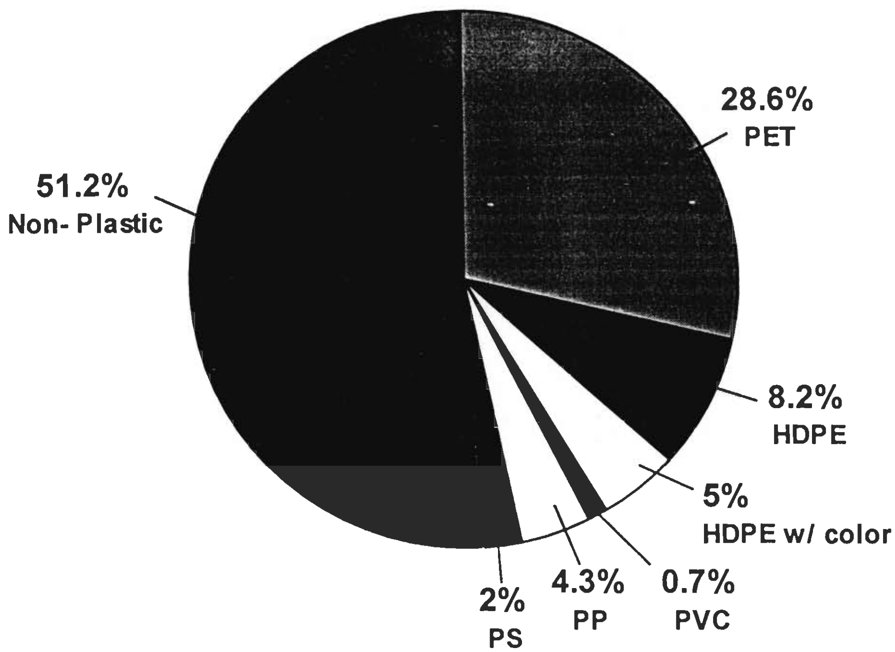
Product	Type 1	Type 2	Type 2 Colored	Type 3	Type 5	Type 6	Unknown	Non-Plastic
baby oil	100							
condiments	40				10	10		30
juice		50						50
milk								100
other dairy products					20	60	20	
oil	50	37.5		12.5				
shampoo, conditioner, hand creams	10.7	46.4		14.3			28.6	
soda	95							5
syrups	33.3	33.3						33.3
water	50	50						

Due to the inaccuracy in our first data collection, we later collected additional data at *Automercado*, in the Los Yoses district of San Pedro. This grocery store is approximately twice the size of *Palí*, and is better organized and stocked. Here, it was possible to tally the amount of a particular product housed in each plastic type as a fraction of the total shelf space occupied by that product. The shelves are approximately one-meter sections, and the results are recorded as the percentage each product occupied per shelf (see Table 4-9). Since bottles come in varying sizes, simply counting the bottles would generate a misrepresentation of the total volume of plastics. Shelves, on the other hand, are of constant size, and when well stocked, provide a more accurate depiction of total volume. This method of quantifying our data later allowed us to chart the relative frequency of products contained in plastic at *Automercado* (see Figure 4-2).

Table 4-9. Percentage of Products in Plastic Containers at *Automercado* Supermarket, Los Yoses

Product	Type1	Type 2	Type 2 colored	Type 3	Type 5	Type 6	Unknown	Other
baby oil	50			50				
condiments	5	0.7	0.5					94.3
dishwashing soap		7.7	11.5		17.3			57.7
juice	16.9	3.9	1.3					77.9
milk		3.8						96.2
other dairy products			4.2		11.3	33.6	50.7	
mouthwash	66.7			33.3				
oil	50	14.3	7.1					28.6
shampoo and conditioner	20	80						
soda	76.7							23.3
syrup and jellies	3.6		2.4		36.2	14.4		43.4
water	87.5	7.5	2.5					2.5

Figure 4-2. Percentage of Plastic Containers, by Type, of Total Containers Surveyed at *AutoMercado*



There were a number of differences in the data from the two grocery stores, based on factors of size and variety as previously noted. Milk, for example, was housed entirely in carton at *Palí.* There was also a very limited juice selection at this supermarket in Santa Ana that offers only two brands of juice, as compared to 38.5 total shelves of juice at *Automercado*. Soda, however, was contained almost exclusively in plastic at *Palí,* whereas *Automercado* offered several shelves of non-plastic soda containers. In general, the comparisons that can be made between the two facilities are limited because of the two different methods we employed to tally the plastic products.

In our interview with Liliana Umaña, we learned that in Costa Rica, manual labor is highly preferred over mechanized operations. One reason is that there is a large availability of workers, both skilled and unskilled, and culturally, employing workers is valued over using machines. A second factor that contributes to this preference of manual labor is the current stage of technological advancement. A developing nation, Costa Rica is not yet at the level of technology, nor has adequate funding, as do many other countries, such as the United States.

Prior to acquiring this knowledge, we planned to investigate a variety of simple automated sorting systems, mainly involving conveyor belts. As discussed in Chapter Two, numerous highly advanced sorting systems are available. Even before arriving in Costa Rica, however, we deemed that these systems of sorting by density with water or air, as well as those that employ methods of light transmittance, were too complex for a pilot-recycling program and that a simpler system involving conveyor belts would be more appropriate.

During our interview, in addition, we learned that the Santa Ana municipality has only sufficient funding to purchase the collection truck and to build the new collection center. Consequently, we ruled out the option of using conveyor belt systems to facilitate the sorting process, as these systems are generally costly. We have analyzed, alternatively, the collection center's resources, including workers, and have devised various manual sorting methods that may be suitable for the collection center. Each of these methods, although slightly different, involves a series of sorting tables with three to four employees at each station. Ultimately, the sorting at these tables will result in storage bins containing separated and unwashed recyclables.

4.6 The Preparation of Plastics

Following separation but prior to the washing process, plastic recyclables must be treated to remove any incompatible materials and be prepared in order to facilitate the washing process.

The owners of *Gente Reciclando* explained that although bottle caps and their attached rings are usually composed of plastic, they seldom are composed of the same type as that of the bottle. Therefore, they must be removed as this creates a problem during the melting process because different plastic types are often incompatible and do not mix properly. This mixture alters the quality and properties of the secondary plastic products. Ms. Soto of *Gente Reciclando* explained that bottle caps are usually composed of type #5 plastics, but there are some exceptions. Due to their concern for the environment, she and Mr. Molina volunteered to accept these caps and sell them to the Cartago cement plant, even though the costs incurred by shredding the caps will exceed the price paid by the plant for each kilogram.

Furthermore, adhesives and labels that are attached to the outer surfaces of the bottles must be removed as well, prior to the washing process. First, labels and adhesives are incompatible with plastic resins and interfere with the melting process and quality of the secondary product. Second, if adhesives are not removed, they can damage the machinery used for shredding and pellet forming, as they stick to the metal components and impede proper function. Additionally, the materials used for labels can jam the aforementioned machines and hinder the flow of plastics during their processing.

In a small-scale experiment, we tested the effectiveness of baking soda as an abrasive cleaning agent to remove paper labels and adhesives from a salad dressing and water bottle. We investigated this technique after learning that *Gente Reciclando* uses baking soda to clean remnants of PVC from their shredding machinery. Approximately one minute of scrubbing removed the salad dressing bottle's label and adhesive, which was gummier than that of the water bottle and covered a larger area. Two minutes of scrubbing removed the water bottle's label and adhesive, which was similar to a hardened glue substance and existed only in a small strip.

Once these incompatible materials are removed, the plastics must then be cleaned of contaminants. One problem, however, is that many bottles are oddly shaped and have narrow openings. These characteristics can inhibit thorough washing, especially when it is performed by hand. As explained in Chapter Two, in a more automated process, plastics are shredded before washing. This step eliminates the difficulty of cleaning these oddly shaped bottles. After the plastics are shredded, a machine is used to methodically and completely clean the plastic flakes.

As mentioned previously, we learned from Liliana Umaña that there is little funding available for and little interest in automated processes at the Santa Ana collection center. Furthermore, shredding need not take place at the collection center, because secondary facilities, like *Gente Reciclando,* already own the equipment necessary to carry out this process. In order to facilitate the cleaning operations at the collection center, we have investigated the use of saws to cut the plastic bottles lengthwise, thus making their inner surfaces more accessible for cleaning.

Table 4-10 compares five different saws that we have investigated for use at the collection center. Carlos Solis of *Capris Almacén Técnico*, a large hardware store in San José, provided the following information on each of the three considered saw types.

Table 4-10. Saw Descriptions and Specifications

Product Name	Description	Blade Diameter	Power Specifications	Safety Features	Price in Colones, w/o Tax (in dollars)
Ryobi TS254	Circular bench saw	10"	12.5 Amp	Double insulated blade, electric brake	90.640 ($302.13)
Ryobi C356	Circular bench saw, stationary disc	Not specified	15 Amp	Single insulated blade	89.111 ($297.04)
Dayton 4TJ91	Band saw	Not specified	115 V, 60 Hz	None specified	198.000 ($660)
Dayton 4TJ88 (lightweight), 4TJ89 (heavyweight)	Table saws	10"	110 V, 60 Hz	Protective side guards	185.600 ($618.67), 297.000 ($990)

Bench saws, the most inexpensive of the three saw types, make vertical cuts through materials positioned beneath a blade when the blade's handle is manually lowered. The TS254 model provides two insulating shields that meet to cover the entire circumference of the blade when not in use. When the blade is lowered and comes into contact with the material to be cut, one shield retracts, therefore allowing the material to pass through the blade. The C356 model, however, is more capable of heavy-duty cutting, including pieces of metal, but does not include the instantaneous electric brake feature or the full 360 degrees of blade shield protection that are found in the TS254 model. Instead, this model offers approximately 270 degrees of shield protection. Although not likely, when the shield retracts on either model, it is possible that a worker's hands or other body parts might be exposed to the blade as it is lowered. An additional problem with this saw is that the size of materials that may be cut is limited to the five-inch radius of the blade.

The band saw, which offers the least protection to the worker, operates when a material is manually pushed through a circulating saw blade. Band saws can be especially dangerous as the saw belt may snap on rare occasions and, due to the great rotational velocity, be flung from the machine. Moreover, the cutting surface of the blade is limited to a set distance, as instability increases with greater lengths of exposed saw blade. This restriction consequently limits the size of objects that this saw is capable of cutting.

Finally, table saws cut materials horizontally, again to an extent limited to the radius of their blades. The 4TJ88 and 4TJ89 models both offer ten-inch diameter circular saw blades, and the 4TJ89 model is stabilized for heavy-duty projects. Both are equipped with side-guards to protect workers from off-shooting bits of material. The table saw also allows for the installation of a safety shield around the entire saw area, as well as a protective mechanism to push materials through the saw. Both of these devices would prevent workers' hands and forearms from being exposed to the rotating blade. Unfortunately, neither of these features is currently available for purchase from the saw company. Yet as Carlos Solis noted, in the case of the Santa Ana collection center, a private contractor could be hired to build such a system.

Among the three types of saws discussed, it would be feasible to build extensive, adaptable safety features for the table saw; thus making it appropriate for the collection center. A sizable, protective hood or screen, for example, could be built surrounding the circular blade of the table saw to prevent all human contact. Rather than pushing bottles through the saw by hand, a device, set upon runners along both sides of the blade, could stabilize the bottles while the worker pushes the device, rather than the bottle itself, toward the blade. This device would be designed to stop at a specified point, which therefore would prevent the operator from accidentally extending it too far and putting his or her hands in danger. This device, in addition, would be long enough to fully push the cut bottle to the end of the saw table, and possibly directly into a bin. Furthermore, the limited cutting diameter would be compensated for by the fact that hardware stores generally purchase larger, gallon size containers for reuse rather than recycling. A 10-12" diameter would be adequate for the cutting of the vast majority of non-gallon sized containers.

4.7 Washing, Rinsing and Drying Data

During our visits to the grocery stores, *Palí* and *Auto Mercado*, we created a complete list of products housed in plastics. This list aided in the determination of the nature of contaminants to be found on the inner surfaces of the plastic bottles, which consequently indicated the washing technique necessary to remove these contaminants. The contaminants have been categorized into two distinct groups: water-soluble and non-water-soluble (see Table 4-11). This type of categorization was chosen because it designates what cleaning agent is necessary for each bottle. For example, it is possible to clean a bottle that contains water-soluble contaminants using only pressurized water; however, non-water soluble contaminants require the use of an additional cleaning agent, such as a detergent. In addition, some products housed within plastic containers are hazardous to humans and the environment. These products (indicated in Table 4-11) are deemed hazardous regardless of their water solubility, and it is imperative that their containers be washed for recycling only if the resulting wastewater is properly treated with a method such as a septic system.

Table 4-11. List of Wastewater Contaminants, Types of Plastic Containing Them, and Their Solubility

Contaminant	Plastic types found housing contaminant	Solubility Non-water – NW Water – W Hazardous – **H**
Baby oil	1,3	NW
Bleach	2	**H**
Carbonated beverages	1	W
Cooking oil	1, 2, 3	NW
Conditioner (hair)	1, 2	W
Cough syrup	1	W
Dairy (yogurt, cream cheese, ice cream, sour cream)	2, 5, 6	NW
Dishwashing soap	2, 5	W
Fruit juice/sports drinks	1, 2	W
Household cleaners	1, 2, 3, 5	**H**
Ketchup	1	W
Laundry detergent	2, 5	W
Milk	2	NW
Mouthwash	1, 3	W
Mustard	1, 4	W
Salad dressing	1	NW
Sauces	1	NW
Shampoo	1, 2	W
Sunscreen	2	NW
Syrup, jelly, honey	1, 2, 3, 5	W
Vanilla flavoring	2	W
Water	1, 2	W

In our experimentation with microorganisms, performed to search for an effective cleaning agent, we found that bacteria did not grow on cultures of orange juice, soda, hand soap, or vegetable oil. Bacteria did grow, however, on the milk culture. When we performed a Gram Stain Analysis on these bacteria, we identified them as *Streptococcus bovis, Streptococcus equinas, Enterobacter* and *Pseudomonas aerudinosa.* We then researched their specifications and found that *Streptococcus bovis, Enterobacter*, and *Pseudonomas aerudinosa* are human pathogens. We did not find any information regarding *Streptococcus equinas.* Specific toxicology and additional information found on the three strains are described in detail in Appendix H.

In searching for a specific biodegradeable detergent for use at the collection center, we contacted Dr. Obando, a colleague of Dr. Arrieta. Dr. Obando has worked with a biodegradable detergent in his research with the IREX chemical company. This detergent, the name of which was undisclosed, costs approximately twenty percent more than traditional detergents. As of the date this report was submitted, the IREX product lacked analysis reports of its composition, specifications of use and toxicology. Dr. Arrieta, however, found the main chemical component to be a linear benzene sodium sulfonate surfactant. According to his phone conversation with Dr. Obando, Dr. Arrieta also learned the detergent cleans grease and fats, does not contain excess foaming agents, and is not irritating to the skin. Dr. Arrieta further stated that the difference in cost, when compared to traditional detergents, would be negligible, if the cost of ridding wastewater of traditional detergent residues is considered.

4.8 Wastewater Treatment and Disposal

In our interview with Dr. Rosales, we discussed and examined two forms of wastewater treatment: manmade treatment ponds and septic systems. These systems do not re-circulate wastewater after treatment, but rather treat wastewater to a level of quality where it can be directly deposited into the environment.

The manmade treatment ponds at the Instituto Technológico de Costa Rica are managed by Dr. Rosales and organized into two groups containing wastewater from different locations.

The first set of ponds receives wastewater from facilities within the Institute: labs, kitchens, restrooms, etc. The water flows out of a pipe and into a collecting basket that filters out large solids. This basket is cleaned every two days in order to maintain steady water flow into the system. The removed contaminants are treated as any other solid waste, either incinerated or deposited in a landfill.

From the basket, the water then flows into the first treatment pond in the series. Approximately fifty meters in length and one meter in depth, this pond contains clusters of water lilies that are separated by floating pipes. In their natural metabolic process, the water lilies remove suspended organic matter from the water. Since this organic matter is a source of nutrients for the water lilies, they thrive and reproduce in this highly contaminated treatment pond. Therefore, these water lilies not only aid in the water treatment process, but also serve as an indicator of poor water quality. When the population of water lilies becomes too large, some of the plants are removed and their fibrous roots are used to make paper. One cannot simply dispose of the lilies in the environment, as they are contaminated from the organic material that they have ingested from the water.

The previously mentioned floating pipes act as a barrier to any floating solids, such as oils and grease, which must be skimmed and removed from the surface regularly. Naturally occurring environmental processes, including wind, oxygen and sun exposure, also assist in the water treatment process. Solids not consumed by the water lilies, nor trapped by the floating pipes, eventually settle to the bottom of the treatment ponds where they form an anaerobic sludge. This sludge must also be removed on a regular basis to prevent the ponds from becoming too shallow, which would alter the treatment process. Once removed, the sludge will be dehydrated and treated as solid waste.

Once the water has reached the far end of the first treatment pond, it then flows into a small cement channel that leads to the second treatment pond of the series. This second pond, similar in size to the first pond, only contains sparse clusters of water lilies, as the water quality at this point is much greater than the initial quality. While held within this pond, the majority of the remaining solids settle to bottom, as the aforementioned natural processes further purify the water. Upon arrival to the far end of the second pond, the water flows through a second cement channel and into a nearby river, thus completing the wastewater treatment process.

The second set of treatment ponds at the facility receives wastewater from the small community surrounding the Institute. The composition of this wastewater is slightly different from that of the Institute, as it contains large concentrations of detergents from laundry and bathing facilities. Water lilies and floating pipes are not used to treat this wastewater. Instead, naturally occurring algae are plentiful and assist in the removal of organic waste. The great prevalence of algae is due in part to the increased level of phosphates introduced by the detergents in the water. Since the concentration of natural phosphates is commonly a limiting factor to biological growth, the excess in this pond leads to eutrophication; in this case, an overabundance of algae. As in the first set of treatment ponds, this set also contains a series of two ponds connected by a cement channel. These two ponds, however, are identical in their construction. The only difference is the quality of their water, which gradually improves as suspended solids settle. Floating solids, in addition, are skimmed and removed, algae consume organic matter and the previously discussed natural processes occur. Once the water has reached the end of the second pond, it then flows through a cement channel into the same nearby river.

With Dr. Rosales, we then discussed the applications and specifications of using a septic system. He was unable to show us a septic system in use, as it is buried underground upon installation. However, Dr. Rosales did show us a septic system that had not yet been installed. This system was composed of two main components: a settling tank and a filtering tank, which are commonly constructed of concrete, plastic or fiberglass. This particular system was made of plastic and fiberglass, as it requires less space underground than concrete. Water flows directly from the adjacent facility, the household or commercial building, into a settling tank, which is sized according to the peak quantity of wastewater generated by facility. Depending upon the nature and amount of contaminants in the wastewater, the water must be contained within the settling tank for an extent of time that allows the majority of solids to settle. Following the settling tank, the water then flows via pipes into the filtering tanks, in which the remaining solids are removed from the water. The number of necessary filtering tanks also depends upon the nature and amount of contaminants in the wastewater, as a greater amount of contaminants require more filtering tanks.

At the completion of the settling and filtering processes, pipes then dispose of the water into a lined leach field, unlined leach field, or a natural body of water. A leach field, whether lined or unlined, is essentially a natural filtration system that uses a series of large rocks, gravel, and finally sand to further decontaminate wastewater. In choosing any of these three means of disposal, one must consider the presence and level of water tables, the composition and absorption rate of the surrounding land, and regional regulations for the quality of disposed water. High water tables and land with a poor absorption rate will both cause the septic system to back up and potentially overflow, in this case a liner would be necessary. Also, regional regulations may prohibit the release of treated water into natural bodies or water, or may even prohibit an unlined leach field if there is a possibility that the leaching of the water will contaminate another water supply. As with the man-made wastewater treatment ponds, it is necessary to remove the sludge from the settling and filtering tanks, usually every three years, to maintain system efficiency.

Since the price of building and maintaining the man-made wastewater treatment ponds is highly dependent on the quantity and quality of the wastewater, we were unable to obtain a cost estimate for such a system. However, Dr. Rosales was able to provide us with the approximate cost for a septic system that could accommodate a facility of eight people. Although this particular figure is not necessarily applicable to the Santa Ana collection center, it can be used as a baseline for septic system costs. According to Dr.

Rosales, the settling tank for such a system would cost approximately $4,000, and each filtering tank would cost approximately $2,500. The sludge removal process would incur a cost of approximately $700, every three years.

In our brief meeting with Dr. Arrieta, we learned that the new collection center will be built in close proximity to an agricultural farm, which provides a disposal option for the center's wastewater. Dr. Arrieta also explained that the Costa Rican agricultural soil is generally acidic. Detergents, on the other hand, are alkaline, and therefore would help to neutralize the soil and promote growth. Hence, if a type of detergent, either conventional or biodegradable, were chosen as the cleaning agent, its eventual disposal onto the fields would be beneficial. Biodegradable detergents would most likely be the best option in this case, as they would fully degrade in a period of seven days. Conventional detergents, as well as residues left in the wastewater from the rinsing of household detergent bottles, may pose threats to the soils, such as buildup. However, a holding tank could further enhance this option by allowing the wastewater contaminants to settle for a given period of time before their disposal on the fields. With the use of a holding tank, the hazard posed by conventional detergents or residues could be eliminated. Ultimately, this disposal technique would be the least costly, since the only required equipment would be the plumbing and irrigation system, and possibly a holding tank.

Unfortunately, it will not be possible to recommend one specific wastewater treatment or disposal process before the completion of our project on July 3, 2000, since the collection center will not be in operation at this time. In order to recommend a specific process, it is necessary that the Santa Ana collection center be in full operation in order to determine the peak quantity and overall quality of the wastewater generated by the center. Therefore, we have provided a series of questions that can be used to evaluate these factors and aid in the selection of an appropriate wastewater treatment method (see questions in Appendix I).

The first factor that must be considered is the available space surrounding the collection center. Man-made treatment ponds, for example, require far more space than a septic system because the ponds are entirely above ground and must be of a specific surface area to allow for adequate exposure to the aforementioned natural environmental processes.

Another factor that will contribute to the determination of necessary space is peak water quantity, which is the greatest volume of water that a facility will generate at any given time. It is necessary to consider peak water quantity, rather than average water quantity, in order to account for the "worst case scenario." This value will be used to ascertain an appropriate volume, which prevents back up or overflow, for either treatment system. Additionally, the required holding time for the wastewater affects the necessary volume. If a biodegradable detergent, for example, is the chosen cleaning agent, the required holding time must be at least seven days to allow for full degradation of the detergent. Therefore, the volume of the system must be able to accommodate the accumulation of at least seven days worth of wastewater.

Water quality and composition is the third factor that must be considered, as the specifics of any treatment system are designed according to this factor. For example, the length of treatment ponds and the number of filtering tanks vary depending on the quantity of suspended solids in the wastewater. When the quantity of suspended solids is large, it is necessary to use ponds of greater length to allow adequate settling time. Similarly, under the same conditions, a septic system requires a greater number of filtering tanks to ensure complete filtration for a septic system. On the other hand, the number of treatment ponds and the volume of the settling tank vary in accordance with the quantity of non-suspended solids in the wastewater. A large quantity of non-suspended solids necessitates a greater number of treatment ponds and a larger settling tank, as well as more frequent sludge removal for either system.

The final contributing factor is the cost of each system. The allotted budget and available funding will ultimately determine which processes are financially feasible for the Santa Ana collection center. Simply stated, if there are not enough financial resources for a particular treatment system, that system cannot be installed at the center.

4.9 Compacting and Transport of Plastics

In speaking with Dr. Arrieta, we learned that the Santa Ana collection center is hoping to purchase a used compactor from an incineration plant in Cartago, Costa Rica. This acquisition will be extremely beneficial to the collection center since compacting the plastics can decrease their volume significantly. The compaction of plastics will not only conserve space within the collection center, but it will also reduce transportation costs. The owners of *Gente Reciclando*, in fact, noted that transportation is one of the greatest costs in the overall recycling process. With the exception of cleaned gallon-sized post-consumer plastic bottles purchased individually by hardware stores, secondary markets buy plastics by weight rather than volume. Thus, when plastics are compacted, more weight can be transported, and therefore purchased, per delivery.

Gente Reciclando is willing to pay more for semi-processed plastics if delivered directly to their facility. This, however, may not be the most profitable choice for the collection center. If the total transportation costs of the collection center, including gas, labor and truck upkeep, exceed the additional price paid by the secondary market, then profits will be negligible. In this case, it would be more profitable for the collection center to avoid transportation costs and to accept the lower price paid by *Gente Reciclando* or another purchaser willing to pick up these recyclables from Santa Ana.

Finally, in a subsequent meeting with Ms. Soto and Mr. Molina of *Gente Reciclando*, we found that clean, weather-resistant fabric sacks are used by their business to store and transport plastics. They purchase these sacks from industries that would otherwise discard them. Each reusable sack contains, on average, 4.5 cubic meters of storage space, and costs approximately five hundred colones ($1.66). Most importantly, these sacks keep cleaned plastics dry and protected from recontamination during storage and transportation.

4.10 Further Processing and Secondary Marketing of Plastics

Following transportation to marketing and secondary processing facilities, the cleaned plastics from the Santa Ana collection center will either be shredded or reused intact.

The owners of *Gente Reciclando* have stated that they are interested in purchasing all types of cleaned and separated post-consumer plastics from the collection center. At their facility, *Gente Reciclando* will shred, package, and market the cleaned plastics for secondary purchasers. These buyers are located in Costa Rica and Central America, as well as throughout the globe. In order to boost and ensure current demand, *Gente Reciclando* considers the quality of recycled plastics as an important factor for gaining market confidence. In the future, the company will consider implementing a method of testing plastic cleanliness, or a secondary washing process if necessary to assure high quality products.

Currently, *Gente Reciclando* operates on one shift per week, consisting of six eight-hour working days. Under these conditions, they presently process twenty to twenty-five tons of plastics per month. Hoping to accommodate post-consumer plastics, the company plans to add a second shift to allow for the processing of forty to forty-five tons of plastic per month. The company, in addition, plans to relocate to a facility twice as large, by September 2000, as well as to hire up to three additional employees.

Adriana Soto and Jonathon Molina of *Gente Reciclando* furthermore explained the financial details of the recycled plastic industry. The company presently pays thirty to fifty colones ($.10-$.15) per kilogram of post-industrial plastics, and would pay the same for clean post-consumer plastics. Processing costs between thirty and forty colones per kilogram, and the company is able to sell each kilogram of its processed flakes for one hundred twenty-five colones. This generates a profit of up to sixty-five colones per kilogram. Moreover, secondary purchasers ordinarily must pay two hundred to three hundred colones for each kilogram of virgin plastics. The purchase of recycled plastics, which *Gente Reciclando* attests to be of the same quality as virgin plastics, therefore, represents a savings of fifty percent.

While *Gente Reciclando* is interested in clean post-consumer plastics of all types, *Panamco* currently accepts un-processed post-consumer PET. Upon arrival at the facility, the plastics are shredded with their caps and labels intact. Cap flakes, which are composed of a plastic type different from that of the PET bottles, are then separated from the PET flakes. A machine that generates an air current performs this separation, selecting different plastic types by their densities. Since contaminants, labels and adhesives are still attached to the plastic flakes, they cannot be melted and molded into pellets. Therefore, these flakes are marketed to buyers in the United States and China, who use these impure PET flakes as additives to concrete or plastic lumber.

Despite these impurities, secondary purchasers in the United States and China pay *Panamco* approximately twenty-five colones ($.09) per kilogram for this post-consumer PET. *Panamco*, however, experiences a loss, as it pays one hundred colones ($.33) for un-processed PET. This does not include transportation costs, since *Panamco* picks up these plastics from municipal collection centers. As *Gente Reciclando* explained, it is important to note that while *Panamco* accepts all post-consumer PET bottles, they pay only for those originally housing *Coca-Cola* products.

Recco, a plastics marketing consulting company, of which *Panamco* is a primary client, locates buyers for recycled plastics. Max Thompson of *Recco* explained that, to date, the company only works with post-industrial plastic markets. Mr. Thompson noted, however, a future interest in locating markets for the Santa Ana collection center, as it will be the first in Costa Rica to offer clean post-consumer plastics.

While the previously mentioned companies are interested in marketing shredded post-consumer plastics, hardware stores provide an additional market for clean, un-shredded, and un-compacted gallon jugs. *Gente Reciclando* explained that these stores use the jugs for a variety of purposes, including the storage or sale of nails, bolts, paint, turpentine, etc. We called five hardware stores in the Santa Ana region to inquire about this practice, and have compiled a list of these companies, including contact information, that is shown in Appendix J. Three of these contacted stores currently do, or are willing to purchase gallon jugs, provided they are thoroughly clean and delivered by the collection center. *Ferretería San Joaquín*, which is located directly in Santa Ana, will pay twenty colones for each clean gallon jug. *Ferretería del Centro S.A.* and *Ferretería Solis*, both located in Escazu, will pay twenty-five colones and fifteen colones per gallon, respectively. Additionally, *Ferretería Solis* will accept clean liter jugs for ten colones each.

It is impossible at this time, without knowing the specifications of Santa Ana's forthcoming collection truck, to calculate the exact cost of transportation to any of these three hardware stores. While *Ferretería del Centro S.A.* will pay five more colones per gallon container than *Ferretería San Joaquín*, it may be more profitable to sell the plastics at the latter hardware store, as it is a shorter transportation distance. These costs must be carefully calculated once the truck arrives.

4.11 Conclusion

In summary, we have learned that the majority of Santa Ana residents surveyed are willing to recycle and that a public education campaign on recycling is currently underway. Furthermore, we compared our findings of the current collection practices to alternative methods, which may improve collection in the future. We also have presented a variety of processing techniques, both manual and automated, along with their respective advantages and disadvantages. We have examined ways to facilitate the washing process, as well as specific cleaning agents, such as microorganisms and biodegradable detergents, to be used in the process. Since the collection center has no plans for wastewater treatment or disposal, we next considered the possibility of using septic tanks, man-made treatment ponds and agricultural disposal. Finally, we discovered the importance of compacting plastics to maximize storage and transportation capacity, and identified *Gente Reciclando*, *Panamco* and hardware stores as profitable future markets.

The findings of this chapter are the basis for developing recommendations for the Santa Ana collection center. These recommendations reflect the issues analyzed in this chapter, more precisely: necessary public awareness, collection receptacles, the layout of processes, separation techniques, preparation to facilitate washing, washing methods, wastewater analysis and treatment, compacting, transport specifics, and profitable secondary markets, for the Santa Ana collection center. Furthermore, we have consulted Chapter Two, specifically sections regarding Costa Rican wastewater regulations, detergents, microorganisms, and recycling processes. This consultation was beneficial as it complemented our data and analyses, providing a more thorough foundation for the development of our recommendations.

Chapter 5. RECOMMENDATIONS

5.1 Introduction

The recommendations in this chapter reflect both the analysis of the data presented in the previous chapter as well as the background information that was collected in the United States and Costa Rica. These recommendations served as a basis for creating a concise recommendations manual, written in both English and Spanish, which can be found in Appendices K and L respectively. This manual was made accessible to CICA and the Santa Ana municipal collection center for the purpose of guiding its pilot plastics recycling program. Additionally, many of these recommendations were presented to the management and employees of the Santa Ana collection center in the form of a workshop.

Tracing the entire process chronologically, we begin with suggestions for the improvement of plastics collection as well as public collaboration with the program, based upon survey findings and our background studies in this area. We then explain an appropriate sequence of processes, and propose recommendations for equipment allocation, to aid in preparing post-consumer plastics for washing at the center. Based upon our study of different cleaning agents and washing methods found in the background information, our microorganism experimentation at UCR, and data gathered from interviews with Dr. Arrieta, Ms. Umaña, Ms. Soto and Mr. Molina, we propose the most appropriate washing procedure for the Santa Ana program. Moreover, the recommendations for a washing procedure rely also on the findings and suggestions regarding all stages of the plastics recycling process, which both affect and are affected by the washing method. The treatment of wastewater resulting from the cleaning process is a primary example of this relationship. From the study of different wastewater treatments, we have learned that the collection center must calculate a number of factors pertaining to the composition and quantity of their wastewater before an appropriate treatment can be chosen. Thus, we next provide a list of these specific factors, as well as recommendations for later selecting a treatment method once the calculations are complete. Finally, we address the link between the collection center and secondary processors and markets, based upon those we have located and contacted in Costa Rica.

5.2 Public Awareness

Currently in Santa Ana, there is an educational campaign concerning recycling that is led by UCR students. Our data support the need for this campaign. Table 4-1, in fact, shows that seventy percent of Santa Ana residents do not know or are unsure of the existence of a recycling program in the city. We further recommend that this campaign continue in order to promote and evaluate the success of the pilot-recycling program.

This educational campaign should also stress the importance of washing plastics before they are set aside for collection. Additional data in Table 4-7 show that only 7.1 percent of residents were unwilling to wash plastics before placing them in collection receptacles. Therefore, if encouraged, it is likely that most residents will comply and wash their plastics.

5.3 The Collection of Recyclables

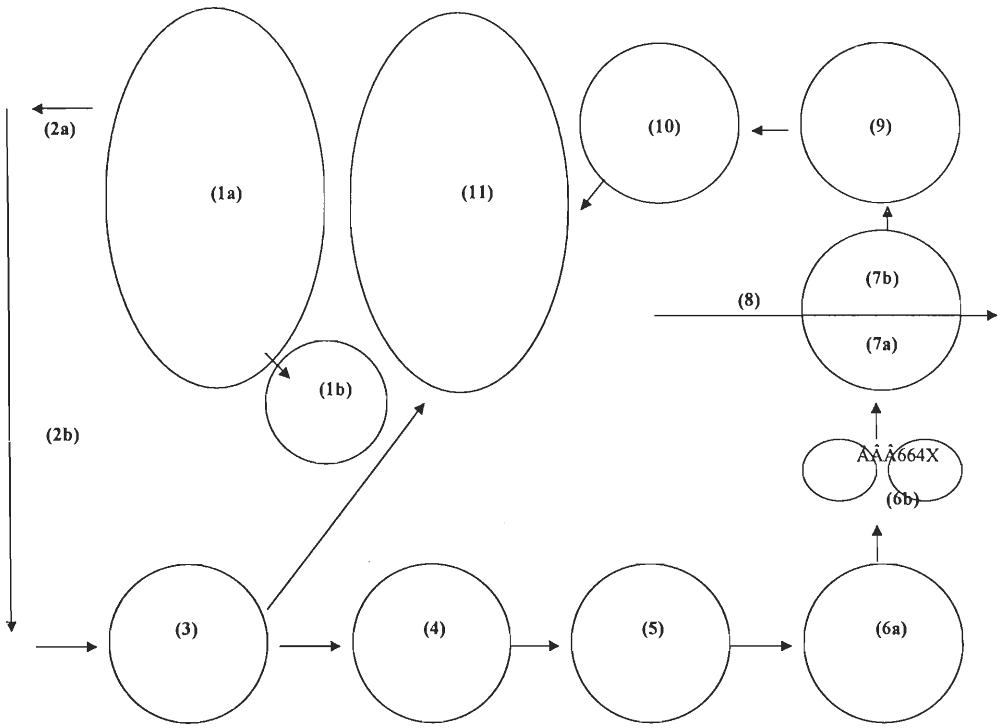
Since the Santa Ana municipality has already devised a collection schedule and purchased a truck, it was not necessary to further investigate and make recommendations regarding these factors. We did, however, explore the choices of collection containers and have concluded upon what is best for the preliminary stages of the program, as well as for the future.

We recommend that during the early stages of Santa Ana's recycling program, commingled recyclables be collected from the curb in plastic bags. Paper products, meanwhile, should not be mixed with the commingled recyclables, but rather collected in a bundle of their own. Paper should be collected separately for two reasons: first, to prevent it from becoming soiled by contaminants left on other recyclables, and second, to prevent further complications in the sorting process, as paper often adheres to other materials.

Plastic bags were used for commingled recyclables in past programs, which failed not because of a lack of participation due to an inconvenient receptacle, but because the collection truck broke down. Presently, a mixture of recyclables and MSW is collected using plastic bags. Therefore, the same amount of bags as currently used should be sufficient to house MSW and recyclables, when separated. Homeowners will not encounter any additional costs in abiding by the collection guidelines and separating recyclables from MSW. Furthermore, the use of a familiar and economical receptacle will promote public participation in the recycling program.

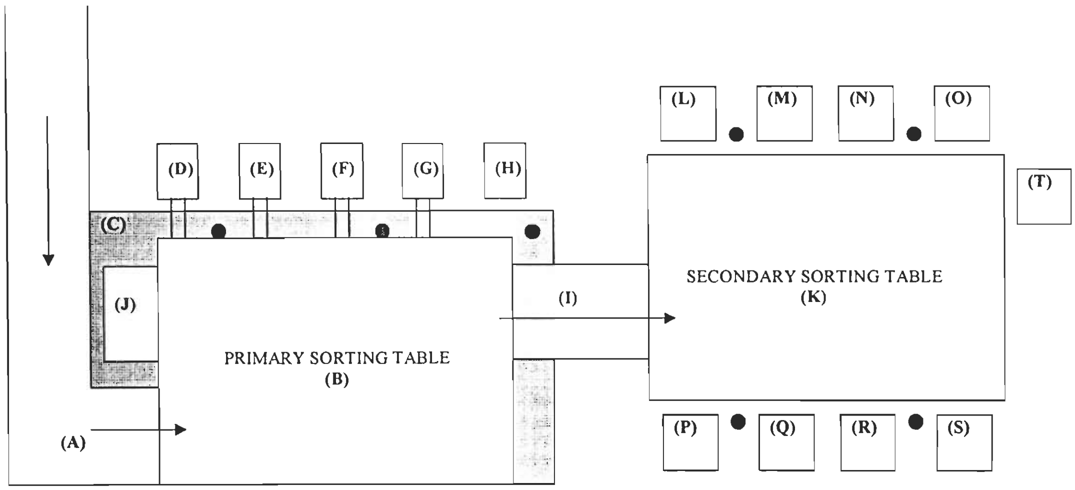
As evidenced in data from both the United States and the United Kingdom, there is a substantial increase in participation when durable, reusable bins are distributed within

Figure 5-1. Proposed Layout for New Collection Center



(1a)	Storage of commingled recyclables collected from Santa Ana
(1b)	Removal of paper products inadvertently mixed with commingled recyclables
(2a)	Wheelbarrow transport of commingled recyclables to primary sorting table
(2b)	Ramp leading from the commingled recyclables pile to the top of the primary sorting table
(3)	Primary sorting table - see Figure 5-2 and Table 5-2
(4)	Secondary sorting table – see Figure 5-2 and Table 5-2
(5)	Temporary storage of sorted plastics
(6a)	Removal of caps, rings and labels
(6b)	Sorting of plastics according to water solubility
(7a)	Plastics washing area
(7b)	Plastics rinsing area
(8)	Disposal of wastewater for treatment
(9)	Screen drying racks with pegs and fans
(10)	Plastics compacting area
(11)	Storage of compacted plastics and other sorted recyclables

Figure 5-2. Diagram of Proposed Sorting Tables



* note: dark circles represent workers

(A) Ramp leading from commingled recyclables pile to level flush with primary sorting table
(B) Table for sorting of recyclables by material
(C) Raised cement platform, approximately 60 centimeters in height, holds primary sorting table, three workers and trash bin
(D) Storage bin for clear glass, attached to table by chute
(E) Storage bin for colored glass, attached to table by chute
(F) Storage bin for aluminum, attached to table by chute
(G) Storage bin for tin, attached to table by chute
(H) Storage bin for plastic film, not attached to table
(I) Wide chute for plastics, leading to secondary sorting table
(J) Trash bin for cleaning of primary table
(K) Table for sorting of plastics by type
(L) Storage bin for *Coca-Cola* PET (type #1)
(M) Storage bin for other PET (type #1)
(N) Storage bin for natural HDPE (type #2)
(O) Storage bin for colored HDPE (type #2)
(P) Storage bin for PVC (type #3)
(Q) Storage bin for solid LDPE (type #4)
(R) Storage bin for PP (type #5)
(S) Storage bin for PS (type #6)
(T) Storage bin for other types (type #7, unidentifiable and hazardous)

5.5 The Separation of Plastics

Based upon the distribution of plastic types displayed in the grocery store findings, we have concluded that it is economical to recycle most, but not all plastic types. We were unable to locate any type #7 plastics during our grocery store visits, and therefore stress that these should not be separated into a category of their own, but rather placed among unidentifiable plastics to be discarded. The reason for such a decision is that this type is composed of mixed plastics and when melted and reused, does not form a pure plastic product. Type #4 rigid containers, which we found housing only *French's* mustard, should also be grouped with unidentifiable plastics. It is not practical for the Santa Ana collection center to recycle this type of plastic, due to its extreme scarcity.

Though much more abundant than type #4, PVC (type #3) is another plastic found in minimal quantities. However, recycling PVC at the Santa Ana collection center is justified, as secondary markets currently demand this plastic type in great quantities. Additionally, type #1 (including natural PET and colored PET), type #2 (including natural and colored HDPE) type #5 and type #6 should separated and further processed, as they are both prevalent in the consumer waste stream and demanded by future markets.

Due to the frequency of mis- or unnumbered plastic containers, we have provided a series of guideline in Table 5-1 that when followed, will help resolve this problem. We recommend that each employee be familiar with these guidelines to ensure proper separation of plastic types. Following these guidelines will not only guarantee accurate separation, but will reduce the number of unidentifiable plastics, thus increasing the total number recycled.

Table 5-1. Distinguishing Characteristics of Various Plastic Types

#	Abbreviation	Distinguishing Characteristics
1	PET	clear, small round indent on bottom, injection molded, no seams
2	HDPE (bottles)	natural- not clear, foggy yet transparent; white and colored- opaque, smells like candle when burned, no flame
	(bags)	clear, white and colored, makes a crinkling noise
3	PVC	clear, has seams
4	LDPE (containers)	opaque, pliable
	(bags)	clear, white and colored, makes no noise
5	PP	colored or clear- transparency level between PET and HDPE, not as pliable as LDPE
6	PS	opaque, cracks when bent, burns with a flame and turns black
7	Other	various types and characteristics

In order to accomplish this separation process with the resources available, we recommend that a series of sorting tables be used to first separate commingled recyclables by material, then to further separate plastics by type. As mentioned in the collection recommendations section, paper should be collected separately from commingled recyclables at the curbside. However, any paper products that have been inadvertently included with the commingled recyclables must continually be removed from the pile and placed in a designated storage receptacle. We recommend that simultaneously, an employee shovel commingled recyclables into a wheelbarrow that will be transported up a ramp ending at the same level as the first sorting table. At this point, recyclables will be dumped onto this raised table and sorted into six categories: clear glass, colored glass, aluminum, tin, solid plastic, and plastic film. Employees will guide all materials, except solid plastic and plastic film, down short chutes that lead to separate storage bins. Solid plastics will be guided down a wider chute that leads to the second sorting table. On the other hand, a chute should not be used for plastic film, which is flimsy and lightweight, as it is easier for workers to gather it directly from the table to place in a bin. After the materials are manually removed from the first sorting table, one of the workers will sweep any remaining trash, using a hand broom, into a barrel located at the side of the table.

While this report focuses on the recycling of rigid plastic containers, it important to note here that *Gente Reciclando* is willing to locate buyers for any plastic bags the collection center may receive. After these bags are handpicked from the sorting table, HDPE must then be separated from LDPE bags by using the identification methods explained in Table 5-1. In compliance with Ms. Soto and Mr. Molina's requests, these bags must be cleaned of any non-plastic materials, such as paper or masking tape. Thorough washing will not be necessary however, as this level of cleanliness is not demanded by plastic bag purchasers.

At the second sorting table, a team of workers will sort the solid plastics by type: *Coca-Cola* brand PET (type #1), other PET (type #1), natural HDPE (type #2), colored HDPE (type #2), PVC (type #3), PP (type #5), PS (type #6), and other types (type #4, type #7, unidentifiable, and hazardous). These plastic types will be placed in temporary storage bins to await further processing, or disposal, in the case of plastics categorized as "other." At the same time, many unmarked types may be salvaged by the collection center, using Table 5-1 as a reference guide for plastic identification. Additionally, the recommendation to separate *Coca-Cola* brand PET from other PET stems from our secondary market findings, and will be discussed in section 5.9.

5.6 The Preparation of Plastics

Following sorting, plastic bottles and containers will then be prepared for the washing process by the removal of caps, rings and labels. Given the present financial situation at the Santa Ana collection center, we recommend that this removal process be executed by hand. First, employees will unscrew and discard caps, along with the plastic rings, which can be removed with wire cutters. The caps must then be placed aside to later be rinsed and stored for transport to *Gente Reciclando.* Next the workers will cut, peel and remove the label material from the plastics' surfaces. We recommend using a knife or razor that has been chosen and approved by the collection center's management. To this extent, the management will take special care in selecting workers to operate this station, which involves the use of sharp instruments, since safety is a primary concern at the center. Because it is difficult to remove label material with scraping alone, we recommend that the plastics successively be soaked in a hot water bath. Employees, however, must take special care to not fully submerge plastics in the bath, as contaminants from the inner surfaces may remain in the water and soil the remaining plastics that are later soaked in it. The employees will then perform a preliminary scraping of the softened labels.

In the future, the Santa Ana collection center may find it beneficial to purchase an automated label and adhesive removing machine, such as that which *Panamco* currently uses. The machine would increase efficiency in this preparation step, which without the machine, will most likely require the greatest time and labor investment in the center's scheme of recycling processes. Additionally, this machine achieves a consistent level of label and adhesive removal, a factor that will heighten consumer confidence in secondary plastic products. This machinery requires two workers for operation and when purchased new, costs approximately three million colones ($10,000).

To further prepare the plastics for washing, we originally believed that plastic bottles should be cut lengthwise to facilitate the cleaning of hard to reach inner surfaces. To accomplish this task, we considered using three types of stationary electric saws: table saws, bench saws and band saws. However, upon completion of our saw investigation, we determined that there are several reasons for which saws will not be appropriate in the Santa Ana collection center. The lack of extensive safety features presents a great risk to the collection center employees, as many of them are neither educated nor skilled in the use of such equipment. As previously mentioned, the management's great concern for safety explains why they are not willing to employ potentially risky machinery in order to increase facility efficiency. Additionally, some plastic bottles have a greater diameter than the cutting surface of the saws. Therefore, it would not be possible to cut completely through these bottles. A secondary bottle cutting technique would be necessary, thus incurring further labor, capital and time expenses.

Due to the abovementioned factors, we have concluded that the best option for the Santa Ana collection center is not to use saws for cutting the plastics. If in the future the collection center decides that a saw would greatly enhance the washing process, we recommend the use of a table saw equipped with the safety features outlined in the previous chapter. Although not as efficient, it is possible to wash the whole bottles by using specially designed faucets and flexible wash brushes. This technique is explained in greater detail in the following section, which describes the washing process.

The plastics will, however, need to be further separated into two bins by the solubility of the products originally housed within them, according to the contents of Table 4-11, before they can be washed. This final sorting phase is the last preparation step that will occur at the label removal station before the employees transfer the plastics to the washing and rinsing area.

5.7 The Washing, Rinsing and Drying of Plastics

Inevitably, portions of labels and adhesives will remain on a significant number of plastics, even after the preliminary scraping procedure. Based on the results of our experimentation, we recommend that, as the first step of the washing station, employees use baking soda in a solution of water with an abrasive sponge to fully clean the plastic surfaces of these remnants. The solution need not be rinsed from the plastic surfaces at the time the adhesives are removed, as the entire container will be rinsed in the subsequent process. It is important, however, that containers housing water-soluble products not be mixed with those housing non-water-soluble products during this step.

Following this procedure, employees standing on one side of the washbasin will rinse the inner and outer surfaces of all containers housing water-soluble contaminants only, using high-pressure water. There is no standard duration of rinsing time for the containers. Each container, however, must be rinsed until the contaminants cannot be detected by touch or sight. Meanwhile, employees standing on the other side of the wash basin will wash the remaining containers housing non-water-soluble contaminants, using high-pressure water, a biodegradable detergent, and if necessary, flexible wash brushes.

We suggest that the collection center obtain two types of nozzles to allow for variations in water pressure and direction. The first type will be used to clean bottles, and must therefore be narrow, in order for it to pass through the neck of each type of bottle and to allow for drainage from the neck during the washing procedure. The nozzle will be porous so it can direct water in all directions inside the bottle. We recommend that the collection center use a standard kitchen nozzle as the second type to wash open containers such as butter tubs.

For a number of reasons, we do not recommend that microorganisms be used to wash the plastics. All gathered information identified the cultured microorganisms as human pathogens. Because the processes at the Santa Ana collection center will be performed by hand and skin contact with the washing agent is inevitable, pathogenic bacteria cannot be used. Consequently, using these bacteria would require a bioreactor or other type of machinery, which is too complex for the collection center, which favors manual labor.

We recommend that the collection center's management contact Dr. Obando (see Appendix I) to determine the name, cost, chemical composition and other specifications of the biodegradable detergent he suggested, as he was unable to supply these data at the completion date of this report. Biodegradable detergents are ideal because, by definition, they degrade within seven days of application, and do not contain hydrocarbon solvents, acids, terpines, or other toxic chemicals. After employees wash these containers to the same level of cleanliness described above, we recommend they rinse them in a manner comparable to containers housing water-soluble products.

Upon completion of the rinsing process, a worker will then place the containers on racks to dry. These racks will consist of several levels of screen trays, among which pegs will be evenly spaced for the stabilization of the overturned bottles. A number of fans will be strategically placed throughout the levels to increase airflow and accelerate the drying process. We further recommend that the drying area be well ventilated, but at the same time, separated from other areas of the collection center to prevent plastic re-contamination.

5.8 Wastewater Treatment and Disposal

As noted in Chapter Three, it is not possible to recommend one specific method for the collection center's wastewater treatment and disposal at this time. Since the new collection center is not yet built or in operation, the exact composition and peak quantity of wastewater must be calculated once the facility is in use. Additionally, the precise amount of available space surrounding the center, both above and below ground, is also yet undetermined.

Despite these variables, we believe that disposal of the wastewater onto the nearby agricultural fields will be the best option for the collection center. This method will benefit both the collection center, as it provides an inexpensive treatment and disposal option, and the nearby agricultural farm. Since biodegradable detergents are the recommended cleaning agent, their alkalinity will aid in neutralizing the acidic soil. The organic compounds left in the wastewater by the rinsed contaminants will provide a source of nutrients in the soil for the vegetation as well.

This recommendation relies on a number of conditions, as we are unable to determine the need for a holding tank without knowing the make-up of the wastewater. One particular concern is that the concentration of non-biodegradable chemicals that have been rinsed from post-consumer plastic detergent bottles may be hazardous to the environment. For this reason an expert must be hired to perform an analysis of the wastewater composition in the presence of a biodegradable detergent. Should any levels be found unacceptable, the center must then determine whether a holding tank or other treatment, as outlined in our wastewater findings, must be installed before this water can be disposed on the agricultural fields.

5.9 Compacting and Transport of Plastics

Once the clean plastic containers have thoroughly dried, we recommend they be placed into clean storage sacks, maintaining separation by plastic type, to await compacting. These sacks may be used also to later transport the plastics to purchasers. The Santa Ana collection center should obtain a compactor, either as arranged from the incineration plant in Cartago, or elsewhere if necessary. The compaction of plastics will benefit the center by maximizing storage space within the facility, as well as the amount of plastics that may be transported.

Gente Reciclando is willing to pay more for semi-processed plastics if they are delivered directly to their facility. However, the collection center must determine whether or not this is the most profitable option. We recommend that once the collection truck arrives, the management examine the truck's specifications and calculate the total cost of transport per kilogram of plastic. This value should then be compared with the additional price *Gente Reciclando* will pay for delivered plastics. If the total cost of transport per kilogram exceeds the extra payment offered for each kilogram of plastic, the center's profits will be decreased. In this case, we recommend that the center accept the lower price which *Gente Reciclando* is willing to pay if the company itself has to retrieve the plastics from the Santa Ana collection center.

Panamco, on the other hand, prefers to recover the plastics itself and does not offer the option of paying a higher price for the collection center to deliver the plastics. Meanwhile, all the contacted hardware stores, require that the collection center deliver the plastic gallon jugs directly to their store. In contrast to *Gente Reciclando*, hardware stores demand that the jugs not be compacted, thus reducing transport capacity and incurring greater costs to the collection center. As these two markets have specific requirements regarding the transport of post-consumer plastics, compliance with these requests is recommended.

5.10 Further Processing and Secondary Marketing of Plastics

In the initial stages of Santa Ana's program, we recommend that the clean post-consumer plastics be marketed to the three above-mentioned purchasers: *Gente Reciclando, Panamco* and various hardware stores (see Appendix I for contact information).

Specifically, quality gallon jugs, such as those without dents or other damages, should not be compacted but rather, separated and marketed to hardware stores. This practice is very profitable, as hardware stores are willing to pay between fifteen and twenty-five colones per jug. This amount is equivalent to what *Gente Reciclando* will pay for a half kilogram of plastic.

Coca-Cola brand PET, additionally, should be separated from other plastics at the secondary sorting table, as mentioned in section 5.5, bypass all other processes, and be marketed to *Panamco*. We recommend this distinct separation even though it requires added effort at the separation table, which will be compensated for, as subsequent processing is not necessary. Furthermore, *Panamco* will pay one hundred colones per kilogram ($0.33), double that of *Gente Reciclando*, to pick up this unwashed, unprocessed PET. This higher offer makes this procedure very profitable for the collection center. All post-consumer PET should not be marketed to *Panamco*, however, since the company will not pay for PET bottles formerly housing products other than those of *Coca-Cola* brand.

Finally, we recommend that all other plastics, those not marketed to hardware stores or *Panamco*, be sold to *Gente Reciclando*. They are looking to accept all plastic types and will pay a reasonable price, approximately thirty to fifty colones per kilogram ($0.09-0.15), for clean post-consumer plastics.

5.11 Conclusion

As noted in the introduction to this section, the above-described recommendations were reformatted as a manual to provide convenient reference for CICA and the Santa Ana collection center. The manual presents this information in a direct and visual manner to clearly guide the post-consumer plastics recycling program.

Furthermore, we have collaborated with *Gente Reciclando* to direct a workshop at the collection center that addressed the importance of the pilot program to the community and to Costa Rica. One purpose of this workshop was to illustrate to the workers the significance and meaning of their role in achieving the country's first complete post-consumer plastics recycling system. At the workshop, we also described techniques for separation and basic washing to supplement the manual with hands-on experience. Both the manual and the workshop thus contribute to the realization of the sustainable recycling program that was formulated in this chapter for CICA and the Santa Ana municipality.

Chapter 6. CONCLUSIONS

At the onset of this project, Dr. Arrieta of CICA presented us with his concern for the development of a washing technique, specifically the use of microorganisms. The goal of developing this technique was to eliminate the need for traditional detergents, which contaminate wastewater. Our research, found in Chapter Two, explores several cleaning agent options including microorganisms and biodegradable detergents. We soon discovered, however, that the complexity of the post-consumer plastics problem stretches far beyond the washing process alone. The type of cleaning agents used, for example, determines which type of wastewater treatment is necessary. Additionally, the level of cleanliness is determined by the demand of secondary purchasers. In response, we expanded our preliminary research and began to draw connections between these phases, in essence, tracing the lifetime of consumer plastics. Once in Costa Rica, we furthermore realized that it was critical to consider an individual community's particular resources, needs and constraints when implementing a solution, as advanced recycling technology is not always appropriate in every situation. With this in mind, we referred once again to our background information, then gathered and analyzed data to determine the most appropriate and practical program for Santa Ana.

In Santa Ana, we found the residents to be knowledgeable about recycling and its benefits. At the same time, the community seemed in need of clarification regarding the municipal collection schedule and current state of the recycling program. While the collection center has expressed enthusiasm for reinstating its recycling program and adding all varieties of post-consumer plastics to its collection scheme, it nevertheless has extremely limited financial resources to invest in recycling equipment. At the same time, we realized that it is, in fact, a unique and very efficient facility, endowed with a sizeable staff of fifteen young adults. These workers, all members of a community program that provides activities for citizens with disabilities, work together to manage the many tasks at the collection center.

For this reason, we reevaluated our findings from the United States in order to provide recommendations that emphasize manual, rather than automated processes. In doing so, we carefully considered each type of plastic that might enter the facility as well as each type of contaminant that may arrive adhered to these plastic surfaces on a case-by-case basis. Surprisingly, the separation and processing performed by hand at this small-scale level were actually far more complicated than any technological system previously studied. One of the most significant challenges we encountered was the collection center's lack of plans for wastewater treatment. By understanding the relationship between the washing process and the generation of wastewater, we were able to recommend the steps necessary to determine the most effective wastewater treatment method for the center. Thus, one outcome of our proposal will be the prevention of contaminant transfer from the plastics to natural bodies of water.

Our findings are presented in the form of a manual that concisely describes our recommendations for the collection center, including the aforementioned study of wastewater treatment. This manual displays our results and recommendations in a highly accessible manner for both CICA and the Santa Ana municipality. Additionally, it can serve as a future reference for communities and organizations in Costa Rica seeking to establish similar programs. On one hand, our recommendations are specific for the Santa Ana community. Yet the organization of our study, which traces all aspects of the recycling process, reflects a general model for the development of such programs by any community or organization.

Additionally, we were able to test the effectiveness of our recommended techniques through a workshop we co-developed with *Gente Reciclando*'s assistance. The collection center's employees watched carefully as we explained how to identify and prepare post-consumer plastics for recycling. As explained in the workshop summary found in Appendix M, this experience was met with enthusiasm, from both the collection center staff and our project team as well. Its success not only illustrated the appropriate nature of techniques found in the Recommendations Manual, but also provided a connection between our study and the people who will be affected by it on a daily basis.

While all recommendations have been based upon the careful analysis of gathered data and preliminary background information, we also recognize the limitations of our findings. Due to the relatively short length of our study, we were unable to conduct adequate research on using microorganisms to clean plastics, or to determine the feasibility of their use at the collection center. Our preliminary research, however, indicates that in the future, bioremediation, the use of microorganisms, may prove to be a cost-effective and environmentally friendly alternative to the use of biodegradable detergents. In response, we strongly urge that our project be used to guide further research in the engineering of a washing system that uses microorganisms.

Overall, our project illustrates the development of creative and practical solutions to the complicated problem of plastic recycling, by balancing the use of technology with the specific needs and resources of a given community. Most importantly, by using the provided recommendations, the Santa Ana collection center will become the first in Costa

Rica to prepare cleaned post-consumer plastics for secondary markets. It is our hope that this experience will establish a strong precedence for future recycling endeavors throughout the country.

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APPENDICES

Appendix A: Mission and Organization of CICA

The Centro de Investigacion en Contaminacion Ambiental (CICA) is a research center, founded in 1982, that operates in conjunction with the University of Costa Rica in San Pedro. For the past seventeen years, CICA has been utilizing a variety of techniques for investigating and analyzing environmental pollution. Their technical instruments are currently among the most advanced in the country. CICA's mission is to contribute scientific information that will assist in eliminating the destruction of the natural environment. The organization specifically focuses on the investigation of water quality, atmospheric emissions, and the chemistry of pesticides. Its team consists of forty researchers including physicists, chemists, biologists, toxicologists, pharmacologists, chemical engineers, and microbiologists.

CICA receives its financial support from three different sources. The university's administration provides a small amount of funding for some of CICA's projects. Another source of funding is from consulting "services" within the country, such as chemical analysis and sampling. The final contributor of financial support is the national and international institutional organizations to which CICA directs much of their research and project efforts. Some of these include the Inter-American Development Bank, the National Organization of Atomic Energy, the Pan American Health Organization, the United Nations Development Program, the Institute of Municipal Promotion and Advisory, and the National Service of Underground and Irrigation Waters.

Currently, CICA is involved in several projects that pertain to the recycling of specific waste products, such as plastics, and the composting of biodegradable waste.

Within this organization Doctor Ronald Arrieta and Doctor Milton Alvarez, our project liaisons, are involved in two different areas of waste management, the organic waste program and the air pollution program, respectively. In addition to their contributions within their specified departments, they are also responsible for overseeing many community and university projects related to waste management, such as this project. Our study relates to CICA's mission because as plastics recycling becomes more convenient and efficient, fewer plastics will be dumped into landfills or incinerated, and fewer byproducts from the recycling process will pollute the environment.

Appendix B: Supplemental Wastewater Regulation Tables

Table 2: Minimum Frequency of Sample and Analysis for Residual Waters of the Ordinary Type

Parameter	Volume of Flow (cubic meter/day)		
	< 50	50 to 100	> 100
pH, Sedimental Solids and Volume of Flow	Monthly	Weekly	Daily
Fats and Oils	Annualy	Biannually	Triannually
Biochemical Oxygen Demand			
Total Suspended Solids			
Fecal Coliform			

Table 6: Maximum Allowable Limits for the Dumping of Residual Waters in Bodies of Water

Parameter	Maximum Limit	Parameter	Maximum Limit
Fats/oils	30 mg/l	Dissociable cyanide in weak acid	0.5 mg/l
Potential hydrogen	5-9 mg/l	Copper	0.5 mg/l
Temperature	15°C < T < 40°C	Lead	0.5 mg/l
Sedimentary solids	1 ml/l	Tin	2 mg/l
Floatable material	Absent	Phenols	1 mg/l
Mercury	0.01 mg/l	Nickel	1 mg/l
Aluminum	5 mg/l	Zinc	5 mg/l
Arsenic	0.1 mg/l	Silver	1 mg/l
Barium	5 mg/l	Selenium	0.05 mg/l
Boron	3 mg/l	Sulfites	1 mg/l
Cadmium	0.1 mg/l	Sulfides	25 mg/l
Residual chlorine	1 mg/l	Fluorides	10 mg/l
Color	50	Amount of organic phosphate compounds	0.1 mg/l
Chromium	1.5 mg/l	Amount of carbonates	0.1 mg/l
Total cyanide	1 mg/l	Amount of organic chloride compounds	0.05 mg/l
Free cyanide	0.1 mg/l		
Free cyanide in the body of water, outside of the mixture area	0.005 mg/l		

Table 9: Maximum Allowable Limits for the Reuse of Residual Waters

Type of Reuse	**Parameters**	
	Biochemical Oxygen Demand (mg/l)	Fecal Coliform (1)
type 1	< or = 40	< 100
type 2	---	< 1000
type 3	---	< 100
type 4	---	< 1000 (2)
type 5	---	(3)
type 6 (4)	< or = 40	< or = 1000
type 7	< or = 40	---
type 8	---	< or = 100

Notes:

(1) The results for fecal coliform are reported in units consistent with the method of employed analysis.

(2) The irrigation should cease two weeks prior to the harvest.

(3) One should avoid the sheparding of milk producing livestock during the fifteen days following the finalization of irrigation. If this time period is not respected, the concentration of fecal coliform should not exceed 1000/100 ml.

(4) The residual water should not be a skin or eye irritant. The residual water should be clear, and should not present bothersome odors nor contain substances which are toxic upon ingestion.

(Costa Rica Department of Health, 1998)

Appendix C: Survey for Santa Ana Residents

Thursday, June 1, 2000

1. Is there a recycling project/program in Santa Ana?
   Yes No Not Sure

2. Do you recycle? (Group 1 version), Would you recycle? (Group 2 version)
   Yes No Sometimes

3. If not, why?

4. To what degree do you agree with the idea of recycling?
   Strongly Somewhat Don't Agree

5. What are the benefits of recycling?

6. What types of waste material can be recovered from the trash?
   Paper Tin Glass Aluminum Plastic Biodegradables Cardboard

7. Which waste material is the most contaminating to the environment?
   Paper Tin Glass Aluminum Plastic Biodegradables Cardboard

8. Why do you feel this material is the most contaminating to the environment?

9. Which waste material(s) in the trash do you personally find most repulsive and why?
   Paper Tin Glass Aluminum Plastic Biodegradables Cardboard

10. Knowing that plastics cannot be recycled when they are dirty, would you wash your plastic waste with soap and water at home before setting it aside for collection?
    Yes No Maybe

11. Would you teach others to recycle?
    Yes No Maybe

Appendix D: Response and Analysis of Supplementary Survey Questions

Question 5: What are the benefits of recycling?

Table A-1. Opinions Regarding the Benefits of Recycling

Opinion	Number of Responses	Percent of Responses
It is economically efficient	5	17.1
It allows for reuse and prevents waste	7	20.0
It makes the earth cleaner	19	54.3
It keeps waters clean	1	2.9
It keeps waste under control	2	5.7

As shown in Table A-1, the responses to Question 5 indicate that all Santa Ana residents who participated in the short interviews were familiar with the implications of recycling and were able to explain, to some extent, why it is useful. The thirty open-ended responses were grouped into five categories, four of which relate to environmental concerns. However, five of the thirty interviewees noted economic benefits of recycling as well.

Question 9: Which waste material(s) in the trash do you personally find most repulsive and why?

Table A-2. Summary of Responses to Question 9

Material	# of Responses	% of All Responses
Paper	5	8.0
Tin	6	9.7
Glass	10	16.1
Aluminum	5	8.1
Plastic	13	21.0
Biodegradable	16	25.8
Cardboard	7	11.3

Table A-3. Rationale for Responses to Question 9

Reason	% of Responses
None given	36.7
Cannot be reused	10.0
Not disposed of properly	6.7
Produces a bad odor (generally limited to biodegradable waste)	33.3
Dangerous (glass)	3.3
Takes up space	3.3
Contaminates water	3.3
Is ugly	3.3

Table A-2 shows that biodegradable materials, plastic and glass were the more frequently cited materials to be found the most displeasing in the trash. Biodegradable waste material, in particular, was selected because the respondents did not like the odor produced by decomposing trash. Overall, the answers shown in Table A-3 display that most residents are disgusted by materials left in the trash because they are contaminating to the environment or do not biodegrade.

Appendix E: Interview Questions for Liliana Umaña

Manager Santa Ana Collection Center
Thursday, June 1, 2000, 2:00pm

1. Please provide specific details on the new collection center, including size, capacity and financial resources available for separating/processing machinery.

2. What collection schedule will be followed once the new recycling program is instated?

3. What type of truck has the town purchased? What spatial capacity will it contain? What will its availability be, for example, to transport plastic longer distances to other processing facilities?

4. What increases do you expect for the influx of post-consumer plastics?

5. How effective has collection been in the past? What are your feelings on public cooperation?

6. What types of plastics are prevalent in Santa Ana's waste stream? Of these, which are desired for recycling?

7. At the new collection center, what water resources will be available? How costly is water usage in Santa Ana? Should washing be carried out at the collection center, to what extent would water be re-circulated or disposed? Where would wastewater be disposed?

8. Where separating, washing, and drying machinery do exist, to what extent is manual labor preferred at the collection center? Please explain more specifically how the new center will be staffed.

Appendix F: Interview Questions for Gente Reciclando

Wednesday, May 31, 2000, 9:00 am

1. What quantity of post-consumer plastics are you interested in or able to accommodate?

2. What specific types of post-consumer plastics do you plan on recycling?

3. To what degree must these plastics be separated before their arrival at your facility?

4. In what form (physical state, that is, crushed, whole, flaked, etc) will you accept post-consumer plastics?

5. How clean must these plastics be in order to process them at your facility?

6. How are plastics brought to your facility? Do you make pick-ups?

7. *Panamco* accepts and collects unwashed post-consumer PET at 100 colones per kilo. Would it be more profitable to wash PET and later market it from your facility instead?

8. Would you be willing to invest in the necessary machinery and carry out the washing process at the *Gente Reciclando* facility?

9. What markets do you envision for these plastics? Will they be adequate enough in order to upkeep long-term post-consumer plastic recycling in this region?

Appendix G: Santa Ana Recyclable Collection Schedule

Distinguished Management of Solid Waste
Plan of the Santa Ana Municipality and the University of Costa Rica

Recyclable Collection Days:

District	**Days**
Brasil and Piedades	2nd and 4th Mondays
Pozos	1st and 3rd Tuesdays
Uruca	2nd and 4th Wednesdays
Salitral, San Rafael and Santa Ana Centro	1st and 3rd Wednesdays

Materials	**Recyclable**	**Non-Recyclable**
Paper	newspaper, magazine, telephone book, computer paper, notebooks, cardboard	fax paper, napkins, carbon paper, toilet paper, wet or dirty paper or cardboard, Tetra Brik, Tetra Pak
Glass	bottles, window glass	thermometers, mirrors, light bulbs, florescent lights, ceramic dinnerware
Metal	aluminum cans, rinsed nails, screws, washers, metal tubes	dirty food cans
Plastic	drink bottles (rinsed)	plastic wrappers, dirty plastic

Appendix H: Microorganism Characteristics

Name of the Organism: Streptococcus spp.

The genus Streptococcus is comprised of Gram-positive (bacteria that retain the crystal violet stain when treated by Gram's method), microaerophilic cocci (round), which are not motile and occur in chains or pairs. The genus is defined by a combination of antigenic, hemolytic, and physiological characteristics into Groups A, B, C, D, F, and G. Groups A and D can be transmitted to humans via food.
Group A: one species with 40 antigenic types (S. pyogenes).

Group D: five species (S. faecalis, S. faecium, S. durans, S. avium, and **S. bovis**).

Name of Acute Disease: Group D: May produce a clinical syndrome similar to staphylococcal intoxication.

Nature of Illness/Disease: Group D: Diarrhea, abdominal cramps, nausea, vomiting, fever, chills, dizziness in 2-36 hours. Following ingestion of suspect food, the infectious dose is probably high (greater than 107 organisms).

Diagnosis of Human Disease: Group D: Culturing of stool samples, blood, and suspect food.

Associated Foods: Group D: Food sources include sausage, evaporated milk, cheese, meat croquettes, meat pie, pudding, raw milk, and pasteurized milk. Entrance into the food chain is due to underprocessing and/or poor and unsanitary food preparation.

Relative Frequency of Infection: Group A infections are low and may occur in any season, whereas Group D infections are variable.

Usual Course of Disease and Complications: Group D: Diarrheal illness is poorly characterized, but is acute and self-limiting.

Target Population: All individuals are susceptible. No age or race susceptibilities have been found.

Analysis of Foods: Suspect food is examined microbiologically by selective enumeration techniques which can take up to 7 days. Group specificities are determined by Lancefield group-specific antisera.

Selected Outbreaks: Group D: Outbreaks are not common and are usually the result of preparing, storing, or handling food in an unsanitary manner.

<u>Name of the Organism</u>: Miscellaneous enterics, Gram-negative genera including: Klebsiella, **Enterobacter**, Proteus, Citrobacter, Aerobacter, Providencia, Serratia These rod-shaped enteric (intestinal) bacteria have been suspected of causing acute and chronic gastrointestinal disease. The organisms may be recovered from natural environments such as forests and freshwater as well as from farm produce (vegetables) where they reside as normal microflora. They may be recovered from the stools of healthy individuals with no disease symptoms. The relative proportion of pathogenic to nonpathogenic strains is unknown.

<u>Name of Acute Disease</u>: Gastroenteritis is name of the disease occasionally and sporadically caused by these genera.

<u>Nature of Disease</u>: Acute gastroenteritis is characterized by two or more of the symptoms of vomiting, nausea, fever, chills, abdominal pain, and watery (dehydrating) diarrhea occurring 12-24 hours after ingestion of contaminated food or water. Chronic diarrheal disease is characterized by dysenteric symptoms: foul-smelling, mucus-containing, diarrheic stool with flatulence and abdominal distention. The chronic disease may continue for months and require antibiotic treatment.
Infectious dose--unknown. Both the acute and chronic forms of the disease are suspected to result from the elaboration of enterotoxins. These organisms may become transiently virulent by gaining mobilizeable genetic elements from other pathogens. For example, pathogenic Citrobacter freundii which elaborated a toxin identical to E. coli heat-stable toxin was isolated from the stools of ill children.

<u>Diagnosis of Human Illness</u>: Recovery and identification methods for these organisms from food, water or diarrheal specimens are based upon the efficacy of selective media and results of microbiological and biochemical assays. The ability to produce enterotoxin(s) may be determined by cell culture assay and animal bioassays, serological methods, or genetic probes.

<u>Associated Foods</u>: These bacteria have been recovered from dairy products, raw shellfish, and fresh raw vegetables. The organisms occur in soils used for crop production and shellfish harvesting waters and, therefore, may pose a health hazard.

<u>Relative Frequency of Disease</u>: Acute gastrointestinal illness may occur more frequently in undeveloped areas of the world. The chronic illness is common in malnourished children living in unsanitary conditions in tropical countries.

<u>Usual Course of Disease and Some Complications</u>: Healthy individuals recover quickly and without treatment from the acute form of gastrointestinal disease. Malnourished children (1-4 years) and infants who endure chronic diarrhea soon develop structural and functional abnormalities of their intestinal tracts resulting in loss of ability to absorb nutrients. Death is not uncommon in these children and results indirectly from the chronic toxigenic effects which produce the malabsorption and malnutrition.

Target Populations: All people may be susceptible to pathogenic forms of these bacteria. Protracted illness is more commonly experienced by the very young.

Food Analysis: These strains are recovered by standard selective and differential isolation procedures for enteric bacteria. Biochemical and in vitro assays may be used to determine species and pathogenic potential. Not being usually thought of as human pathogens, they may easily be overlooked by the clinical microbiology laboratory.

Selected Outbreaks: Intestinal infections with these species in the U.S. have usually taken the form of sporadic cases of somewhat doubtful etiology.
Citrobacter freundii was suspected by CDC of causing an outbreak of diarrheal disease in Washington, DC. Imported Camembert cheese was incriminated.

Source:

U.S. Food & Drug Administration
Center for Food Safety & Applied Nutrition
Foodborne Pathogenic Microorganisms
and Natural Toxins Handbook, 2000

Pseudomonas aeruginosa is the epitome of an opportunistic pathogen of humans. The bacterium almost never infects uncompromised tissues, yet there is hardly any tissue that it cannot infect, if the tissue defenses are compromised in some manner. *Pseudomonas aeruginosa* is a Gram-negative, aerobic rod, belonging to the bacterial family *Pseudomonadaceae*. The family includes *Xanthomonas*, which together with *Pseudomonas*, comprise the informal group of bacteria known as Pseudomonads. These bacteria are common inhabitants of soil and water. They occur regularly on the surfaces of plants and occassionally on the surfaces of animals. The pseudomonads are better known to microbiologists as pathogens of plants rather than animals, but three *Pseudomonas* species are pathogens of humans.

Pseudomonas aeruginosa is an opportunistic pathogen that causes urinary tract infections, respiratory system infections, dermatitis, soft tissue infections, bacteremia and a variety of systemic infections, particularly in victims of severe burns, and in cancer and AIDS patients who are immunosuppressed. *Pseudomonas aeruginosa* is occasionally a pathogen of plants, as well. *Pseudomonas mallei* causes a disease in horses known as glanders. It is a true parasite, since it is unable to survive in nature in the absence of its host. The primary focus of infection is the lungs. The disease can be transmitted to humans from the horse. *Pseudomonas pseudomallei* is the agent of melioidosis, a highly fatal tropical disease of humans and other mammals. It is also an opportunistic pathogen contracted through the contamination of wounds with mud or soil. The typical *Pseudomonas* bacterium in nature might be found in a biofilm, attached to some surface or substrate, or in a planktonic form, as a single cell actively motile my means of polar flagella. *Pseudomonas* is one of the most vigorous, fast-swimming bacteria seen in hay infusions and pond water samples. *Pseudomonas aeruginosa* is motile by means of a single polar flagellum. *P. aeruginosa* can live in a sessile biofilm form, or it can live in a planktonic form, as a free-swimming cell.

Pseudomonas aeruginosa is not particularly distinctive as a pseudomonad, but there are a few characteristics that are noteworthy and relate to its pathogenesis. The organism can be isolated from soil and water, particularly in enrichments for denitrifying bacteria. Although the bacterium is respiratory and never fermentative, it will grow in the absence of O2 if NO3 is available as a respiratory electron acceptor. *P. aeruginosa* possesses the metabolic versatility for which pseudomonads are so renowned. Organic growth factors are not required, and it can use more than thirty organic compounds for growth. *Pseudomonas aeruginosa* is often observed growing in "distilled water" which is evidence of its minimal nutritional requirements. Its optimum temperature for growth is 37 degrees, and it is able to grow at temperatures as high as 42 degrees. Its tolerance to a wide variety of physical conditions, including temperature, contributes to its ecological success as an opportunistic pathogen. *Pseudomonas aeruginosa* does, however, show a predilection for growth in moist environments, a reflection of its natural existence in soil and water.

P. aeruginosa isolates may produce three colony types. Natural isolates from soil or water typically produce a small, rough colony. Clinical samples, in general, yield one or another of two smooth colony types. One type has a fried-egg appearance which is large, smooth, with flat edges and an elevated appearance. Another type, frequently obtained from respiratory and urinary tract secretions, has a mucoid appearance, which is attributed to the production of alginate slime. The smooth and mucoid colonies are presumed to play a role in colonization and virulence. *P. aeruginosa* produces two types of soluble pigments, pyocyanin and (fluorescent) pyoverdin. The latter is produced abundantly in media of low-iron content, and could function in iron metabolism in the bacterium. Pyocyanin (from "pyocyaneus") refers to "blue pus" which is a characteristic of suppurative infections caused by *Pseudomonas aeruginosa*.

Pseudomonas aeruginosa is notorious for its resistance to antibiotics and is, therefore, a particularly dangerous and dreaded pathogen. The bacterium is naturally resistant to many antibiotics due to the permeabiliity barrier afforded by its outer membrane LPS. Also, its tendency to colonize surfaces in a biofilm form makes the cells impervious to therapeutic concentrations of antibiotics. Since its natural habitat is the soil, living in association with the bacilli, actinomycetes and molds, it has developed resistance to a variety of their naturally-occuring antibiotics. Moreover, *Pseudomonas* maintains antibiotic resistance plasmids, both R-factors and RTFs, and it is able to transfer these genes by means of the bacterial processes of transduction and conjugation. Only a few antibiotics are effective against *Pseudomonas*, including fluoroquinolone, gentamicin and imipenem, and even these antibiotics are not effective against all strains. The futility of treating *Pseudomonas* infections with antibiotics is most dramatically illustrated in cystic fibrosis patients, virtually all of whom eventually become infected with a strain that is so resistant it cannot be treated.

Pseudomonas aeruginosa can usually be isolated from soil and water, as well as the surfaces of plants and animals. It is found throughout the world, wherever these habitats occur, so it is quite a "cosmopolitan" bacterium. It is sometimes present as part of the normal flora of humans, although the prevalence of colonization of healthy individuals outside the hospital is relatively low (estimates range from 0 to 24 percent depending on the anatomical locale). Although colonization usually precedes infections by *Pseudomonas aeruginosa*, the exact source and mode of transmission of the pathogen are often unclear because of its ubiquitous presence in the environment. *Pseudomonas aeruginosa* is primarily a nosocomial pathogen.'According to the CDC, the overall incidence of *P. aeruginosa* infections in US hospitals averages about 0.4 percent (4 per 1000 discharges), and the bacterium is the fourth most commonly-isolated nosocomial pathogen accounting for 10.1 percent of all hospital-acquired infections. Pathogenesis For an opportunistic pathogen such as *Pseudomonas aeruginosa*, the disease process begins with some alteration or circumvention of normal host defenses. The pathogenesis of *Pseudomonas* infections is multifactorial, as suggested by the number and wide array of virulence determinants possessed by the bacterium. Multiple and diverse determinants of virulence are expected in the wide range of diseases caused by *Pseudomonas aeruginosa* such as *Pseudomonas* septicemia, urinary tract infections, *Pseudomonas* pneumonia and chronic lung infections, endocarditis, dermatitis, and osteochondritis. Most *Pseudomonas* infections are both invasive and toxinogenic. The ultimate *Pseudomonas* infection may be seen as composed of three distinct stages: (1) bacterial attachment and colonization; (2) local invasion; (3) disseminated systemic disease. However, the disease process may stop at any stage. Particular bacterial determinants of virulence mediate each of these stages and are ultimately responsible for the characteristic syndromes that accompany the disease. The fimbriae of *Pseudomonas* will adhere to the epithelial cells of the upper respiratory tract and, by inference, to other epithelial cells as well. These adhesins appear to bind to specific galactose or mannose or sialic acid receptors on epithelial cells.

Colonization of the respiratory tract by *Pseudomonas* requires fimbrial adherence and may be aided by production of a protease enzyme that degrades fibronectin in order to expose the underlying fimbrial receptors on the epithelial cell surface. Tissue injury may also play a role in colonization of the respiratory tract since *P. aeruginosa* will adhere to tracheal epithelial cells of mice infected with Influenza virus but not to normal tracheal epithelium. This has been called opportunistic adherence, and it may be an important step in *Pseudomonas* keratitis and urinary tract infections, as well as infections of the respiratory tract. The receptor on tracheal epithelial cells for *Pseudomonas* pili is probably sialic acid (N-acetylneuraminic acid). Mucoid strains, which produce an a exopolysaccharide (alginate) have an additional or alternative adhesin which attaches to the tracheobronchial mucin (N-acetylglucosamine). Besides pili and the mucoid polysaccharide, there are possibly two other cell surface adhesins utilized by *Pseudomonas* to colonize the respiratory epithelium or mucin. In addition, it is likely that surface-bound exoenzyme S could serve as an adhesin for glycolipids on respiratory cells. The mucoid exopolysaccharide produced by *P. aeruginosa* is a repeating polymer of mannuronic and glucuronic acid referred to as alginate. Alginate slime forms the matrix of the *Pseudomonas* biofilm which anchors the cells to their environment and, in medical situations, protects the bacteria from the host defenses such as lymphocytes, phagocytes, the ciliary action of the respiratory tract, antibodies and complement. Biofilm mucoid strains of *P. aeruginosa* are also less susceptible to antibiotics than their planktonic counterparts. Mucoid strains of *P. aeruginosa* are most often isolated from patients with cystic fibrosis and they are usually found in post mortem lung tissues from such individuals. Invasion The ability of *Pseudomonas aeruginosa* to invade tissues depends upon its resistance to phagocytosis and the host immune defenses, and the extracellular enzymes and toxins that break down physical barriers and otherwise contribute to bacterial invasion. As mentioned above, the bacterial capsule or slime layer effectively protects cells from opsonization by antibodies, complement deposition, and phagocyte engulfment. Two extracellular proteases have been associated with virulence that exert their activity at the invasive stage: elastase and alkaline protease. Elastase has several activities that relate to virulence. The enzyme cleaves collagen, IgG, IgA, and complement. It also lyses fibronectin to expose receptors for bacterial attachment on the mucosa of the lung. Elastase disrupts the respiratory epithelium and interferes with ciliary function. Alkaline protease interferes with fibrin formation and will lyse fibrin. Together, elastase and alkaline protease destroy the ground substance of the cornea and other supporting structures composed of fibrin and elastin. Elastase and alkaline protease together are also reported to cause the inactivation of gamma Interferon (IFN) and Tumor Necrosis Factor (TNF). *P. aeruginosa* produces three other soluble proteins involved in invasion: a cytotoxin (mw 25,000) and two hemolysins. The cytotoxin is a pore-forming protein. It was originally named leukocidin because of its effect on neutrophils, but it appears to be cytotoxic for most eukaryotic cells. Of the two hemolysins, one is a phospholipase and the other is a lecithinase. They appear to act synergistically to break down lipids and lecithin. The cytotoxin and hemolysins contribute to invasion through their cytotoxic effects on eukaryotic cells. The *Pseudomonas* pigments are probably determinants of virulence for the pathogen. The blue pigment, pyocyanin, impairs the normal function of human nasal cilia, disrupts the respiratory epithelium and exerts a proinflammatory effect on phagocytes. A derivative of pyocyanin, pyochelin, is a siderophore that is produced under low-iron conditions to sequester iron from the environment for growth of the pathogen. No role in virulence is known for the fluorescent pigment, pyoverdin.

Blood stream invasion and dissemination of *Pseudomonas* from local sites of infection is probably mediated by the same cell-associated and extracellular products responsible for the localized disease, although it is not entirely clear how the bacterium produces systemic illness. *P. aeruginosa* is resistant to phagocytosis and the serum bactericidal response due to its mucoid capsule and possibly LPS. The proteases inactivate complement, cleave IgG antibodies and inactivate IFN, TNF, and probably other cytokines . The Lipid A moiety of *Pseudomonas* LPS (endotoxin) mediates the usual pathologic aspects of Gram-negative septicemia, e.g. fever, hypotension, intravascular coagulation, etc. It is also reasonable to assume that *Pseudomonas* Exotoxin A exerts some pathologic activity during the dissemination stage. Toxinogenesis *P. aeruginosa* produces two extracellular protein toxins, Exoenzyme S and Exotoxin A. Exoenzyme S is probably an exotoxin. It has the characteristic subunit structure of the A-component of a bacterial toxin, and it has ADP-ribosylating activity (for a variety of eukaryotic proteins) characteristic of exotoxins. Exoenzyme S is produced by bacteria growing in burned tissue and may be detected in the blood before the bacteria are. It has been suggested that exoenzyme S may act to impair the function of phagocytic cells in the bloodstream and internal organs to prepare for invasion by *P. aeruginosa*. Exotoxin A has exactly the same mechanism of action as the diphtheria toxin; it causes the ADP ribosylation of eukaryotic elongation factor 2. It is partially-identical to diphtheria toxin, but it is antigenically-distinct. It utilizes a different receptor on host cells but otherwise it enters cells in the same manner as the diphtheria toxin and it has the exact enzymatic mechanism. The production of Exotoxin A in both organisms is regulated by exogenous iron, but the details of the regulatory process are distinctly different in *C. diphtheriae* and *P. aeruginosa.* Exotoxin A appears to mediate both local and systemic disease processes caused by *Pseudomonas aeruginosa.* It has necrotizing activity at the site of bacterial colonization and is thereby thought to contribute to the colonization process. Toxinogenic strains cause a more virulent form of pneumonia than nontoxinogenic strains. In terms of its systemic role in virulence, purified Exotoxin A is highly lethal for animals including primates. Indirect evidence involving the role of exotoxin A in disease is seen in the increased chance of survival in patients with *Pseudomonas* septicemia that is correlated with the titer of anti-exotoxin A antibodies in the serum.

Disease caused by *Pseudomonas aeruginosa:*

Endocarditis. *Pseudomonas aeruginosa* infects heart valves of IV drug users and prosthetic heart valves. The organism establishes itself on the endocardium by direct invasion from the blood stream.

Respiratory infections. Respiratory infections caused by *Pseudomonas aeruginosa* occur almost exclusively in individuals with a compromised lower respiratory tract or a compromised systemic defense mechanism. Primary pneumonia occurs in patients with chronic lung disease and congestive heart failure. Bacteremic pneumonia commonly occurs in neutropenic cancer patients undergoing chemotherapy. Lower respiratory tract colonization of cystic fibrosis patients by mucoid strains of *Pseudomonas aeruginosa* is common and difficult, if not impossible, to treat.

Bacteremia. *Pseudomonas aeruginosa* causes bacteremia primarily in immunocompromised patients. Predisposing conditions include hematologic malignancies, immunodeficiency relating to AIDS, neutropenia, diabetes mellitus, and severe burns. Most *Pseudomonas* bacteremia is acquired in hospitals and nursing homes. *Pseudomonas* accounts for about 25 percent of all hospital acquired Gram-negative bacteremias.

Central Nervous System infections. *Pseudomonas aeruginosa* causes meningitis and brain abscesses. The organism invades the CNS from a contiguous structure such as the inner ear or paranasal sinus, or is inoculated directly by means of head trauma, surgery or invasive diagnostic procedures, or spreads from a distant site of infection such as the urinary tract.

Ear infections including external otitis. *Pseudomonas aeruginosa* is the predominant bacterial pathogen in some cases of external otitis including "swimmer's ear". The bacterium is infrequently found in the normal ear, but often inhabits the external auditory canal in association with injury, maceration, inflammation, or simply wet and humid conditions.

Eye infections. *Pseudomonas aeruginosa* can cause devastating infections in the human eye. It is one of the most common causes of bacterial keratitis, and has been isolated as the etiologic agent of neonatal ophthalmia. *Pseudomonas* can colonize the ocular epithelium by means of a fimbrial attachment to sialic acid receptors. If the defenses of the environment are compromised in any way the bacterium can proliferate rapidly and, through the production of enzymes such as elastase, alkaline protease and exotoxin A, cause a rapidly destructive infection that can lead to loss of the entire eye.

Bone and joint infections. *Pseudomonas* infections of bones and joints result from direct inoculation of the bacteria or the hematogenous spread of the bacteria from other primary sites of infection. Blood-borne infections are most often seen in IV drug users, and in conjunction with urinary tract or pelvic infections. *Pseudomonas aeruginosa* has a particular tropism for fibrocartilagenous joints of the axial skeleton. *Pseudomonas aeruginosa* causes chronic contiguous osteomyelitis, usually resulting from direct inoculation of bone, and is the most common pathogen implicated in osteochondritis after puncture wounds of the foot.

Urinary tract infections. Urinary tract infections (UTI) caused by *Pseudomonas aeruginosa* are usually hospital-acquired and related to urinary tract catheterization, instrumentation or surgery. *Pseudomonas aeruginosa* is the third leading cause of hospital-acquired UTIs, accounting for about 12 percent of all infections of this type. The bacterium appears to be among the most adherent of common urinary pathogens to the bladder uroepithelium. As in the case of *E. coli* urinary tract infection can occur via an ascending or descending route. In addition, *Pseudomonas* can invade the bloodstream from the urinary tract, and this is the source of nearly 40 percent of *Pseudomonas* bacteremias.

Gastrointestinal infections. *Pseudomonas aeruginosa* can produce disease in any part of the gastrointestinal tract from the oropharynx to the rectum. As in other forms of *Pseudomonas* disease, those involving the GI tract occur primarily in immunocompromised individuals. The organism has been implicated in perirectal infections, pediatric diarrhea, typical gastroenteritis, and necrotizing enterocolitis. The GI tract is also an important portal of entry in *Pseudomonas* septicemia.

Skin and soft tissue infections, including wound infections, pyoderma and dermatitis. *Pseudomonas aeruginosa* can cause a variety of skin infections, both localized and diffuse. The common predisposing factors are breakdown of the integument which may result from burns, trauma or dermatitis; high moisture conditions such as those found in the ear of swimmers and the toe webs of athletes and combat troops, in the perineal region and under diapers of infants, and on the skin of whirlpool and hot tub users; neutropenia; and AIDS. *Pseudomonas* has also been implicated in folliculitis and unmanageable forms of acne vulgaris.

Source:

Pseudomonas aerudinosa
http://www.bactwisc.edu/microtextbook/disease/pseudomonas.html
University of Wisconsin-Madison, 1999

Factors Affecting the Growth of Microorganisms in Foods

Food is a chemically complex matrix, and predicting whether, or how fast, microorganisms will grow in any given food is difficult. Most foods contain sufficient nutrients to support microbial growth. Several factors encourage, prevent, or limit the growth of microorganisms in foods, the most important are aw, pH, and temperature.

aw: (Water Activity or Water Availability). Water molecules are loosely oriented in pure liquid water and can easily rearrange. When other substances (solutes) are added to water, water molecules orient themselves on the surface of the solute and the properties of the solution change dramatically. The microbial cell must compete with solute molecules for free water molecules. Except for Staphylococcus aureus, bacteria are rather poor competitors, whereas molds are excellent competitors.

aw varies very little with temperature over the range of temperatures that support microbial growth. A solution of pure water has an aw of 1.00. The addition of solute decreases the aw to less than 1.00.

The aw of a solution may dramatically affect the ability of heat to kill a bacterium at a given temperature. For example, a population of Salmonella typhimurium is reduced tenfold in 0.18 minutes at 60°C if the aw of the suspending medium is 0.995. If the aw is lowered to 0.94, 4.3 min are required at 60°C to cause the same tenfold reduction.

An aw value stated for a bacterium is generally the minimum aw which supports growth. At the minimum aw, growth is usually minimal, increasing as the aw increases. At aw values below the minimum for growth, bacteria do not necessarily die, although some proportion of the population does die. The bacteria may remain dormant, but infectious. Most importantly, aw is only one factor, and the other factors (e.g., pH, temperature) of the food must be considered. It is the interplay between factors that ultimately determines if a bacterium will grow or not. The aw of a food may not be a fixed value; it may change over time, or may vary considerably between similar foods from different sources.

pH: (hydrogen ion concentration, relative acidity or alkalinity). The pH range of a microorganism is defined by a minimum value (at the acidic end of the scale) and a maximum value (at the basic end of the scale). There is a pH optimum for each microorganism at which growth is maximal. Moving away from the pH optimum in either direction slows microbial growth.

A range of pH values is presented here, as the pH of foods, even those of a similar type, varies considerably. Shifts in pH of a food with time may reflect microbial activity, and foods that are poorly buffered (i.e., do not resist changes in pH), such as vegetables, may shift pH values considerably. For meats, the pH of muscle from a rested animal may differ from that of a fatigued animal.

A food may start with a pH which precludes bacterial growth, but as a result of the metabolism of other microbes (yeasts or molds), pH shifts may occur and permit bacterial growth.

Temperature. Temperature values for microbial growth, like pH values, have a minimum and maximum range with an optimum temperature for maximal growth. The rate of growth at extremes of temperature determines the classification of an organism (e.g., psychrotroph, thermotroph). The optimum growth temperature determines its classification as a thermophile, mesophile, or psychrophile.

Interplay Of Factors Affecting Microbial Growth In Foods: Although each of the major factors listed above plays an important role, the interplay between the factors ultimately determines whether a microorganism will grow in a given food. Often, the results of such interplay are unpredictable, as poorly understood synergism or antagonism may occur. Advantage is taken of this interplay with regard to preventing the outgrowth of C. botulinum. Food with a pH of 5.0 (within the range for C. botulinum) and an aw of 0.935 (above the minimum for C. botulinum) may not support the growth of this bacterium. Certain processed cheese spreads take advantage of this fact and are therefore shelf stable at room temperature even though each individual factor would permit the outgrowth of C. botulinum.

Therefore, predictions about whether or not a particular microorganism will grow in a food can, in general, only be made through experimentation. Also, many microorganisms do not need to multiply in food to cause disease.

Source:

U.S. Food & Drug Administration
Center for Food Safety & Applied Nutrition
Foodborne Pathogenic Microorganisms
and Natural Toxins Handbook

Appendix I: Series of Questions for Wastewater System Assessment

1. In meters, what are the dimensions of free ground space surrounding the collection center? Underground space? (underground space must be free of pipes, etc.)
2. What is the peak wastewater quantity generated by the center in any given day, in liters?
3. Describe the composition of the generated wastewater. Include data regarding the contents in the following table.

Fats/oils	Dissociable cyanide in weak acid
Potential hydrogen	Copper
Temperature	Lead
Sedimental solids	Tin
Floatable materail	Phenols
Mercury	Nickel
Aluminum	Zinc
Arsenic	Silver
Barium	Selenium
Boron	Sulfites
Cadmium	Sulfides
Residual chlorine	Fluorides
Color	Amount of organic phosphate compounds
Chromium	Amount of carbonates
Total cyanide	Amount of organic chloride compounds
Free cyanide	Biochemical oxygen demand
Free cyanide in the body of water, outside of the mixture area	Fecal coliform
pH	

4. What cleaning agents are currently employed within the collection center? Conventional detergents, biodegradable detergents, etc.? What holding time does this agent require to degrade or settle?
5. What is your budget for a wastewater treatment system? (this budget must cover initial fees, as well as the costs of upkeep)

Appendix J: Contact Information

Dr. Ronald Arrieta
Professor of Chemistry, UCR
207-5038

Dr. Eduardo Obando
Professor of Chemistry, UCR
207-4000 (University Extension)

Gente Reciclando
Adriana Soto & Jonathon Molina, owners
285-2035

Panamco Tica S.A.
Division of the *Coca-Cola* bottling company
Accepts unwashed, unprocessed post-consumer PET
256-2020

HARDWARE STORES:

Ferretería Del Centro S.A.
Pays 25 colones per gallon jug, accepts them in bundles of 50, must be delivered
Escazu, Costa Rica
228-0086

Ferretería El Mar
Does not purchase gallon jugs
Escazu, Costa Rica
289-9192

Ferretería Leja S.A.
No longer accepts post-consumer plastic containers
Santa Ana, Costa Rica
282-5152

Ferretería San Joaquín
Pays 20 colones per gallon jug, must be delivered
Santa Ana, Costa Rica
282-5397

Ferretería Solis
Pays 15 colones per gallon jug, 10 colones for liter jugs, must be delivered
Escazu, Costa Rica
228-1696

Appendix K: Recommendations Manual

Recycling Post-Consumer Plastics in Santa Ana, Costa Rica

Recommendations Manual

Developed by:
Janelle Arthur
Elizabeth Caswell
Katherine Wheeler

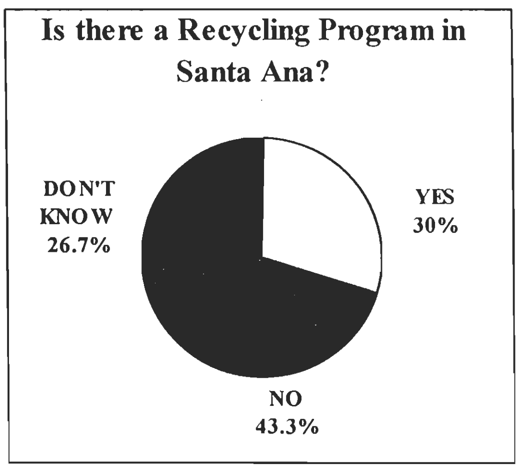
Plastic Types

Type #	Proper Name & Products Housed
1	Polyethylene terephthalate (PET): soda, water, cooking oil, ketchup, juices
2	High-Density Polyethylene (HDPE): detergents, milk, orange juice
3	Polyvinyl chloride (PVC): cooking oil, water, mouthwash
4	Low-Density Polyethylene (LDPE): container lids, plastic films and bags
5	Polypropylene (PP): dairy products, household cleaners, syrups
6	Polystyrene (PS): dairy products
7	Other – plastics of mixed resin types: variety of products ** within this manual, type #7 indicates a mixture of unidentifiable and hazardous types

Public Awareness

The success of any public program depends on the community's participation, which can be heightened through education. Currently in Santa Ana, there is an educational campaign concerning recycling that is led by UCR students. Our data support the need for this campaign, as Figure 1 shows that 70% of the Santa Ana residents surveyed do not know or are unsure of the existence of a recycling program in the city. We further recommend that this campaign continue in order to promote and evaluate the success of the pilot-recycling program.

Figure 1. Public Knowledge of Santa Ana Recycling Program



This educational campaign should also stress the importance of washing plastics before they are set aside for collection. Additional data in Table 1 show that only 7.1% of residents surveyed were unwilling to wash plastics before placing them in collection receptacles. Therefore, if encouraged, it is likely that most residents will comply and wash their plastics.

Table 1. Percent of Survey Participants Willing to Wash Plastics

	Yes	No	Maybe
Would Wash	75.0	7.1	17.9

Curbside Collection

During the early stages of Santa Ana's recycling program, commingled recyclables should be collected from the curb in plastic bags. Paper products, meanwhile, should not be mixed with the commingled recyclables, but rather collected in a bundle of their own. Paper should be collected separately for two reasons: first, to prevent it from becoming soiled by contaminants left on other recyclables, and second, to prevent further complications in the sorting process, as paper often adheres to other materials.

Presently, a mixture of recyclables and MSW is collected using plastic bags. Therefore, the same amount of bags as are currently used should be sufficient to house MSW and recyclables, when separated. Homeowners will not encounter any additional costs in abiding by the collection guidelines and separating recyclables from MSW. Furthermore, using a familiar and economical receptacle will promote public participation in the recycling program.

Recommendation for the Future

As evidenced in data from both the United States and the United Kingdom, there is a substantial increase in participation when durable, reusable bins are distributed within the community. Specifically in the United Kingdom, an average of 3.5 kilograms of plastic were collected per household, per year when plastic bins were distributed, whereas only 1.5 kilograms were collected using other receptacles. These bins would be both physically convenient and serve as a daily visual reminder to recycle. Such a method would be beneficial in Santa Ana, as data from our survey show that among other excuses for not recycling, inconvenience and lack of habit are two prominent responses.

Once the collection center has earned sufficient profits from marketing semi-processed recyclables, these may, in turn, be used to purchase such bins. Therefore, once more financial resources become available, Santa Ana should instate a collection scheme in which plastic receptacles are distributed to each household within the city.

The Santa Ana Collection Center

When the new collection center is built, it should house the processes of separation, preparation, washing, compacting and transport.

Figure 2 on the following page illustrates the general layout and flow of processes that we recommend occur at the Santa Ana collection center. The numbers within the diagram are referred to later in the text, as each process is described in detail.

Separation of Recyclables

Based upon an analysis of plastic types in grocery stores, we have concluded that it is possible to recycle most, but not all plastic types. While we were unable to locate any type #7, we stress that the collection center not separate these into a category of their own, but rather placed among unidentifiable plastics to be discarded. This type is, in fact, composed of mixed plastics and when melted and reused, does not form a pure plastic product.

As there is demand for all remaining plastic types, all should be separated for recycling as described below.

Figure 2. Recommended Layout of New Collection Center

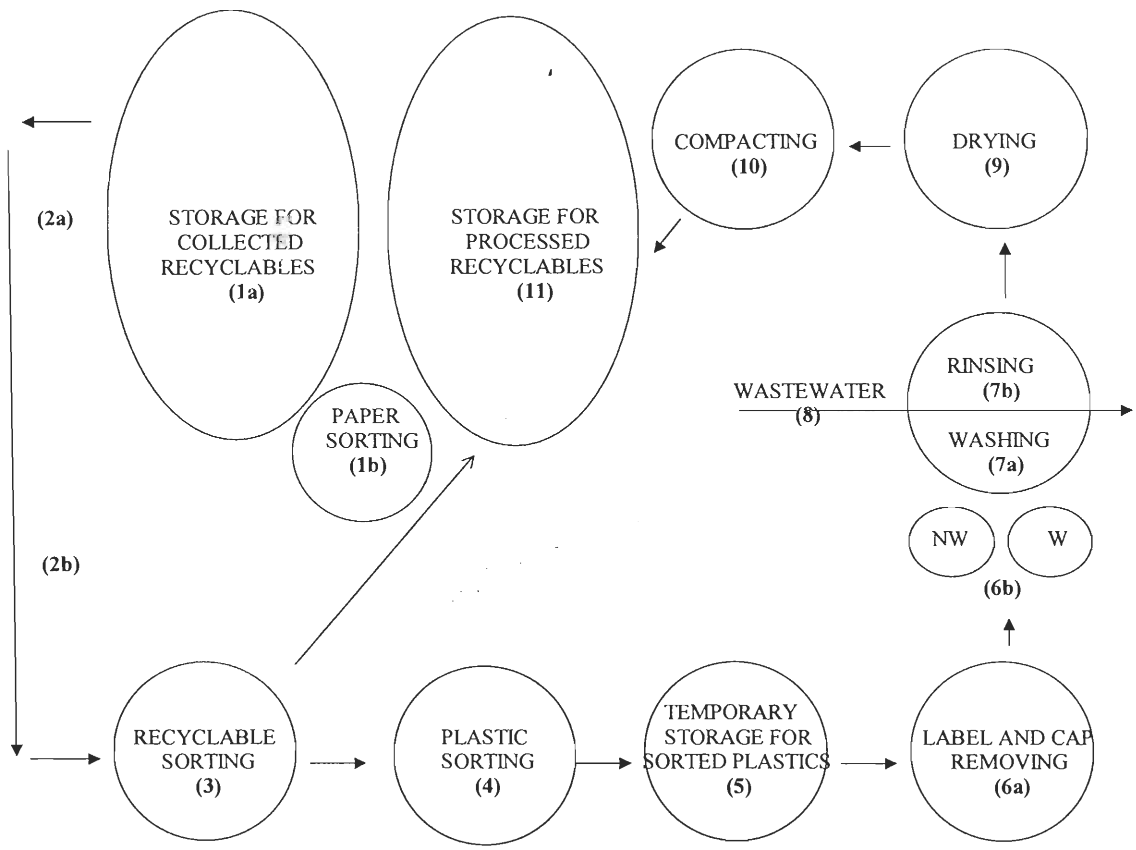
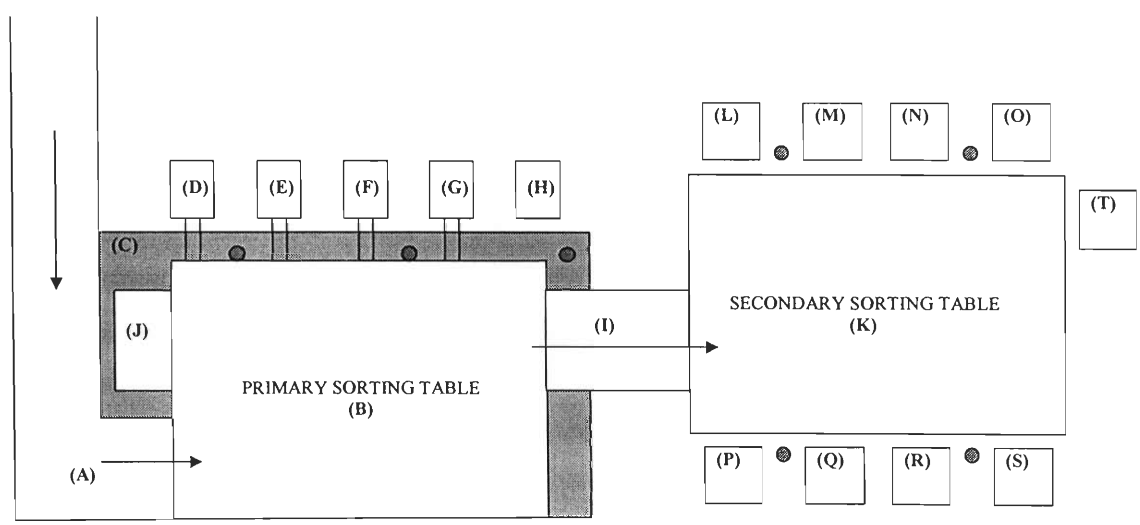


Figure 3. Detailed Layout of Sorting Tables



Due to the frequency of mis-numbered or unnumbered plastic containers, we have provided a series of guidelines in Table 2 that when followed, will help resolve this problem. Each employee should be familiar with these guidelines to ensure proper separation of plastic types. Following these guidelines will not only guarantee accurate separation, but will reduce the number of unidentifiable plastics, thus increasing the total number recycled.

Table 2. Distinguishing Characteristics of Various Plastic Types

#	Abbreviation	Distinguishing Characteristics
1	PET	clear, small round indent on bottom, injection molded, no seams
2	HDPE	
	(bottles)	natural- not clear, foggy yet transparent; white and colored- opaque, smells like candle when burned, no flame
	(bags)	clear, white and colored, makes a crinkling noise
3	PVC	clear, has seams
4	LDPE	
	(containers)	opaque, pliable
	(bags)	clear, white and colored, makes no noise
5	PP	colored or clear- transparency level between PET and HDPE, not as pliable as LDPE
6	PS	opaque, cracks when bent, burns with a flame and turns black
7	Other	various types and characteristics

In order to accomplish this separation process with the resources available, a series of sorting tables will be used to first separate commingled recyclables by material, then to further separate plastics by type. See figure 3 on the previous page for a detailed layout of these tables (dark circles on the diagram indicate the placement of workers at these tables). As mentioned in the collection recommendations section, paper should be collected separately from commingled recyclables at the curbside. However, any paper products that have been inadvertently included with the commingled recyclables must continually be removed from the pile and placed in a designated storage receptacle **(1b)**. Simultaneously, an employee will shovel commingled recyclables **(1a)** & **(2a)** into a wheelbarrow that will be transported up a ramp **(2b)** & **(A)** ending at the same level as the first sorting table **(3)** & **(B)**. At this point, recyclables will be dumped onto this raised table **(C)** and sorted into six categories: clear glass **(D)**, colored glass **(E)**, aluminum **(F)**, tin **(G)**, solid plastic **(I)**, and plastic film **(H)**. Employees will guide all materials, except solid plastic and plastic film, down short chutes that lead to separate storage bins. Solid plastics will be guided down a wider chute that leads to the second sorting table. On the other hand, a chute should not be used for plastic film, which is flimsy and lightweight, as it is easier to gather it directly from the table to place in a bin. After the materials are manually removed from the first sorting table, one of the workers will sweep any remaining trash, using a hand broom, into a barrel located at the side of the table **(J)**.

At the second sorting table **(4)** & **(K)**, a team of workers will sort the solid plastics by type: *Coca-Cola* brand type #1 **(L)**, other type #1 **(M)**, natural type #2 **(N)**, colored type #2 **(O)**, type #3 **(P)**, type #4 **(Q)**, type #5 **(R)**, type #6 **(S)**, and others - type #7, unidentifiable and hazardous plastics **(T)**. These plastic types will be placed in temporary storage bins to await further processing, or disposal, in the case of plastics categorized as "other."

Preparation of Plastics

Following sorting, plastic bottles and containers should be temporarily stored **(5)** and then prepared for the washing process by the removal of caps, rings and labels **(6a)**. Given the present financial situation at the Santa Ana collection center, this removal process should be performed by hand.

First, employees must unscrew and discard caps, along with the plastic rings, which can be removed with wire cutters. Next they will cut, peel and remove the label material from the plastics' surfaces. A knife or razor, which has been chosen and approved by the collection center's management, should be used. Additionally, the management will take special care in selecting workers to manage this station, which involves the use of sharp instruments, since safety is a primary concern at the center.

Because it is difficult to remove label material with scraping alone, the plastics must be soaked in a hot water bath. Employees, however, should take special care to not fully submerge plastics in the bath, as contaminants from the inner surfaces may remain in this bath and soil the remaining plastics that are later soaked in it. The employees will then perform a preliminary scraping of the softened labels.

The plastics will, however, must be further separated into two bins **(6b)** by the solubility of the products originally housed within them, according to Table 3, before they can be washed. This final sorting phase is the last preparation step that will occur at the label removal station before the employees transfer the plastics to the washing and rinsing area.

Recommendation for the Future

In the future, the Santa Ana collection center may find it beneficial to purchase an automated label and adhesive removing machine, such as that which *Panamco* currently uses. The machine would increase efficiency in this preparation step, which without the machine, will most likely require the greatest time and labor investment in the center's scheme of recycling processes. Additionally, this machine achieves a consistent level of label and adhesive removal, a factor that will heighten consumer confidence in secondary plastic products. This machinery requires two workers for operation and when purchased new, costs approximately ¢3.000.000.

Washing, Rinsing & Drying

Inevitably, portions of labels and adhesives will remain on some plastics even after the preliminary scraping procedure. For this reason, it is important that in the first step of the washing station **(7a)**, employees use a solution of baking soda and water with an abrasive sponge to clean the plastic surfaces of these remnants. The baking soda mixture need not be rinsed from the plastic surfaces at this time, as the container will be rinsed in the subsequent process. It is important,

Recommendation for the Future

Once more financial resources are available, the collection center may determine that using a saw to cut plastics lengthwise will expose more surface area and increase washing efficiency. In this regard, we considered three types of stationary electric saws, however, all lack extensive safety features. This presents a great risk to the collection center employees, as many of them are not educated, nor skilled, in the use of such equipment.

Consequently, using a saw at this time is not recommended. However, if in the future the collection center decides that a saw would greatly enhance the washing process, it should investigate the use of a table saw equipped with safety features such as a sizable, protective hood surrounding the blade of the table saw to prevent all human contact. Additionally, a device, set upon runners along both sides of the blade, could stabilize the bottles while the worker pushes the device, rather than the bottle itself, toward the blade. This device would be designed to stop at a specified point; therefore preventing the operator from accidentally extending it too far and putting his or her hands in danger.

however, that containers housing water-soluble products not be mixed with those housing non-water-soluble products during this step. See Table 3 to the right.

Following this procedure, employees standing on one side of the wash basin **(7a)** will rinse all surfaces of the containers housing water-soluble contaminants, using only high-pressure water. There is no standard duration of rinsing time for the containers; however, each container must be rinsed until the contaminants are not noticeable by touch or sight.

Meanwhile, employees standing on the other side of the wash basin **(7a)** will wash containers housing non-water-soluble contaminants, using high-pressure water, a biodegradable detergent, and if necessary, flexible wash brushes.

The collection center should purchase two types of nozzles to allow for variations in water pressure and direction. The first will be used to clean bottles, and must therefore be narrow, in order for it to pass through the neck of each type of bottle and to allow for drainage from the neck during the washing procedure. It will be porous to direct water in all directions inside the bottle. The collection center may consider the use of a standard kitchen nozzle as the second type to wash open containers such as butter tubs.

Table 3. Categorization by Solubility

Contaminant		**Solubility** Non-water – NW Water – W Hazardous – **H**
Baby oil		NW
Bleach		**H**
Carbonated beverages		W
Cooking oil		NW
Conditioner (hair)		W
Cough syrup		W
Dairy (yogurt, cream cheese, ice cream, sour cream)		NW
Dishwashing soap		W
Fruit juice/sports drinks		W
Household cleaners		**H**
Ketchup		W
Laundry detergent		W
Milk		NW
Mouthwash		W
Mustard		W
Salad dressing		NW
Sauces		NW
Shampoo		W
Sunscreen		NW
Syrup, jelly, honey		W
Vanilla flavoring		W
Water		W

The collection center's management should contact Dr. Obando (see page 14 for contact information) to determine the name, cost, chemical composition and other specifications of the biodegradable detergent he suggested, as he was unable to supply this data as of the date this manual was completed.

Upon completion of the rinsing process **(7b)**, a worker should then place all plastic containers on the racks to dry **(9)**. These racks will consist of several levels of screen trays, among which pegs will be evenly spaced for the stabilization of the overturned bottles. A number of fans should be strategically placed throughout the levels to increase airflow and accelerate the drying process. The drying area in consideration must be well ventilated, but at the same time, separated from other areas of the collection center to prevent plastic re-contamination.

Wastewater Treatment & Disposal

We have researched three types of wastewater treatment or disposal options for the Santa Ana collection center: man-made treatment ponds, septic systems and agricultural disposal. Man-made treatments ponds are a series of open ponds with dimensions varying according to the specific composition and quantity of wastewater generated. The wastewater is treated by methods that may include the photosynthetic and metabolic processes of algae or water hyacinths, as well as the natural processes of sun, wind and weather exposure. Septic systems, on the other hand, are a series of underground settling and filtering tanks, which eventually lead to either a leach field or a natural body of water. The number of tanks necessary also depends on the specific composition and quantity of wastewater generated by the facility. Finally, agricultural disposal involves no wastewater treatment, except possibly a simple holding tank, and is a method of using the wastewater to irrigate nearby agricultural fields.

As many factors that we cannot currently examine must be considered, it is not possible to recommend one specific method for the collection center's wastewater treatment and disposal **(8)** at this time. Since the new collection center is not yet built and in operation, the exact composition and peak quantity of wastewater is unknown. Additionally, the precise amount of available space surrounding the center, both above and below ground, is also undefined at present.

Nonetheless, at this time we suggest investigating the disposal of the wastewater onto nearby agricultural fields. The investigation must consider Costa Rican wastewater regulations. This method of disposal will benefit both the collection center, as it provides an inexpensive treatment and disposal option, and the agricultural farm. Since biodegradable detergents are the recommended cleaning agent, the alkalinity of these detergents will aid in neutralizing the acidic soil. The organic compounds left in the wastewater by the rinsed contaminants will provide a source of nutrients for the vegetation as well.

This recommendation relies on a number of conditions, however, as we are unable to determine whether or not a holding tank will be necessary without knowing the make-up of the wastewater. One particular concern is that the concentration of non-biodegradable detergents that have been rinsed from post-consumer plastic detergent bottles may be hazardous to the environment. For this reason an expert must be hired to perform an analysis of the wastewater composition in the presence of a biodegradable detergent. Should any levels be found unacceptable, the center must then determine whether a holding tank or other treatment, as outlined in our wastewater findings, must be installed before this water can be disposed on the agricultural fields.

A series of questions to assist in the assessment of an appropriate wastewater treatment and disposal technique are provided below.

Wastewater Treatment & Disposal Method Assessment

1. In meters, what are the dimensions of free ground space surrounding the collection center? Underground space? (underground space must be free of pipes, etc.)

2. What is the peak wastewater quantity generated by the center in any given day, in liters?

3. Describe the composition of the generated wastewater. Include data regarding the contents in the following table, table 4.

Table 4. Wastewater Composition

Fats/oils	Dissociable cyanide in weak acid
Potential hydrogen	Copper
Temperature	Lead
Sedimental solids	Tin
Floatable materail	Phenols
Mercury	Nickel
Aluminum	Zinc
Arsenic	Silver
Barium	Selenium
Boron	Sulfites
Cadmium	Sulfides
Residual chlorine	Fluorides
Color	Amount of organic phosphate compounds
Chromium	Amount of carbonates
Total cyanide	Amount of organic chloride compounds
Free cyanide	Biochemical oxygen demand
Free cyanide in the body of water, outside of the mixture area	Fecal coliform
pH	

4. What cleaning agents are currently employed within the collection center? Conventional detergents, biodegradable detergents, etc.? What holding time does this agent require to degrade or settle?

5. What is your budget for a wastewater treatment system? (this budget must cover initial fees, as well as the costs of upkeep)

Compacting and Transport

Once the clean plastic containers have thoroughly dried, they are placed into clean storage bins, maintaining separation by plastic type, to await compacting **(10)**. The Santa Ana collection center should obtain a compactor, either as arranged from the incineration plant in Cartago, or elsewhere if necessary. Compacting plastics will benefit the center by maximizing storage space within the facility, as well as the amount of plastics that may be transported.

Gente Reciclando is willing to pay more for semi-processed plastics if they are delivered directly to their facility. However, the collection center must determine if this is the most profitable option. Once the collection truck arrives, the management should examine the truck's specifications and calculate the total cost of transport per kilogram of plastic. They should then compare this value to the additional price *Gente Reciclando* will pay for delivered plastics. If the total cost of transport per kilogram exceeds the extra payment offered for each kilogram of plastic, the center's profits will be decreased. In this case, the center should accept the lower price at which *Gente Reciclando* will recover the plastics themselves from the Santa Ana collection center.

Panamco, on the other hand, prefers to recover the plastics itself and does not offer the option of paying a higher price for the collection center to deliver the plastics. Meanwhile, all the hardware stores contacted, require that the collection center deliver the plastic gallon jugs directly to their store. In contrast to *Gente Reciclando*, hardware stores demand that the jugs not be compacted, thus reducing transport capacity and incurring greater costs to the collection center. As these two markets have specific requirements regarding the transport of post-consumer plastics, there should be compliance with these requests.

Further Processing & Secondary Markets

In the initial stages of Santa Ana's program, the clean post-consumer plastics are to be marketed to the three above-mentioned purchasers: *Gente Reciclando, Panamco* and various hardware stores.

Specifically, quality gallon jugs, such as those without dents or other damages, should not be compacted but rather, separated and marketed to hardware stores. This practice is very profitable as hardware stores are willing to pay between ¢15-25 per jug, which is equivalent to what *Gente Reciclando* will pay for a half kilogram of plastic.

Coca-Cola brand type #1 bottles, additionally, should be separated from other plastics at the secondary sorting table, bypass all other processes, and be marketed to *Panamco*. This arrangement is a good solution, even though it requires added effort at the separation table, which will be compensated for, as subsequent processing is not necessary. Furthermore, *Panamco* will pay ¢100 per kilogram, double that of *Gente Reciclando*, and will pick up this unwashed, unprocessed type #1. This higher price offered makes this procedure very profitable for the collection center. All post-consumer type #1 plastic can be marketed to *Panamco*, however, since the company will not pay for type #1 bottles formerly housing products other than those of *Coca-Cola* brand.

Finally, all other plastics, those not marketed to hardware stores or *Panamco*, should be sold to *Gente Reciclando*. They are looking to accept all plastic types and will pay a reasonable price, approximately ¢30-50 colones per kilogram, for clean post-consumer plastics.

Contact Information

Dr. Ronald Arrieta
Professor of Chemistry, UCR
207-5038

Dr. Eduardo Obando
Professor of Chemistry, UCR
207-4000

Gente Reciclando
Adriana Soto & Jonathon Molina, owners
285-2035

Panamco Tica S.A.
Division of the *Coca-Cola* bottling company
Accepts unwashed, unprocessed post-consumer PET
256-2020

HARDWARE STORES:

Ferretería Del Centro S.A.
Pays 25 colones per gallon jug, accepts in bundles of 50, must be delivered
Escazu, Costa Rica
228-0086

Ferretería El Mar
Does not purchase gallon jugs
Escazu, Costa Rica
289-9192

Ferretería Leja S.A.
No longer accepts post-consumer plastic containers
Santa Ana, Costa Rica
282-5152

Ferretería San Joaquín
Pays 20 colones per gallon jug, must be delivered
Santa Ana, Costa Rica
282-5397

Ferretería Solis
Pays 15 colones per gallon jug, 10 colones for liter jugs, must be delivered
Escazu, Costa Rica
228-1696

El reciclaje de los plásticos pos-consumidores en Santa Ana, Costa Rica

Manual de Recomendaciones

Desarrollado por:
Janelle Arthur
Elizabeth Caswell
Katherine Wheeler

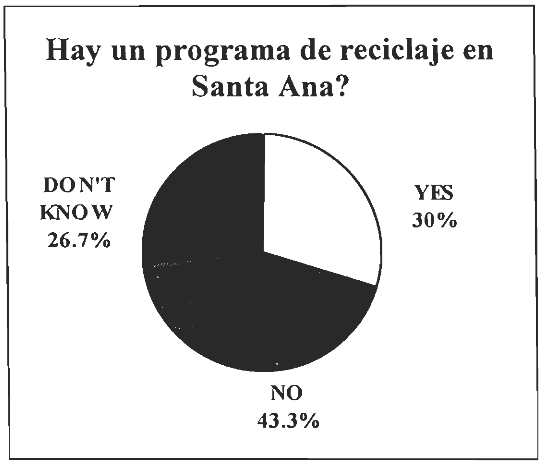
Tipos de Plástico

Numero de Tipo	Nombre de Tipo y Contenidos
1	Polietileno tereftalato (PET): refrescos, agua, aceite comestible, salsa de tomate, jugo
2	Polietileno de alta densidad (HDPE): detergentes, leche, jugo de naranja
3	Cloruro de Polvinilo (PVC): aceite comestible, agua, elixir bocal
4	Polietileno de baja densidad (LDPE): tapas de envases, bolsa plásticas
5	Polipropilenos (PP): productos lácteos, productos de limpieza, sirope
6	Poliestirenos (PS): productos lácteos
7	Otros – plásticos de una mezcla de resinas: una variedad de productos ** en esta manual, tipo #7 indica una mezcla de los plásticos no identificados y arriesgados

Conciencia Pública

Actualmente, en Santa Ana, existe una campaña educativa de reciclaje guiada por estudiantes de la UCR. Nuestros datos demuestran la necesidad de tener esta campaña. La Figura 1 muestra que un 70% de la gente que entrevistamos en Santa Ana no conoce o no está segura de la existencia de un programa de reciclaje en la ciudad.

Figura 1. Conocimiento público del programa de reciclaje de Santa Ana



Por eso, recomendamos que esta campaña educativa continue, y que también enfatice la importancia de lavar los plásticos antes de ponerlos a un lado para reciclaje. Datos adicionales en la Tabla 1 demuestran que solamente 7.1% de los residentes que hicieron la encuesta no estaban dispuestos a lavar los plásticos antes de separarlos. Por lo tanto, si se alenta a las personas a que laven los plásticos, es muy probable que lo hagan.

Tabla 1. Porcentaje de Participantes dispuestos a lavar los plásticos

	Sí	No	Tal vez
Lavaría	75.0	7.1	17.9

Recolección de los Reciclables

Nosotros recomendamos que durante la etapa temprana del programa de reciclaje en Santa Ana, se recolecten en bolsas los materiales reciclables que estan mezclados. Sin embargo, los materiales de papel no se deben juntar con los materiales mezclados, sino que se deben de poner por separado. Esto es por dos razones: primero, para prevenir que se ensucie o contamine con residuos de los otros materiales, y segundo, para prevenir complicaciones al separar los materiales, ya que el papel normalmente se adhiere a los otros materiales.

Actualmente, los materiales reciclables y la basura se recolectan usando bolsas plásticas. Por lo tanto, la misma cantidad de bolsas que se usan ahora será suficiente para la basura y los materiales reciclables ya separados. Los dueños de las casas no pagarán costos adicionales si siguen las guías para la recolección y separación de materiales reciclables de la basura. Además, el uso de un receptáculo familiar y económico promoverá la participación pública en este programa.

Recomendación para el Futuro

Como lo demuestran datos de los Estados Unidos y del Reino Unido, la participación aumenta substancialmente cuando se distribuyen, en las comunidades, recipientes duraderos y que pueden volverse a usar. En el Reino Unido, un promedio de 3.5 kilogramos de plástico se recolectaban por casa, por año, cuando se distribuyeron recipientes plásticos; mientras que solamente 1.5 kilogramos cuando se distribuyeron otros tipos de recipientes. Estos recipientes fueron muy convenientes, ya que servían porque eran mejores físicamente, y que también eran un aviso visual que les recordaba reciclar. Este método podría ser beneficioso en Santa Ana, ya que entre las excusas para no participar en el programa de reciclaje, dos respuestas comunes eran la inconveniencia y la falta de hábito.

Cuando el centro de recolección haya ganado suficiente dinero con el mercadeo de materiales reciclables semi-procesados, puede empezar a comprar estos recipientes. Por lo tanto, recomendamos que cuando sean disponibles más recursos financieros, Santa Ana debería implemenar un plan de recolección en que se distribuyen los recipientes para la recolección de plásticos a cada casa dentro de la ciudad.

Centro de Acopio de Santa Ana

Recomendamos el nuevo centro de acopio quc contenga los procesos de separación, preparación, lavado, compresión, y transporte.

La figura 2 en la siguiente página ilustra la distribución general y el flujo de procesos que recomendamos para el centro de recomendación de Santa Ana. Se refiere a los números en la diagrama en el texto siguiente, cuando describimos los procesos con más detalle.

Separación de los Reciclables

Basándonos en la distribución de los tipos de plásticos en el super mercado, hemos concluido que es posible reciclar la mayoría de los plásticos, pero no todos. No pudimos localizar ninguno del tipo #7, pero sugerimos que estos no se separen en su propia categoría, sino que se descarten y se clasifiquen como no identificables. La razón es que este tipo está compuesto por un mezcla de plásticos y cuando se derrite y se usa de nuevo, no forma un producto de plástico puro.

Como existe una demanda para todos los otros tipos de plásticos, el acopio debe

Figura 2. El Acopio Nuevo

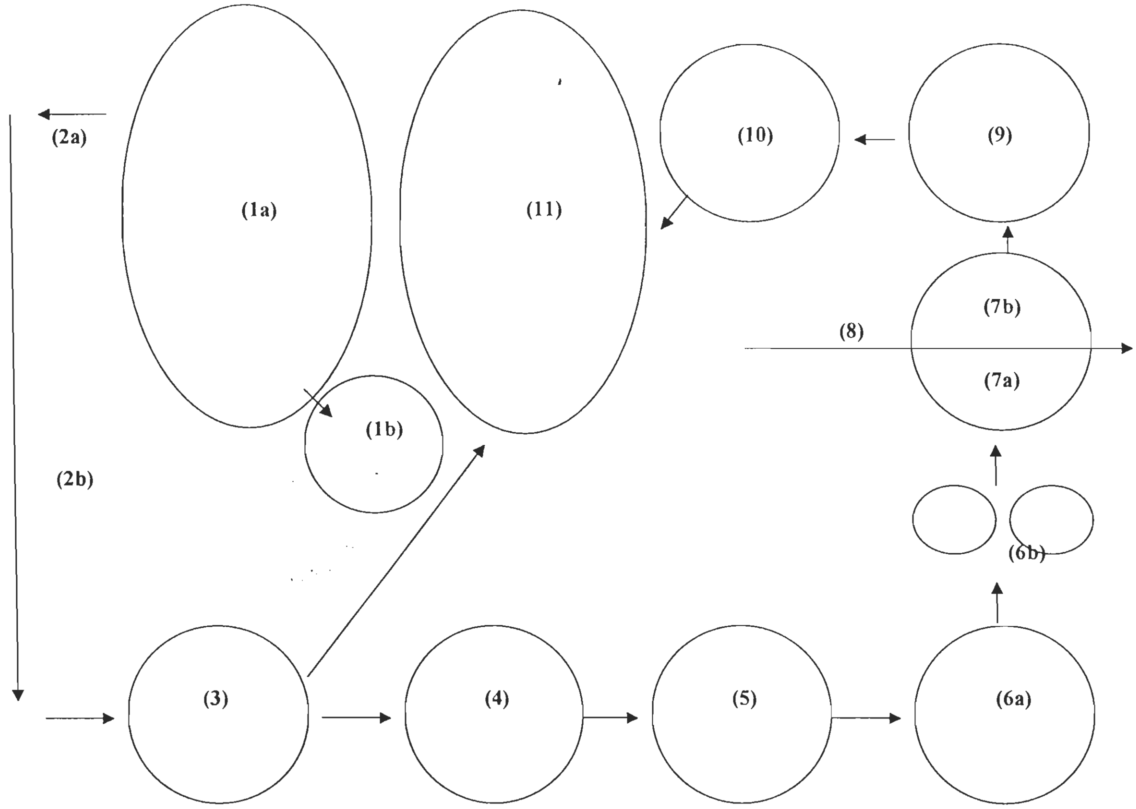
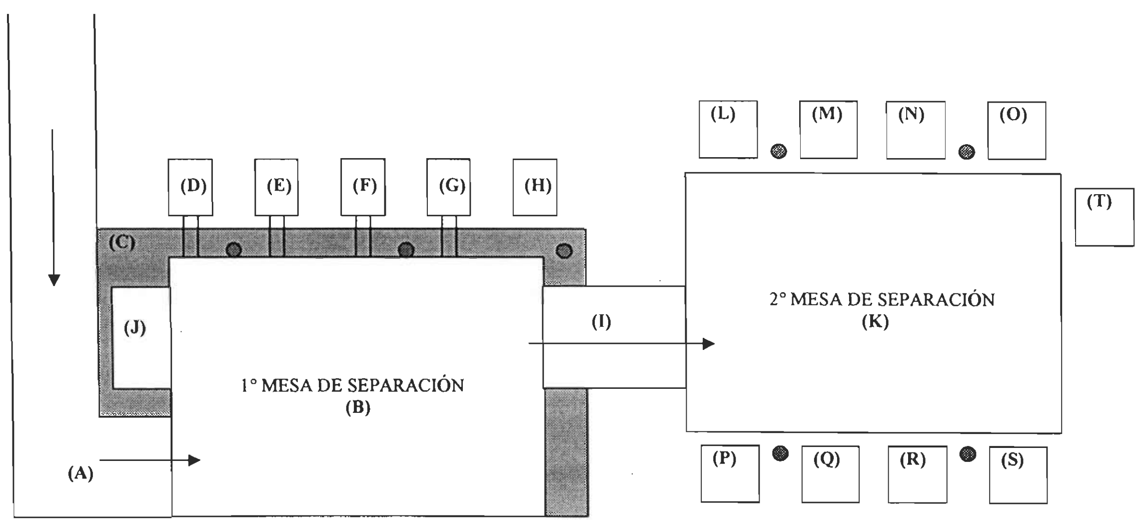


Figura 3. Diagrama de las Mesas de Separación



separarlos como está descrito abajo.

A causa de la existencia de los plásticos sin números, hemos incluido una serie de pautas en la Tabla 2, que si son seguidas, ayudarán a solucionar este problema. Recomendamos que los empleados se familiarizen con estas pautas para asegurar la separación apropiada de los tipos de plásticos. El seguir esta guía no sólo garantizará una separación precisa, sino que también reducirá el número de plásticos no identificados, llevando a un incremento en el reciclaje total.

Tabla 2. Características Distinguidas de los Plasticos

#	Abreviatura	Características Distinguidas
1	PET	claro, punto debajo, moldeado por inyección, sin rayos
2	HDPE	
	(botellas)	natural- no es claro, blanco y colorado- opaco, huele como candela al quemar, sin llama
	(bolsas)	claro, blanco y colorado, hace un sonido crujiente
3	PVC	claro, con rayos
4	LDPE	
	(envases)	opaco, flexible
	(bolsas)	claro, blanco y colorado, no hace un sonido
5	PP	colorado o claro- un nivel de transparencia entre el PET y HDPE, no es tan flexible como LDPE
6	PS	opaco, rompe cuando lo apreta, quema negro y con una llama
7	Otros	tipos y características variados

Para llevar a cabo el proceso de separación con los recursos disponibles, recomendamos que primero se usen una serie de mesas de clasificación para separar materiales mezclados y luego para separar los diferentes plásticos. En la Figura 3 de la página anterior se puede apreciar una presentación más detallada de estas mesas (los círculos oscuros en el diagrama indican dónde se sitúan los trabajadores en estas mesas). Como se mencionó en la sección de recomendaciones para la recolección en las calles, el papel se debe de recolectar por separado. Sin embargo, cualquier producto de papel que por error se haya incluido en los reciclables mezclados, se debe de eliminar y poner en un contenedor asignado para su almacenamiento (1b). Recomendamos que simultaneamente, un empleado utilize una pala para introducir los materiales reciclables mezclados (1a) & (1b) en una carretilla que será conducido por una rampa (2b) & (A) que lleva al mismo nivel de la primera mesa de clasificación (3) & (B). Los materiales reciclables se colocarán es esta mesa (C) y se clasificarán en 6 categorías: vidrio transparente (D), vidrio teñido (E), aluminio (F), lata (G), plástico sólido (I) y envolturas transparentes de plástico (H). Los empleados tirarán todos los materiales, excepto los plásticos, por rampas que llevarán a recipientes de almacenamiento separados. Los plásticos sólidos se tirarán por una rampa más ancha que llevará a una segunda mesa de clasificación. Las envolturas de plástico no se deben separar usando una rampa, ya que son endebles y de muy poco peso, es más fácil reunirlas y ponerlas en un contenedor en la mesa. Cuando la primera mesa de clasificación ha sido manualmente desalojada de todos los materiales, uno de los trabajadores barrerá el material restante utilizando una escoba de mano y lo botará en un barril que estará al lado de la mesa (J).

En la segunda mesa de clasificación (4) & (K), un equipo de trabajadores clasificará los tipos de plásticos sólidos: tipo #1 de marca Coca Cola (L), otros de tipo #1 (M), tipo natural #2 (N), de color #2 (O), tipo #3 (P), tipo #4 (Q), tipo #5 (R), tipo #6 (S), y otros – tipo #7, los no identificados, y los plásticos peligrosos (T). Estos tipos de plásticos se pondrán en contenedores para su almacenamiento temporal hasta que llegue el momento de procesarlos o desecharlos, en el caso de los clasificados como "otros".

Preparación de los Plásticos

Después de que los plásticos han sido clasificados, los plásticos serán almacenados temporalmente (5) y luego serán preparados para el proceso de lavado removiéndoles las tapas, anillos y etiquetas (6a). Dada la situación económica actual del centro de acopio de Santa Ana, recomendamos que esto se haga a mano.

Primero, los empleados quitarán y descartarán las tapas, así como los anillos de plástico, los cuales se pueden quitar con un alicate. Después cortarán o arrancarán las etiquetas de los plásticos. Recomendamos que para esto se utilize un cuchillo o una navajilla que haya sido aprobada por los administradores del centro de recolección. Además, la administración debe ser especialmente cuidadosa al escoger los trabajadores que manejarán esta estación, ya que se usa instrumentos filosos y que la seguridad es la mayor preocupación en el centro.

Como es difícil deshacerse de las etiquetas raspándolas, recomendamos que después de este proceso, los plásticos se coloquen en un baño de agual caliente. Sin embargo, los empleados deben de asegurarse de no sumergir los contenerores totalmente, ya que los contaminantes de la parte de adentro de estos plásticos pueden quedar en el agua y ensuciar el resto de los plásticos que pasen por el baño. Luego los empleados rasparán las etiquetas suavizadas.

De acuerdo a la tabla de abajo, antes de lavar los plásticos es necesario separarlos en dos recipientes (6b) dependiendo de la solubilidad de los productos que originalmente contenían. Esta fase de clasificación es el último paso de preparación, ya que luego los empleados pasarán los plásticos al area de lavado y enjuague.

Recomendación para el Futuro

En el futuro, el centro de acopio de Santa Ana, podría beneficiarse de una máquina automatizada como la que utiliza *Panamco*, que quite las etiquetas y se deshaga de cualquier adhesivo. Esta máquina haría más eficiente este paso de preparación, el cual estará tomando el mayor tiempo y trabajo en el proceso de reciclaje del centro. Además, esta máquina es constante en su nivel y calidad de trabajo, un factor que llevará a un incremento en la confianza de los consumidores de plásticos secundarios. Operar esta machina requiere dos trabajadores, y si se compra una nueva, cuesta aproximadamente ¢3.000.000.

Recomendación para el Futuro

Cuando sean disponibles más recursos financieros, el centro puede llegar a decidir que utilizar una sierra para cortar los plásticos a lo largo expondrá más de su área de superficie, incrementando la eficiencia del lavado. Tomando esto en consideración, hemos investigado tres tipos de sierras eléctricas estacionarias. Sin embargo, ninguno tiene características especiales de seguridad. Esto presenta un gran riesgo a los empleados del centro de acopio, ya que muchos no son educados ni tienen las habilidades que se requieren para utilizar este equipo.

Por lo tanto, no recomendamos que se use una sierra en este momento. Sin embargo, si en el futuro el centro de acopio decide que una sierra mejoraría el proceso de lavado notablemente, recomendamos que se ivestigue el uso de una sierra de mesa que traiga características de seguridad, tal como una capucha protectora de un tamaño considerable alrededor de la cuchilla para prevenir el contacto humano. Además, un dispositivo, montado sobre carro, a ambos lados de la cuchilla, puede utilizarse para estabilizar las botellas mientras que un trabajador empuja el aparato, en vez de que las botellas pasen por un aparato estático. Este dispositivo sería diseñado para que pare en un punto específico, previniendo que el trabajador lo lleve muy lejos y ponga sus manos en peligro por accidente.

Limpieza, Enjuagado, y Secado

Inevitablemente, porciones de las etiquetas y los adhesivos quedarán en algunos de los plásticos después del último proceso de raspado. Por esta razón, recomendamos que en el primer paso de la estación de lavado (7a), los empleados usen una solución de bicarbonato de sodio y agua y una esponja abrasiva para limpiar la superficie de los plásticos de cualquier material restante. La mezcla de bicarbonato de sodio no se tiene que enjuagar todavía, ya que los recipientes se enjuagarán en otro proceso. Sin embargo, sí es importante que en este paso no se mezclen los recipientes que contenían productos solubles en agua con aquellos que contenían productos no-solubles. Ver la Tabla 3.

Despues de este procedimiento, los empleados que están de pie a un lado del recipiente de lavado (7a) enjuagarán, utilizando solamente agua a presión, la superficie de los recipientes que contenían contaminantes solubles en agua. No hay un tiempo standard para el enjuague de los recipientes; sin embargo, cada recipiente debe ser enjuagado hasta que los contaminantes no se sientan y no se vean.

Mientras tanto, los empleados situados al otro lado del recipiente de lavado (7a), lavarán los recipientes que contenían contaminantes no-solubles en agua utilizando agua a presión, detergente biodegradable, y cepillos flexibles si es necesario.

Recomendamos que el centro de acopio consiga dos tipos de boquillas para permitir variaciones en la presión y dirección del agua. El primero será usado para limpiar botellas, y por lo tanto debe ser angosto para que pueda pasar por el cuello de las botellas y para que permita el drenaje durante el procedimiento de lavado. También será poroso para que permita rociar agua en todas direcciones dentro de la botella. Sugerimos que el centro de acopio utilize una boquilla de cocina standard como el segundo tipo para lava recipientes abiertos, como recipientes de mantequilla.

Tabla 3. Clasificación de Solubilidad

Contaminantes	**Solubilidad** Insoluble en agua: I Soluble en agua: S Peligroso: P
Aceite para el piel de bebe	I
Lejía	S, P
Gaseosas	S
Aceite de cocinar	I
Suavizante para el pelo	S
Jarabe para la tos	S
Productos lácteos	I
Jabón de laviplatos	S
Jugos	S
Agentes de limpieza para la casa	S, P
Catsup	S
Detergente para la ropa	S
Leche	I
Elixir bucal	S
Mostaza	S
Aliño para la ensalada	I
Salsas	I
Champú	S
Loción de broncear	I
Sirope, jalea, miel	S
Sabor de vainilla	S
Agua	S

Recomendamos que la administración del centro de acopio se ponga en contacto con el Dr. Obando (ver la pagina 12 para más información) para determinar el nombre, costos, la composición química y otras especificaciones del detergente biodegradable que el sugirió, ya que no nos pudo dar estos datos cuando se completó este manual.

Después de que los trabajadores lavan los recipientes, recomendamos que los enjuaguen de la misma manera que se enjuagaron los recipientes que contenían productos solubles en agua.

Después de completar el proceso de enjuague, un trabajador pondrá los recipientes a secar sobre una rejilla (9). Esta rejilla consistirá de varios niveles de bandejas de cedazo, en las que habrán perchas para estabilizar las botellas que estarán al revez. Use situarán varios abanicos en lugares estratégicos entre los niveles para incrementar el flujo de aire y acelerar el proceso de secado. También recomendamos que el área de secado esté bien ventilada, pero al mismo tiempo separada de las otras áreas del centro de acopio para prevenir re-contaminación del plástico.

Tratamiento y Eliminación de las Aguas Residuales

Hemos investigado tres tipos de tratamientos y opciones de eliminación de aguas sucias residuales para el centro de acopio de Santa Ana: estanques de tratamiento hechos por humanos, fosas sépticas, y eliminación por medio de agricultura. Los estanques de tratamiento son una serie de lagos abiertos con dimensiones que varían dependiendo de la composición específica y de la cantidad de aguas residuales que se hayan generado. Las aguas son tratadas con métodos que pueden incluir procesos fotosintéticos y metabólicos de algas o jacintos, así como procesos naturales del sol, aire y exposición al clima. Las fosas sépticas son una serie de tanques subterráneos para filtrar y asentar materiales y que eventualmente llevan a un campo de sanguijuelas o a una fuente de agua natural. El número de tanques necesarios también depende de la composición especifica y la cantidad de agua residual generada por las instalaciones. Por último, la eliminación agricultural no lleva tratamiento de las aguas, excepto por la posibilidad de que se mantenga en en tanque, y es un método en que se utilizan las aguas residuales para irrigar campos de agricultura cercanos.

Ya que se deben tomar en consideración muchos otros factores que no podemos examinar por el momento, no podemos recomendarle un método específico de tratamiento y eliminación de aguas residuales al centro de acopio (8) en este momento. Como el nuevo centro de acopio todavía no está terminado, la composición y la máxima cantidad de aguas residuales es desconocida. Además, la cantidad exacta de espacio disponible alrededor del centro, ya sea sobre y bajo tierra, tampoco han sido definidos.

Creemos que la eliminación de estas aguas utilizándolas en campos de agricultura cercanos es la mejor opción para el centro de recolección. Este método da un tratamiento barato y es una opción de eliminación, no sólo beneficiando al centro de acopio sino también a la finca. Como se recomienda el uso de detergentes biodegradables para limpiar las aguas, la alcalinidad de estos detergentes ayudan a neutralizar la tierra ácida. Además, los compuestos orgánicos que quedan en el agua residual serán una fuente de nutrientes para la vegetación.

Sin embargo, esta recomendación depende de varias condiciones, ya que no podemos determinar si va a ser necesario tener un tanque para contener el agua si no sabemos los materiales que constituyen el agua residual. Una preocupación importante es que la concentración de los detergentes biodegradables que han sido enjuagados de los recipientes de detergentes de los consumidores, pueden ser dañinos para el medio ambiente. Por esta razón se debe contratar un experto para que lleve a cabo un análisis de la composición del agua residual que contiene detergente biodegradable. Si los niveles fueran inaceptables, el centro debe determinar el tratamiento que debe instalar antes de que esta agua se lleve a los campos de agricultura.

En la siguiente página se encuentran una serie de preguntas que puede asistir en la asesoría adecuada del tratamiento y eliminación de aguas residuales.

Asesoría del Tratamiento y Método de Eliminación de las Aguas Residuales

1. ¿En metros, cuáles son las dimensiones del campo de terreno libre alrededor del centro de recolección? De campo subterráneo? (en el terreno subterráneo de ser libre de cañerías, etc.)

2. ¿Cúal es la cantidad máxima de aguas residuales generadas por el centro en cualquier día (en litros)?

3. Describa la composición del agua residual. Incluya datos de la Tabla 4.

Tabla 4. Composición de Aguas Residuales

grasas/aceites	cianuro disociable en ácido débil
potencial hidrógeno	cobre
temperatura	plomo
sólidos sedimentables	estaño
materia flotante	fenoles
mercurio	níquel
aluminio	zinc
arsénico	plata
bario	selenio
boro	sulfitos
cadmio	sulfuros
cloro residual	fluoruros
color	sumatoria de los compuestos organofosforados
cromo	sumatoria de los carbamatos
cianuro total	sumatoria de los compuestos organoclorados
cianuro libre	sustancias activas al azul de metileno
	pH

4. ¿Cuáles agentes se están utilizando para la limpieza dentro del centro de recolección? Detergentes convencionales, biodegradables, etc.? ¿Cuánto tiempo requiere este agente para degradarse o asentarse?

5. ¿Cuál es su presupesto para un sistema de tratamiento de aguas residuales? (este presupuesto debe cubrir costos iniciales así como costos de mantenimiento)

Compresión y Transporte

Cuando los plásticos limpios están secos, recomendamos que se guarden en recipientes de almacenamiento, manteniendo la separación de los diferentes plásticos para esperar el momento de compresión (10). Recomendamos que el centro de acopio de Santa Ana consiga un compresor, ya sea si se arregla con la planta de incineración de Cartago, o de cualquier otro lugar si es necesario. Comprimir los plásticos beneficiará al centro maximizando el campo de almacenamiento dentro del establecimiento, así como la cantidad de plástico que se puede transportar.

Gente Reciclando está dispuesto a pagar más por los plásticos si son llevados directamente al establecimiento. Sin embargo, el centro de acopio debe determinar si esta es la opción más beneficiosa. Nosotros recomendamos que la administración examine las especificaciones una vez que llegue el camión de recolección y que calcule el costo total de transporte por cada kilogramo de plástico. Después deben comparar este valor a la cantidad adicional que Gente Reciclado paga por plásticos entregados. Si el costo total de transporte por kilogramo excede el pago extra ofrecido por cada kilogramo de plástico, se reducen las ganancias del centro. En este caso, recomendamos que el centro acepte el precio mas bajo que ofrece Gente Reciclando por recoger el plástico en el centro de acopio de Santa Ana.

Panamco prefiere recoger los plásticos y no ofrece la opción de un precio más alto si el centro entrega los plásticos. Sin embargo, todo las tiendas de equipo que contactamos, requieren que el centro de acopio lleve los repientes plásticos de galones a su tienda. En contraste con Gente Reciclando, las tiendas de equipo piden que los recipientes no sean comprimidos, reduciendo la capacidad de transporte e incrementando los costos del centro de recolección. Ya que estos dos mercados tienen diferentes requisitos en cuanto al transporte de los plásticos, simplemente recomendamos que se cumplan ests requisitos.

Más Procesamiento y Mercados Secundarios

En las etapas iniciales del programa de Santa Ana, recomendamos que los plásticos se comercien con los tres tipos de compradores mencionados: *Gente Reciclando*, *Panamco*, y las ferreterías locales.

Específicamente, recipientes de galones de calidad, como los que no tienen abolladuras u otro tipo de daños, no se deben comprimir, sin que se deben separar y comerciar con las ferreterías. Esto trae muchas ganancias, ya que estas tiendas están dispuestas a pagar entre ¢15-25 colnes por recipiente, lo cual es equivalente a los que paga *Gente Reciclando* por cada medio kilo de plástico.

Las botellas de *Coca-Cola* de tipo #1, también deberían separarse de los otros plásticos en la mesa de clasificación secundaria, pasar por alto todos los otros procesos, y comerciarse directamente con *Panamco*. Recomendamos esto aunque cueste más trabajo en la mesa de separación, ya que se compensa al no requerir ninguno de los otros procesos. Además, *Panamco* paga ¢100 por kilogramo, el doble de lo que paga *Gente Reciclando* por recoger este plástico tipo #1 sin procesar. El precio que ofrecen hace que este esfuerzo adicional le traiga muchas ganancias al cento. Sí recomendamos que todos los plásticos de tipo #1 se comercien con *Panamco*, ya que la compañía no paga por recipientes de tipo #1 que hayan contenido productos que no sean Coca-Cola.

Por último, recomedamos que todos los plásticos que no se comercien con las ferreterías o Panamco se vendan a Gente Reciclando. Ellos buscan aceptar todo tipo de plásticos y tienen precios razonables de aproximadamente ¢30-50 colones por kilogramo de plásticos limpios usado.

Información de Contacto

Dr. Ronald Arrieta
Profesor de Química, UCR
207-5038

Dr. Eduardo Obando
Profesor de Química, UCR
207-4000

Gente Reciclando
Adriana Soto & Jonathon Molina, dueños
285-2035

Panamco Tica S.A.
División de la compañía de *Coca-Cola*
256-2020

FERRETERÍAS:

Ferretería Del Centro S.A.
Paga 25 colones por cada galón
Escazu, Costa Rica
228-0086

Ferretería El Mar
No compra los galones
Escazu, Costa Rica
289-9192

Ferretería Leja S.A.
No compra los galones
Santa Ana, Costa Rica
282-5152

Ferretería San Joaquín
Paga 20 colones por cada galón
Santa Ana, Costa Rica
282-5397

Ferretería Solis
Paga 15 colones por cada galón,
10 colones por cada litro
Escazu, Costa Rica
228-1696

Appendix M: Plastics Recycling Workshop

Santa Ana Collection Center
June 28, 2000

Purpose: To introduce our team and our project to the Santa Ana collection center employees who will aid in implementing the pilot recycling program, and to demonstrate the techniques outlined in the Recommendations Manual.

Presented by: CICA project team, with Adriana Soto of *Gente Reciclando*

Presentation Outline:

I. Introduction
  A. Presentation of team members
  B. Description of project

II. Discussion: Why is it important to recycle plastics?

III. Recommendations overview
  A. Presentation of flow-chart (See Figure 5-1) for recycling processes for the new collection center
  B. Demonstration of techniques for separating and identifying plastic containers
  C. Exercise in label removal using baking soda and water

IV. Conclusion
  A. Explanation of the importance of cleaning plastics for recycling
  B. Open discussion with collection center staff for questions and comments

Summary:

The workshop was important and necessary as it allowed the collection center staff to take an active role in the presentation of our recommendations. First, we discussed the importance of plastic recycling, whereby the workers expressed why recycling was important to them. Next, we provided Figure 5-1 as a visual representation of the sequence of plastics recycling stages we recommend be implemented at the new collection center. Afterwards, with Ms. Soto's assistance, we demonstrated methods of recognizing different types of plastic, using touch, sight, and smell. Finally, we distributed sponges and dishes containing the baking soda solution. We demonstrated the technique for scrubbing labels and adhesives from plastic bottle surfaces, and then assisted the employees as they practiced this technique themselves. In doing so, the workers were able to tactilely and visually discover how plastics may be fully cleaned of labels and adhesives, to the level demanded by secondary markets. Most importantly, the workshop connected us, the developers of the manual, with the employees who be affected by the outlined recommendations. Based upon the workers' enthusiasm for the presentation and their degree of participation in the demonstrations, we have concluded that the workshop was indeed a successful and vital supplement to the Recommendations Manual.