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# Reduce, Reuse, and Replace: A Study on Solutions to Plastic Wastes

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# **Reduce, Reuse, and Replace: A Study on Solutions to Plastic Wastes**

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An Interactive Qualifying Project  
Submitted to the faculty of  
Worcester Polytechnic Institute

May 5, 2009

By

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Project Advisor: Professor Robert W. Thompson

## **Abstract**

This project aimed to examine the quantities of plastic wastes discarded and the fate of various plastics in the environment. Our Interactive Qualifying Project was concerned with researching the possible alternatives to plastics, mainly biodegradable plastics that have been claimed to biodegrade and help environment. Moreover, it was also required to evaluate the best methods to deal with our plastic wastes that are environmentally, economically, and energy-wise viable.

## Acknowledgement

We would like to thank a number of people who greatly helped us and shared their knowledge and experiences to complete this project.

First we would like to thank faculty members, who were generous enough to take time to answer our questions; Professor Zhou, Mr. Hutson, Professor Brisson, Professor Fehribach, Professor Padir, Mr. Thomsen, Professor Dollenmayer, Professor Masamune, Miss Kumar, and Professor Pietroforte. We would also like to thank Mr. Kraskousakas, director of the Chartwells Services, and Ms. Tomaszkeski, the coordinator of the Sustainability and the manager of the Facilities systems, for providing us information on recycling programs and plastic uses in WPI.

Finally, we would like to express our sincere gratitude to our advisor, Professor Robert W. Thompson, for guiding and providing feedbacks to us throughout the project.

## Acronyms

ABS: Acrylonitrile-Butadiene-Styrene

BBzP: Butyl Benzyl Phthalate

BLL: Blood Lead Level

BPA: Bisphenol A

BPI: International Biodegradable Products Institute of the United States

BPS: Biodegradable Plastics society of Japan

DEHA: Bis(2-ethylhexyl) Adipate

DEHP: Bis(2-ethylhexyl)Phthalate

EPA: U.S. Environmental Protection Agency

HDPE: High Density Polyethylene

HIPS: High-Impact Polystyrene

LDPE: Low Density Polyethylene

LLDPE: Linear Low Density Polyethylene

MSW: Municipal Solid Waste

PAYT: "Pay-As-You-Throw"

PET: Polyethylene Terephthalate

PHA: Polyhydroxyalkanoate

PHB: Polyhydroxybutyrate

PLA: Polylactic Acid

PLGA: Poly (lactic-*co*-glycolic acid)

PP: Polypropylene

PS: Polystyrene

PUF: Polyurethane Foams

PVC: Polyvinyl Chloride

WPI: Worcester Polytechnic Institute

## Glossary

Downcycling: process where the recycled/reproduce product has inferior quality than the original product

MSW: more commonly known as trash or garbage, consists of everyday items such as product packaging, grass clippings, furniture, bottles, food scraps, newspapers, appliances, paint, and batteries (EPA).

Recyclates: recycled materials that will be used to form new products (AggRegain 2009)

Shredder residue: remaining particles after the sorting processed by the trammel in the recycling industry

Trommels: screening devices

used in the recycling industry for sorting particles of different sizes

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## Background

### Plastics

#### Definition of Plastics

Plastic is a kind of material that is commonly known and used in everyday life. To define plastic at molecular level, plastic is a kind of organic polymer, which has molecules containing long carbon chains as their backbones with repeating units. The structure of these repeating units and types of atoms play the main role in determining the characteristics of the plastic. These long carbon chains are well packed together by entanglements and Van der Waals forces between large molecules, and form a strong, usually ductile solid material. Also, additives are usually added when manufacturing of commercial plastics is carried on, in order to improve the strength, durability or grant the plastic specific characteristics.

Generally, there are two kinds of commercial plastics, thermoplastic and thermosetting plastic. Thermoplastics can be reheated, melted, and molded into different shapes, while thermosetting plastic will degrade and turn into other substances if reheated after molding.

The molecules of thermoplastics are packed together by entanglements and Van der Waals forces. When a thermoplastic is heated up, it loses its entanglements and its molecules get farther away from each other, which causes the plastic changing from solid to liquid without breaking the bonds within the molecules.

On the other hand, the molecules of thermosetting plastic are packed together not only by entanglements and Van der Waals forces, but also by the cross-links between molecules. When a thermosetting plastic is heated up, the cross-linking

bonds between molecules break apart and the plastic turns into another substance when it melts, usually by decomposing (Callister and Rethwisch, Fundamentals of Materials Science and Engineering, 3rd Ed. 2008)

### **Why traditional plastics are not biodegradable**

The nature of traditional plastics is the reason why they cannot be biodegraded. The carbon chains of traditional plastics are too long and too well packed for microorganisms to digest, but if they are broken into small pieces the microorganisms will be able to degrade them. However, the breakdown process is too long for most of the traditional plastics, if there is no any artificial processing before being thrown in a landfill is involved. Therefore, before the plastics degrade themselves naturally, more plastics will be manufactured, causing increasing plastic pollution around the world.

### **Types of Plastics**

Today, there are many different types of plastics manufactured in the plastic industry. They are applied in different areas depending on their properties. The table below summarizes names of all commonly used plastics, their properties, and applications. It shows the importance of plastic materials, since they are used in many different areas.

Table 1. Table of Different Types of Plastics [Callister , Rethwisch, Table13.12

Trade Names, Characteristics, and Typical Applications for a Number of Plastic Materials 2008]

Material Type & Structure	Trade Names	Major Application Characteristics	Typical Application
Thermoplastics			
Acrylonitrile-butadiene-styrene (ABS)	Abson Cycolac Kralastic Lustran Novodur Tybrene	Outstanding strength and toughness, resistant to heat distortion; Good electrical properties; Flammable and soluble in some organic solvents.	Refrigerator linings, lawn and garden equipment, toys, highway safety devices
Acrylics [poly (methylmethacrylate)]	Acrylite Diakon Lucite Plexiglas	Outstanding light transmission and resistance to weathering; only fair mechanical properties	Lenses, transparent aircraft enclosures, drafting equipment, outdoor signs

Fluorocarbons (PTFE or TFE)	Teflon Fluon Halar Hostaflon TF Neoflon	Chemically inert in almost all environments, excellent electrical properties; Low coefficient of friction; may be used to 260 Celsius; relatively weak and poor cold-flow properties	Anticorrosive seals, Chemical pipes and valves, bearings, anti-adhesive coatings, high-temperature electronic parts
Polyadmides (nylons)	Nylon Baylon Durethan Herox Nomex Ultramid Zytel	Good mechanical strength, abrasion resistance, and toughness; Low coefficient of friction; absorbs water and some other liquids	Bearings, gears, cams, bushings, handles, and jacketing for wires and cables
Polycarbonates	Calibre Iupilon Lexan Makrolon Merlon	Dimensionally stable; Low water absorption; transparent; very good impact	Safety helmets, lenses, light globes, bas for

		resistance and ductility; chemical resistance not outstanding	photographic film
Polyethylene	Alathon Alkathene Fortiflex Hi-fax Petrothene Rigidex Rotothene Zendel	Chemically resistant and electrically insulating; tough and relatively low coefficient of friction; low strength and poor resistance to weathering	Flexible bottles, toys, tumblers, battery parts, ice trays, film wrapping materials
Polypropylenes	Herculon Meraklon Moplen Poly-pro Pro-fax Propak Propathene	Resistance to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light	Sterlizable bottles, packaging film, TV cabinets, luggage
Polystyrenes	Carinex Dylene Hostyren Lustrex	Excellent electrical properties and optical clarity; good thermal and	Wall tile, battery cases, toys, indoor lighting

	Styron Vestron	dimensional stability; relatively inexpensive	panels, appliance housings
Vinyls	Darvic Exon Geon Pliovic Saran Tygon Vista	Good low-cost, general-purpose materials; ordinary rigid, but may be made flexible with plasticizers; often copolymerized; susceptible to heat distortion	Floor coverings, pipe, electrical wire insulation, garden hose, phonograph records
Polyesters (PET or PETE)	Celanar Dacron Eastapak Hylar Melinex Mylar Petra	One of the toughest of plastics films; excellent fatigue and tear strength, and resistance to humidity, acids, greases, oils, and solvents	Magnetic recording tapes, clothing, automotive tire cords, beverage containers
Thermosetting Polymers			
Epoxies	Araldite Epikote Epon	Excellent combination of mechanical	Electrical moldings, sinks



	Epi-rez Lekutherm Lytex	properties and corrosion resistance; good adhesion; relatively inexpensive; good electrical properties	adhesives, protective coatings, used with fiberglass laminates.
Phenolics	Bakelite Amberol Arofene Durite Resinox	Excellent thermal stability to over 150C; may be compounded with a large number of resins, fillers, etc; in expensive	Motor housings, telephones, auto distributors, electrical fixtures
Polyesters	Aropol Baygal Derakane Laminac Selectron	Excellent electrical properties and low cost; can be formulated for room- or-high-temperature use; often fiber reinforced	Helmets, fiberglass boats, auto body components, chairs, fans

### Magnitude of the Plastics Industry

From computer shells to water bottles, plastics are everywhere in our everyday life. In fact, plastics are not only important to our life, but also crucial to the economy.

According to the statistics by American Chemistry Council, the production of major plastic resins was 72.9 billion pounds. Although it decreased by a 12.3% compared to in 2007, it is still a very large amount (American Chemistry Council 2009). Also, size of the workforce involved in plastic industry is also gigantic, and change in plastic industry will impact the workers greatly. In the case of the shutdown of a plastic plant in Mt. Olive, 160 people lost their job (Triangle Business Journal 2008).

If one day, biodegradable plastics or other more environmentally viable materials replace traditional plastics, millions of workers will lose their jobs and the economy will also be impacted significantly. Being considerate of the environment is of course beneficial to society, but economy is also a crucial part of any functional society. Therefore, when we are searching for ways to solve the plastics pollution problem, the economic aspects of the plastics industry must be taken into account.

### **Reasons for using plastics**

Although plastic is not good for the environment and is creating tons of trash around the world, it still plays a very important role in our everyday life. Ian Connacher, the director of the film “Addicted to Plastics,” once said in an interview with Greenmuze: “I don't think the material is to blame. I think it is our misuse of the material as consumers, the ineffective recycling policies and lack of producer (Greenmuze staff 2008). “In fact, plastic is a very useful material that brings us convenience and makes many things possible. One of the well-known facts is its cheap price. Making packaging will cost 89% more to the consumers without the use of plastics (American Chemistry Council 2007). Except for some disadvantages, plastic is surprisingly beneficial in different aspects.

Plastic is lightweight. Without plastics, 3.98 times more material by weight would be needed for packaging; for every seven trucks needed to deliver paper to grocery stores, only one truck is needed to carry same number of plastic grocery bags. That means during transportation, a big amount of oil is saved and also less green house gases will be released (American Chemistry Council 2007).

Plastic needs less energy in production process. Foam polystyrene containers take 30 percent less amount of total energy needed to make paperboard container; by using plastic in packaging, European product manufactures annually save the equivalence of 101 million barrels of oil. Although plastic is not very environmental friendly, it does save energy and also lowers the amount of greenhouse gas emissions (Imhoff 2005).

Plastic is also durable and strong. Plastic lumber, made with recycled plastic, holds nails and screws better than wood and is virtually maintenance free. Due to the way the plastics molecules arrange, it can stay intact for a long time as well as is very strong but not brittle. Plastics are also very easy to be molded and shaped (American Chemistry Council 2007).

## **Problems of Plastics**

### **Health hazards of Plastics**

Plastics may be easy and convenient for everyday use. We cannot, however, overlook their negative impacts on our health. In the long run, overuse of plastics and lack of proper recycling are going to yield many undesirable effects on our health. Plastics are harmful to manufacture, use, and pose a great challenge of recycling at

the same time. Hence, when it comes to plastics, it is a full circle of problems and challenges that need to be resolved.

### *Manufacturing Plastics and health hazards related to it*

Chemicals used in manufacturing plastics are highly toxic, mainly carcinogens. They are known to have effects on nervous system, blood, kidneys etc. There are many additives added to plastics at the time of their production like plasticizers, which are known to be harmful. Bis(2-ethylhexyl) adipate or commonly known as DEHA is a plasticizer, which is used in PVC-based plastic wraps. DEHA has been in controversy over the past many years for its potential health hazards. It was proven to be carcinogenic and estrogenic in some lab animals. The U.S. EPA lists DEHA as a human carcinogen.

Another common incident in the field of plastic manufacturing would be lead poisoning. Lead stabilizers like lead sulfate or lead stearate are used commonly as additives in PVC plastics. When used in manufacturing process, these lead compounds are supplied in the form of powders, which exposes the workers to the risk of poisoning. In 1992, the Texas Health Department reported an investigation of lead poisoning at a manufacturer of plastic pigments. Seven out of 22 workers had blood lead level (BLL) above 40µg/dl (Coyle 2005).

Lead is a harmful chemical that can cause severe health problems. When it enters the human body, it gets distributed throughout the body like other minerals would. It can damage red blood cells and impact their ability to carry oxygen to organs and tissues that need them. Lead has the tendency to remain in bones, and over the years it causes accumulated in bones. Lead interferes with blood cell

production and calcium absorption by bones. Long-term lead poisoning has many severe health impacts like a decrease in bone growth and muscle development, damaged nervous system, speech and language problems, unconsciousness etc.

### *Leaching of chemicals*

Oftentimes, high temperatures cause plastics to leach chemicals. Harmful chemicals have been found to be leaching from plastic articles like plastic bottles and plastic containers. A harmful chemical bisphenol A, commonly known as BPA, was found to have leached out of plastic bottles made from Polycarbonate. This is a common component used in plastic bottles and also linings of metal cans. Plastic bottles made for babies contain this chemical that makes the situation even riskier. Frequent wear and tear of bottles like running it in dishwasher can actually be leading to leaching of this chemical. In fact, in a study, new and old bottles filled with room-temperature water released the same amount of BPA. These bottles released BPA up to 55 times more rapidly when exposed to boiling water (Szabo 2008).

BPA is not used in all plastic bottles. It is found in polycarbonate plastics containing a number 7 recycling code. From the animal tests conducted by scientists, it has been found out that BPA affects brain development and reproductive function. Mainly, it is known as an “endocrine disruptor” which means it can mimic the effects produced by sex hormones in the body. It is known to be able to mimic estrogen binding to the same receptors throughout the human body as natural female hormones. Human breast cancer cell growth is predicted to be promoted by this chemical. Enough studies on humans have not yet been conducted to conclude that BPA is extremely harmful to humans, but the tests on animals made so far have increased concerns among scientists

regarding their impacts on humans. When BPA was first approved to be used in food containers in 1963, its negative impacts were not well known. But studies conducted since 1976 have shown that small doses of BPA can be damaging. One study showed that in a fetal mouse prostate, receptors were stimulated with BPA at a thousand times higher rate than with estradiol, which is a sex hormone representing the major estrogen in humans. These mice later developed cancer and other health issues (Biello 2008).

The concern over BPA has become prevalent in other parts of the world as well. In 1997, Japanese manufacturers resorted to use of natural resins over BPA for lining cans when studies proved that it was leaching out of baby bottles. Even though BPA has advantages of being cheap, shatterproof, lightweight in it, there still are other alternatives to the use of BPA to avoid potential health hazards. Polyethylene and polypropylene plastics would be fine substitutes to BPA in at least some applications.

In addition to Polycarbonate, breaking down the seven plastic resin codes and dangerous chemicals it leaches, we can come up with the following categories of resins.

Polyethylene Terephthalate (PETE or PET):

It is commonly used in soft drinks, mouthwash, and detergent containers. It is known to leach “antimony trioxide” which causes respiratory and skin irritation, increased incidences of miscarriages in women and other menstrual problems under exposure for a long period of time.

## Polystyrene

It is commonly used in egg cartons, Styrofoam containers, plastic cutlery, and take out containers. It is known to leach styrene, which is also an endocrine disruptor just like BPA, known to mimic female hormone estrogen. It has the potential to cause reproductive and developmental problems in women, nervous system disorders.

## Polyvinyl chloride (PVC)

It is commonly used in toys, squeeze bottles, shampoo bottles, cooking oil bottles and even in medical tubing. PVC has been described as one of the most hazardous consumer products ever made. It leaches phthalate (DEHP) or butyl benzyl phthalate (BBzP). Just like BPA, these chemicals act as endocrine disruptors mimicking female hormone estrogen. They have also been associated with causing asthma and allergic symptoms in children, effects on spleen and kidneys, bone formation and body weight. In Europe, the use of DEHP or BBzP has been banned for making toys for kids since 1999 (Become Plastic Aware n.d.).

## *Other health problems*

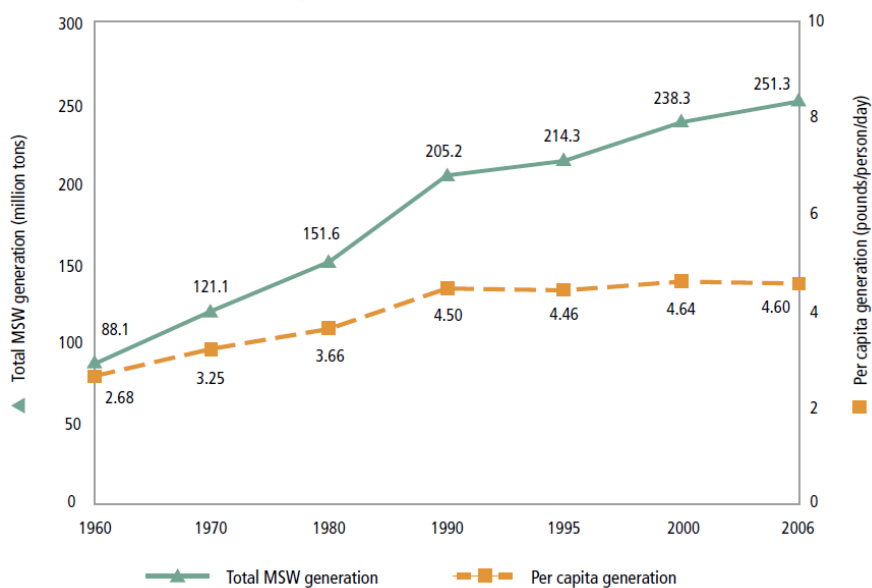
Health hazards of plastics result not only from the manufacturing process and consumption, but also from their destruction by incineration. Incineration pollutes air, water, and land exposing workers to toxic chemicals including carcinogens. Their recycling is a challenge in itself, and the fact that used plastics tossed into land never degrade adds to the problem. Over the years, they are broken down into smaller pieces that are not biodegraded by bacteria in soil. Their accumulation over the years leads to increase in toxicity of soil, which has many adverse effects on plant and animal life that are dependent on soil.

## Plastic Waste and Environmental Impacts

### Plastic Waste

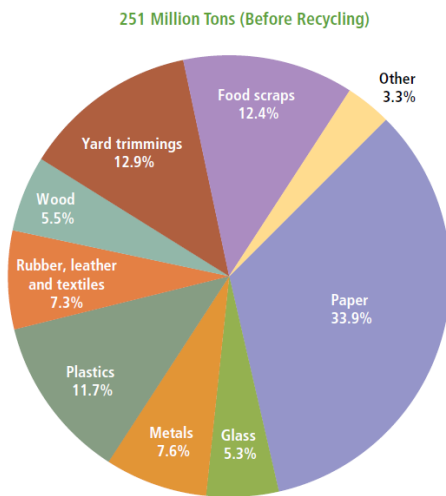
One of the biggest problems today is the waste produced annually by the use of plastics and the long-lasting effects it has on the environment. According to the recent data by EPA, Municipal Solid Waste (MSW) generated in 2006 is 251 million tons and several ways to manage MSW include source reduction, recycling, composting, landfills, and combustion in order of preference (EPA, Municipal Solid Waste 2008). The trend of MSW is shown in Figure 1 and shows that while each person in the U.S. generates about the same amount of MSW per day, the total MSW generation increased.

*Figure 1 MSW Generation Rates from 1960 to 2006 (EPA 2007, Municipal Solid Waste Generation, Recycling and Disposal in the United States)*





*Figure 2 Total MSW Generations (EPA 2007, Municipal Solid Waste Generation, Recycling and Disposal in the United States)*



According to Figure 2, plastics compose about 12 % of the total MSW generated, which is about 29.5 million tons annually. The EPA adds in the “Municipal Solid Waste Generation, Recycling, and Disposal in the U.S.: Facts and Figures for 2006” that the significant amount of materials were recycled or composted in that year, but other tables and data show that plastic has the lowest recycling rate of all materials in the MSW. The data showed that plastics has the lowest recovery rate as a percent of generation with 6.9%, and another figure showing the recycling rates of selected materials showed that the plastic materials (plastic HDPE milk and water bottles, plastic soft drink bottles, and tires) had recycling rates of average 30% while other materials were recycled at higher rates. In more detailed data, nondurable goods made of plastic had negligible recovery as percent of generation and durable goods, and containers and packaging made of plastics had recovery rates of 6.0% and 10.6%, respectively and lower than recovery rates of any other materials (EPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, 7). Table 7 in “2006 MSW Characterization Data Tables” shows data of plastics recovered and discarded in 2006 by different categories and plastic

resins. Overall, the percentage of plastics in total MSW might not be big, the plastic materials show the lowest recycling and recovery rates among other materials in MSW and the effects of plastic waste in the environment are inevitable.

The growing amount of plastic waste and the small amount of plastic being recycled have two major environmental impacts; one is the consumption of petroleum and global warming, and the other is the accumulation of plastic wastes in nature.

### *Consumption of Petroleum and Global Warming*

Traditional plastics are based on petroleum. When we blame oil companies, a growing global economy, or wars for the oil price rise, we neglect the fact that plastic manufacturing is also a huge culprit in the consumption of petroleum. For instance, every year in the U.S., 31.2 billion liters of water are bottled, and 900,000 tons of plastics are needed. Producing a water bottle takes 3.4 megajoules of energy, while a barrel of petroleum can provide 6,000 megajoules of energy. After calculations, 17.6 million barrels of oil are consumed every year just to make water bottles, enough oil to run 1.5 million cars on the U.S. roadways for an entire year (BusinessShrink 2008). Apart from that, the manufacturing process of traditional petroleum based plastics is also a huge contributor to global warming. Two to three pounds of carbon dioxide are released by producing one pound of traditional plastic (Marshall 2008). When the vast size of the plastics industry is taken into account, one can imagine how much carbon dioxide is released into the atmosphere by producing plastics.

### *Environmental Impact*

One of the best examples of the accumulation of plastic waste in the environment is seen in the Pacific Ocean. As the plastics from the waste of cargo ships float on the water and drift by the current, plastics accumulate and make huge garbage patch in the middle of the ocean (Burns 2007, 34-39). With size as big as

Alaska, it contains many different kinds of plastics. Also as plastics do not degrade but break into small and smaller pieces due to environmental forces like sunshine, wind and waves, many sea animals mistake them as food and consume them, which accumulate in their stomachs and can end up on our dishes as food. In some cases, big plastic debris and fishing nets can also entangle ocean creatures and attracting other predators, it can further result in bigger problems.

## **Solutions to the Problems of Plastics**

### **Chemical Decomposing**

Since traditional plastic is cheap and convenient, it is widely used around the world nowadays, and replacing traditional plastic with more environmental friendly but also more expensive biodegradable plastic seems difficult. Therefore, if a technology is developed to chemically break down the plastic to non-harmful molecules, it will be a good solution to the plastic pollution problem. Scientists have found a variety of methods to decompose products such as plastic bags made with traditional plastics, but unfortunately, it seems that decomposition of plastic in a large scale is still challenging.

Recently, a Canadian teenager, Daniel Burd, discovered a way to decompose plastic bags in three months, while normally it would take 20 years or even longer for plastic bags to decompose. Since polyethylene (PE), the major component of the regular plastic bags, does decompose under natural conditions after a very long time, he made an assumption that there exists a kind of bacteria that can digest and break down plastic bags. If a method is developed to isolate this kind of bacteria, it is highly possible that they can be used to decompose plastic bags. Hence, he designed a series of experiments to identify the bacteria from the soil sample collected at a local landfill

in Waterloo, Ontario, and found out that *Sphingomonas* and *Pseudomonas* are two kinds of microorganisms that can consume plastic bags (Burd 2008). Although this experiment was accomplished in a small scale, there is a possibility to develop a technology based on this experiment to decompose PE in an industrial scale, since these two kinds of bacteria were simply obtained from landfill soil. However, it might not be economical and also challenging to isolate a large amount of bacteria from soil if the concentration is low, and also collecting plastic bags before they get buried in the landfill or end up in the ocean may be problematic.

Wheelabrator Technologies Inc. is a company that successfully developed technologies to obtain energy from combusting municipal solid wastes, and is currently operating power plants. Their waste-to-energy facilities not only provide safe municipal solid waste, but also generate clean and renewable electricity for thousands of homes and businesses (Wheelabrator Technologies Inc. ). Take the power plants in Millbury as an example. It processes up to 1,500 tons of municipal solid per day, and provides electricity to more than 57,000 homes in central Massachusetts. The power plant operates in a very simple way. The refuse, which is delivered to the power plant by trucks, goes through a complete combustion process in a boiler at a temperature of 2000 Fahrenheit. Air for the combustion process is drawn from the refuse receiving building, so that the pressure in the building can remain negative. This negative pressure prevents odors and dust from escaping to outside. The heat generated from the combustion is recovered by surrounding boilers as a high-pressure steam, which will be turned into electricity later on. Since toxic gas may generate from the combustion of the waste, emission gas control is crucial. In the Millbury plant, several technologies are applied to clean the emission gas, so that harmful byproducts such as nitrogen oxide, mercury, and organic pollutants will not

be released to the environment. Today, the Wheelabrator power plants meet all current air-quality requirements with the emission gas control technologies. After the waste is completely processed, and ferrous metals are removed from the residue, the volume of the waste can be reduced by 90%, proving that this is a very efficient and environmental way to process the municipal waste (Wheelabrator Technologies Inc. ). However, these waste-to-energy power plants are designed for municipal wastes, not specifically for plastics. They do save some space in the landfill, but do not solve the plastic problem directly. But this is still a very inspiring case, proving that it is possible to build a power plant like the Wheelabrator ones, but just for plastics.

### **Reducing Use of Plastics**

One of the easiest and simplest ways to reduce plastic waste is to reduce the use of plastics in different areas. In our interviews with international faculty members, most of them agreed that they use more plastics in the U.S. than in their home countries, especially in the field of grocery bags and beverage bottles. In most of the European countries, people usually bring their own tote bags to stores since plastic bags are not given out for free, and glass bottles are preferred rather than plastic bottles. In developing countries such as India and China, people tend to reuse materials due to economic concerns, and they do not usually buy bottled water, but drink boiled tap water instead. However, in the U.S., it is rare that people bring their own shopping bags, and nearly all of the beverages and food are packaged in plastic containers.

According to the Gallop survey in 2007, most consumers in the U.S. prefer bottled water mainly out of three reasons- safety, taste, and convenience (American College of Sport Medicine 2007). However, in recent years, reports and researches show that bottled water is neither healthier nor safer than tap water. The TV show

"20/20" also conducted an experiment to prove that tap water is safe to drink. They took bottled water from five different brands and a tap water sample from a drinking fountain in the middle of the New York City, and let microbiologist Aaron Margolin from University of New Hampshire test them for bacteria. The results showed that there is no difference between tap water and bottled water. They also did a blind test on the taste, and most participants could not tell the difference among the tastes of five bottled water brands and the tap water from the New York City. In fact, some thought tap water tasted better than one of the most expensive bottled water brands imported from France, Evian (Stossel 2005). Bottled water may be a better option in developing countries where tap water is not safe to drink, but in most areas in the U.S., tap water is tested and proved to be safe. People think bottled water is safer and taste better because of advertisements and fancy labels. In fact, the packaging of bottled water is threatening the earth's health. PET, the plastic that is used to make water bottles, is derived from crude oil, and to meet America's demand, it takes up to 1.5 million barrels of oil every year. Also, making water bottles generates a large amount of unnecessary garbage, given the fact that 86% of water bottles in the U.S. do not get to be recycled (Owen 2006). Therefore, such unnecessary consumption of plastics should be reduced. However, the impact of reducing the production of bottled water on economy should also be taken into account, due to the huge size of the bottled water market. Statistics show that in 2007, 8,832 millions of gallons of bottled water were produced in the U.S., which gives producer revenues of 11705.9 dollars (International Bottled Water Association 2008).

Grocery and shopping bags is another field where the use of plastics can be reduced because it consumes probably the greatest amount of plastics. Although a lot of supermarkets claim that they recycle the plastic bags they give out, often the

collection containers are either missing or not obvious to customers. Charging for plastic bags will be a better solution, giving the customers an incentive to bring their own reusable bags. This policy has already been applied in most of the European countries for years, according to our interviews with faculties. In the U.S., nearly all supermarkets still give out plastic bags for free, generating another huge amount of unnecessary plastic wastes. However, there are some stores that are concerned enough to be taking actions. Since March of 2007, IKEA has been charging five cents per plastic bag instead of giving free plastic or paper bags at any of their outlets in the U.S. At the same time, reusable bags are also available for 59 cents. Although 5 cents might seem insignificant for most of the families in the U.S., IKEA's plastic bag tax was a huge success according to the company's statistics in 2008. The consumption of plastic bags dropped by 92%, which means about 64 million less bags were used in IKEA store in 2007. This proves that charging plastic bags in stores is applicable and efficient, and more stores in the U.S. should start to take action, since the U.S. is behind many of the developed countries in this matter, given the fact that even stores in China started to charge for plastic bags in recent years. However, there is a small drawback in IKEA's program. IKEA was expecting to donate 7 million dollars from the plastic bags sale, but in the end they only gave out 300,000, since most of the customers chose not to buy the plastic bags. However, to call this a drawback is debatable, compared to the advantages this policy brings (Jelveh 2008).

These are just a few examples of areas where the use of plastics can be reduced. Nevertheless, there are other products in our household or stores where the use of plastic can be reduced if all of us as consumers pay a little more attention, such as buying products packaged in paper instead of plastic or using reusable containers for food storage instead of plastic bags. For many, it is the lifestyle they are

used to and might be hard to change ways of life all of sudden, but for the sake of better environment and safer future, it is not hard for everyone to try to reduce the use of plastics in their everyday life.

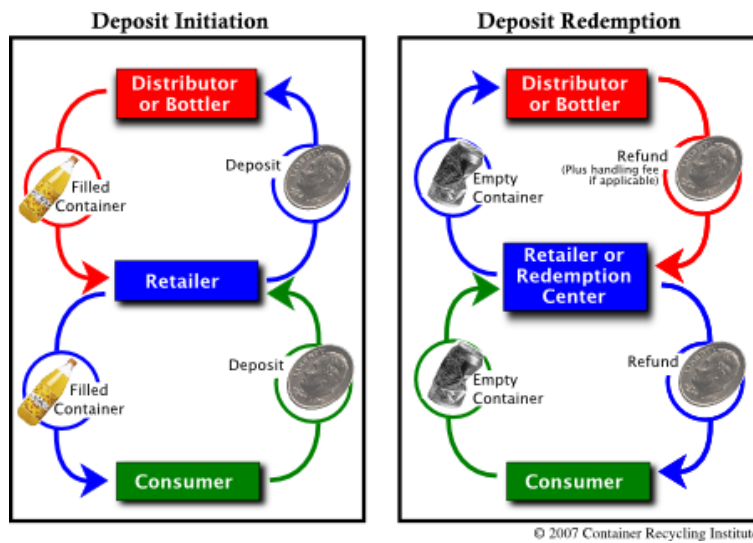
## Recycling

### *Government Regulations and Policies*

There are a number of government regulations and policies on recycling in place to reduce the harms done by the plastic wastes in the environment. Two well-known programs are bottle bills and the curbside recycling program. However, because the U.S. exists as the union of fifty different states, these programs and many other regulations vary from state to state according to the emphasis they put on the plastic waste. “Bottle Bill,” also known as “container deposit law,” was enacted to ensure a higher rate of recycling or reuse of beer, soft drinks and other beverage containers by setting minimum refundable deposits (Bottle Bill Resource Guide 2007). When a distributor sells a beverage to the retailer, the cost includes the deposit and when the customer buys the beverage, they pay the deposit to the retailer. When the customer brings the bottle back to the retailer, they receive the deposit on the cost of the beverage and retailer receives the deposit plus the handling fee in some cases. As Figure 3 shows Bottle Bill is basically funded by producers and consumers of the plastic bottles.

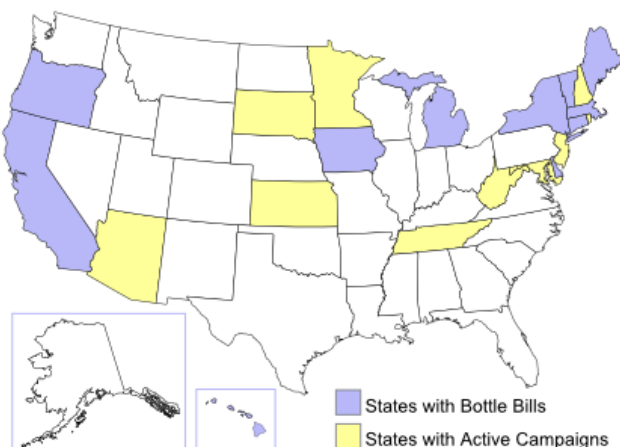


Figure 3 How the Bottle Bill Works (Bottle Bill Resource Guide 2007)



However, as noted above, regulations vary from state to state and the Bottle Bill is not active in all fifty states. Since the first Bottle Bill was passed in Vermont in 1953, only eleven states passed the Bottle Bill so far (Container Recycling Institute 2007). Thus, among fifty states in the U.S., not even half of them have an active Bottle Bill that will encourage consumers to recycle plastic bottles. The figure below shows the number of states with Bottle Bills and the number of states with active campaigns.

Figure 4 the States with Bottle Bills (Container Recycling Institute 2007)



Besides Bottle Bills, curbside recycling programs, targeting the recyclables mainly from the household, are other widely used recycling programs in the U.S.

Usually the program runs locally through city or town governments by their designated private companies. On certain day of every week, the company picks up the bins of recyclable products and takes them to the plants nearby to recycle, decompose or land fill. In city of Worcester, the curbside trash and recycling program runs every week through Casella, a local waste management company, and takes rinsed plastic from resin number 1 to 7, metal, glass bottles, aluminum, and paper (City of Worcester 2008). According to different companies running the local programs, there are different restrictions on things to put or not put on the bins, such as certain resins of the plastics. The curbside is more widespread as Table 2 shows that more than 80% of the U.S. populations have access to about 8700 available programs.

*Table 2 Number of Population Served by Curbside Programs in 2007 (EPA 2007, 2006 MSW Characterization Data Tables)*

Region	Number of Programs	Population* (in thousands)	Population Served	
			(in thousands)	Percent**
NORTHEAST	3,299	50,557	42,592	84%
SOUTH	797	84,524	25,386	30%
MIDWEST	3,749	46,473	28,236	61%
WEST	814	63,985	48,702	76%
<i>Total</i>	<u>8,659</u>	<u>245,539</u>	<u>144,916</u>	59%
Total U.S. Population		301,621		

\* Population in states reporting data  
 \*\* Percent of population served by curbside programs was calculated using population of states reporting data.  
 Source: U.S. Census Bureau 2007, *BioCycle* April 2006, California Integrated Waste Management Board, Illinois Recycling Association, www.coloradocurbside.com, Nebraska State Recycling Association, Pennsylvania Department of Environmental Protection

Two widely available recycling programs, Bottle Bill and the curbside program, in the U.S. complement each other for limitations they have. While Bottle Bill only targets beverage bottles, the curbside program targets any recyclables from household and consumers. Also the financial incentives of the Bottle Bill encourage

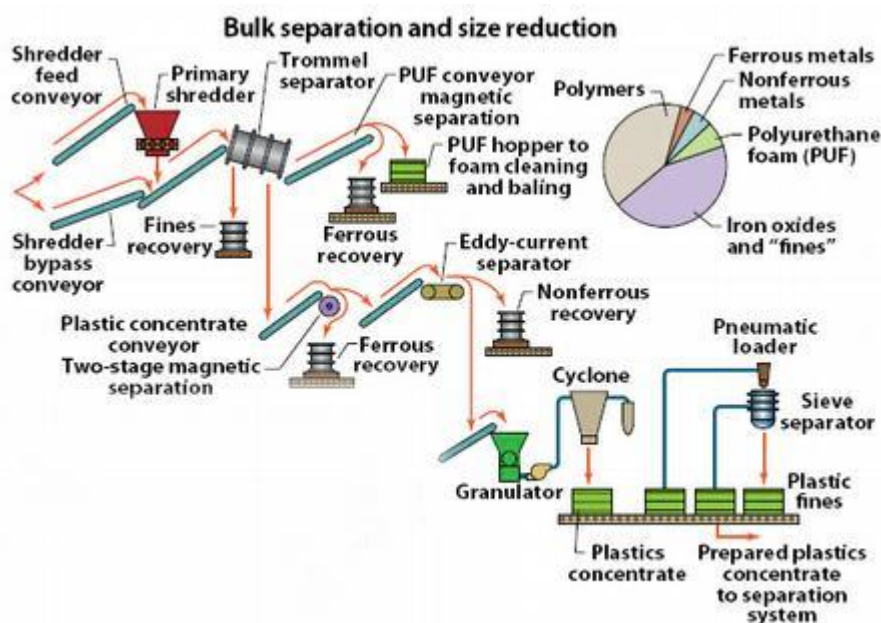
consumers to recycle more plastic bottles, one of the areas with most plastic consumption.

### *Recycling Technology*

Recycling plastics to make new products is not as easy as we might think. For example, obsolete metal containing products such as automobiles and white goods are first turned into fist-sized chunk by giant hammer mills. Then, those chunks go through processes involving air classification of the lightweight fraction, followed by one or multi-stages of magnetic removal of ferrous metals. After that, trommels and screens are used to remove particles smaller than about 5/8 inch. Then, nonferrous metals are recovered by one or more stages of eddy-current separations that leave the materials called shredder residue behind. It is simply a mixture of polymers containing small fraction of impurities. For each ton of metal, 500 lbs of shredder residue is usually recovered. Historically, this byproduct has been mostly ending up in a landfill, since recycling of metal-containing products is mainly driven by the value of metal. However, in the past fifteen years, polymers and composites have been more commonly used in automobiles and white good. Therefore, recycling of shredder residue becomes necessary and profitable. In traditional separation processes for polymer recovery, solid particles are separated by their densities and these methods usually work on certain thermoplastics. But shredder residue may have overlapping densities and shapes, which makes it hard to get materials with enough purity. Such impurities will lead to changes in properties when the shredder residue is further processed to produce plastics and cause devaluation in the regenerated plastics.

Argonne National Laboratory and American Chemistry Council are working on advancing the recycling process by researching on a better process to recover polymeric materials from shredder residue with nearly same properties as the original. In this new technology, the shredder residue goes through a process called bulk separation, where impurities such as metal, polyurethane foams (PUF) and fiber pieces are separated from polymers and produce polymer concentrate. The polymer concentrate gets further purified by processing under a vibrating screen to remove light materials. After that, it will enter another process called froth flotation where different polymers are separated. About one-third of the shredder residue is recovered as a polymer concentrate after the bulk separation.

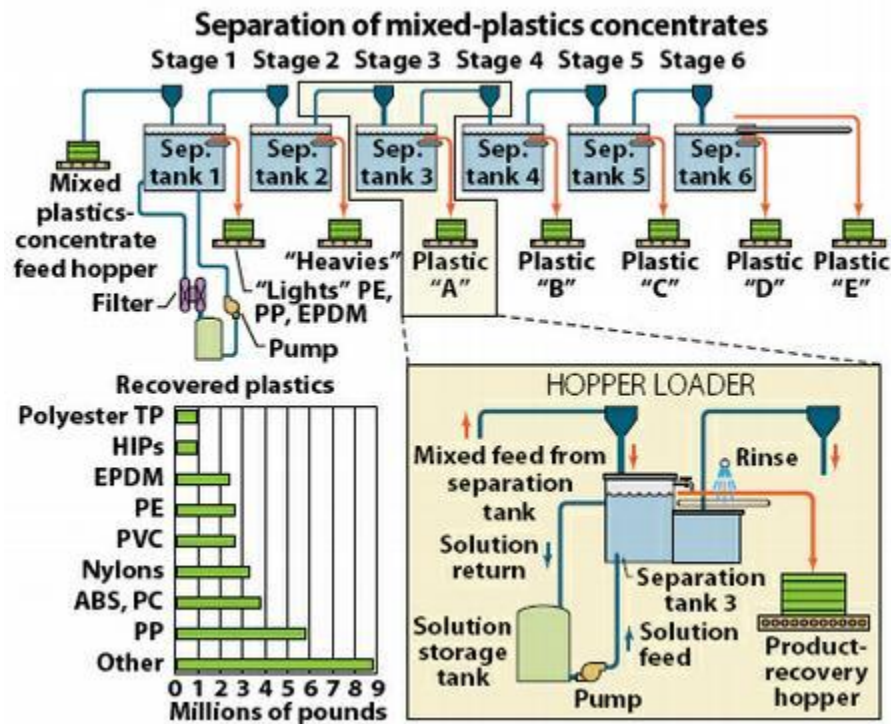
Figure 5 Bulk separation and size reduction process (Hoffman 2008)



In the process called froth flotation, a series of six separation tanks is used. Each tank contains a different solution. Due to the difference in solubility of different polymers, one or more of the targeted plastics can be separated by the

solvent in each tank. Also, light materials such as wood and polyolefin will float in the first tank, and therefore can be removed.

Figure 6 Froth flotation process (Hoffman 2008)



The froth flotation process was first developed to separate acrylonitrile-butadiene-styrene (ABS) from high-impact polystyrene (HIPS). In order to prove the practicability of this method, Argonne built and operated a large-scale pilot plan at the Appliance Recycling Center of America’s Minneapolis facility. The pilot plant recovered ABS at purities of more than 99% and at yields of more than 80%. The recovered ABS has a purity that is high enough to be successfully reused. Therefore, Argonne adapted such process to separate plastics from a mixed-stream waste containing polyolefin, styrenics and rubber. The pilot plan recovered 90% of the polymers in the shredder residue and 90% of ferrous and non ferrous metals.

Argonne also considered the PUF recovery in the recycling of metal-containing product. To make the recovery of PUF profitable, they need to develop an economical recovery process, as well as recover a high quality product. Argonne found that high quality foam can be produced, but it is not economical to separate foam manually. However, researchers from several organizations involved have developed an economical process to recover foam from shredder residue manually. Economic analysis indicates that a plant will be profitable after 2 years of operation, with an annual production of 1000 tons of foam (Hoffman 2008).

### *Problems with Recycling*

#### Not Enough Materials for Recycling

The plastic recycling industry in the U.S. is facing a serious problem now – there are not enough raw materials to process due to the failure in collecting enough recyclables. Although many people in the U.S. think that when they put plastic in the recycling bin, all of it will be recycled when only 5% of the plastics can actually be recycled annually (Greenmuze staff 2008). As a consequence, barely 25% of plastic bottles and containers produced in the U.S. annually get recycled. Since it depends on the consumers of plastic materials to sort out the recycling materials afterwards, the problem should be addressed beginning from the consumers. Therefore, it is important to educate consumers to sort materials in a right way and to give incentives to consumers for recycling. New York and San Francisco are two of the cities that are dedicated to improving their recycling systems, and they have set good examples for different solutions related to the lack of raw materials.

In the New York City, the recycling process starts by putting paper in one container, and glass, metals, and plastics in another, in which about 13 weight % is plastics. The overall residential diversion rate of the city is 18%, whereas sometimes the diversion rate can be as high as 36%, but due to the lack of attention of consumers, half of the materials that should be recycled end up in regular trash. The city, however, has been trying to increase the diversion rate. Their goal is to get a 25% of diversion rate by the end of the year (2007). In longer term, the city is trying to reach a 70% recycle rate of all municipal waste, including commercial trash, by 2015. New York City has considered including all rigid plastic in the recycling program, while now plastics containers such as clear, thermoformed clam shells and HDPE soda cups are excluded since their properties differ from those of blow-molded plastic bottles. Since all types of plastics will be put in the container for recyclables, the public will be less confused. Thus less plastic that should be recycled will get thrown into regular trash by mistake. However, such a system will only increase the diversion rate by 0.4%, which is not significant enough. To increase the diversion rate dramatically, building composting facilities will be a good solution, given that 39% of the waste stream is organic materials, but finding a site for the facility will be a challenge to the city (Tullo 2007).

San Francisco, as a model city for recycling in the U.S., has successfully reached a diversion rate of 69% in 2005, and is seeking to increase to 75% by 2010. The strong “environmental ethic” in the San Francisco community, as well as twelve distinct recycling programs designed for single-family homes, restaurants, apartment buildings, and the like, attribute to a high number of diversion rate. Also, the city’s “pay-as-you-throw” (PAYT) system creates a

strong financial incentive for people to reduce the amount of trash they create. Residents may pay \$23.58 per month for weekly pickup of a 32 gallon black container that holds regular trash that goes to the landfill, and at the same time, the service also empties bins for recyclables and compostable materials. If a resident can recycle more and generate less waste, a 20-gal bin with 25% discount will be offered. Compare to the recycling system in New York City, in which the cost of six bags of trash on regular collecting day is already included in the taxes, the PAYT system is clearly more reasonable and environmental (Tullo 2007)

#### Downcycling

Despite the effort to recycle plastics, one of the biggest problems with recycling plastics is downcycling. The term, popularized by the book, *Cradle to Cradle: Remaking the Way We Make Things*, by William McDonough and Michael Braungart, means that the quality of the material reduces over time and the quality of the recycled product is inferior compared to that of the original product (p.56). The downcycling in plastics is worse than that of glass or aluminum. From many kinds of plastics collected, only 2 to 5% of plastics, such as plastic bottles, can actually be recycled and they are usually downcycled to products such as plastic chairs, fleece jackets, non-food containers, commercial-grade carpet, lumber, speed bump or park benches (Greenmuze staff 2008).

When plastics are forced to be recycled to different products, they cannot be made into the product with same quality and end up being harmful because of their chemical properties and how they were made in the beginning. Plastics can be made into limitless products and can have different physical properties, like color, from different additives. Thus, it is extremely hard to recycle and end up as a cheap and



amorphous product with lower quality (Greenmuze staff 2008) .Also when plastics are recycled, the polymer chains composing the plastic are broken down and weaken the strength of the plastic, making it not suitable for high-end use. For example, #1 can be degraded after about five cycles (Rademacher 1999). Thus, to attain the desired product, more chemicals and additives, such as antimony, catalytic residues, UV stabilizers, plasticizers and antioxidants, are added to the recycled products (McDonough and Braungart 2002, 58). Although the plastics were recycled with good intentions, often it leads to another problem of having harmful products as household goods contaminating biosphere (Tolunay 2003).

One of the problems or disadvantages of downcycling plastic has to do with economy of the market. Because the recycling process attempts to force materials to have longer lifetimes than they were originally made for, the conversion is complicated expanding energy and resources (McDonough and Braungart 2002, 59). Thus, recycling for plastics can be more expensive for businesses. One of the regional recycling manager at Waste Management Inc.'s in San Leandro said that "Plastics is the least profitable part of the business, and it may not even be fair to say that it is profitable at all (Rademacher, 1999)." Also, recycling of plastics goes through open-loop system, where there is a disconnection between manufacturers and the consumers (Greenmuze staff, 2008). Although the recycling would reduce markets for virgin products, plastic cannot go through the closed-loop recycling processes like glass or aluminum. For example, in Coca-Cola, there are over 20 million plastic soda bottles produced in the U.S. everyday, there are no recycled plastic and they are not responsible for disposing containers. Thus, the manufacturers are not responsible for disposal but encourage recycling while they are making containers that are difficult to recycle (Rademacher, 1999).

## Biodegradable Plastics

### *List of ingredients for making biodegradable plastics*

Hydro-biodegradable plastics are prepared in the following manners.

Using renewable resources like plants (starch)

Starch is obtained from corn, wheat or potatoes where they occur as carbohydrates serving as their energy source. However, starch is not used directly to make plastics because of its ability to dissolve in water. If plastics were directly made from starch without any kind of chemical modification, then, articles made from such plastics will swell and deform when exposed to moisture. This is why starch is first modified into a different polymer. The process by which this modification is carried out is quite simple to comprehend. Microorganisms transform starch harvested from crops into a monomer, lactic acid. Lactic acid then undergoes a chemical treatment that results in the linking of molecules of lactic acid into long chains or polymers. These chains form plastics commonly used called polylactide (PLA).

Using bacteria

Science has made tremendous progress over the years. One of the fascinating aspects of science has been utilizing organisms around us for the betterment of environment and our lives in general. Another significant measure of making biodegradable plastics involves using bacteria in the process. They are simply grown in culture and are later used to produce granules of plastic called Polyhydroxyalkanoate (PHA) inside their cells.

It is important to have an idea of how these bacteria can help humans deal with one of the biggest problems of the recent times- increasing use of plastics

and environmental hazards related to it. Many kinds of bacteria are able to produce a substance known as Polyhydroxybutyrate, or PHB. This substance functions as a source of energy for these bacteria, just like the use of stored fat in humans. PHB, interestingly enough, is a kind of biodegradable plastic. Scientists have received tremendous success out of this natural process occurring inside the body of bacteria. These bacteria are fed sugar in the right amounts to carry out a fermentation process so that PHB is produced in the desired amounts. Taking it one step further, scientists have also engineered methods to produce PHB by genetically modifying plants by inserting genes from such bacteria into plants like corn to produce PHB.

#### Oxo-biodegradable plastics

These plastics are made from a by-product of oil refining. One of the reasons why oxo-biodegradable plastics are highly considerable as an option to conventional plastics is the fact that they can be produced by a bi-product that would otherwise be wasted. From environmental point of view, it can be proved to be highly useful to make good use of a by-product instead of wasting it. Also, these plastics can be manufactured with the same machinery and workforce that would be required to make conventional plastics. Hence, from financial point of view, there is a very little or no additional cost to make oxo-biodegradable plastics than making conventional plastics. Additionally, these plastics can be programmed to degrade in the desired amount of time while being manufactured which gives them advantage from conventional plastics. Until they degrade, they possess the same strength and other characters as that of conventional plastics.

## *Pros and cons*

### Economic point of view

Unfortunately, as with PLA, PHA is significantly more expensive to produce and that is the most important reason why it is not yet successful to replace the traditional petrochemical plastics. At present, biodegradable plastics in the market are from 2 to 10 times more expensive than ordinary traditional plastics. Hydro-biodegradable plastics are a little more costly to manufacture than conventional plastics. Another common problem they pose is that they cannot be easily recycled in an ordinary recycling plant. They require special treatment to be recycled. Oxo-biodegradable plastics, can, however be considered as a viable option because they can be manufactured with the same technology and workforce that would be employed in manufacturing conventional plastics. Also, they can be easily recycled and be made from recyclates. This can be a practical approach because making further use of recyclates can be beneficial from economic point of view.

In either case, the most important point that needs to be considered is that when we are buying traditional plastics, we are not paying for its collection and disposal after its use. If we consider all these costs, traditional plastics would cost more than biodegradable ones. Therefore, a little bit of additional cost required for manufacturing of hydro-biodegradable plastics or oxo-biodegradable plastics has to be overlooked, because they do not require as much cost for collection and disposal as traditional plastics would.

## Energy

For starch based plastics, agricultural aspects come into play. Plants like wheat, corn and potatoes are grown to produce hydro-biodegradable plastics. Growing plants for manufacturing plastics can be costly in addition to the consumption of land or space and labor. Using bacteria to produce PHBs by fermentation is a scientific as well as more reliable process. Once the bacteria are grown in a culture and treated with right amounts of sugar, the production of PHBs is almost unhindered. Such security cannot always be expected from starch based plastics because growth and development of plants depends on a lot of environmental factors. Technology used in production of PHA is still in its developmental stages and energy consumption can be reduced further by getting rid of fermentation step or by making use of wasted food for livestock. Other than using crops like corn and starch, other crops like sugarcane from Brazil can be used to lower energy needs.

The primary feedstock is currently corn. As biodegradable plastics make use of renewable resources (starch based), it poses a challenge for increment in food prices. With the increase in their production, more land/space is required to keep up with the demand, PLA). For the US to meet its current output of plastics production with BPs, it would require 1.62 square meters per kilogram produced.

Oxo-biodegradable plastics are simply made from by-products of oil refining and as a result there is not much consumption of energy involved in its manufacture. Fuels and oils are needed for engines in everyday lives anyway. Unless the oil resources are left underground, carbon dioxide is always released and thus, using the by-product instead of wasting it at the refinery and emitting

carbon dioxide to the atmosphere, is an environmentally as well as economically suited idea.

#### Environment

From an environmental point of view, materials used for manufacturing biodegradable plastics have mainly positive effects. Since starch is mainly obtained from natural sources like plants, its effects are usually in favor of the environment. Except for the fact that growing such plants requires land and suitable environmental conditions, the outcome of such efforts is environment-friendly.

Hydro-biodegradable plastics, since they are made from starch, need microorganisms to degrade them. In the presence of suitable conditions, they can degrade to a point of metabolism by microorganisms. This, in turn, reduces litter and is environmentally favorable. However, this degradation takes a long time as it is a very slow process. They need to be subjected to a highly microbial environment such as a compost heap before they begin to degrade. In order to make their use more widespread, it is important to come up with better composting methods.

Oxo-biodegradable plastics can degrade more easily than hydro-biodegradable plastics. They can degrade even when no moisture is present. Also, their rate of degradation is controllable as their life-span can be controlled while they are being manufactured. When being degraded, carbon is released slowly from these plastics, thereby serving as a food source for plants simultaneously.

However, there are negative impacts of these plastics in the environment. Petroleum based biodegradable plastics contribute to global warming. Carbon dioxide is released through the previously stored carbon. But, for the degree of advantages they bring, a few negative aspects can be easily overlooked.

#### *The Market for biodegradable plastics:*

The market for biodegradable plastics is dependent on a lot of factors expanding from its cost to acceptance by people over traditional plastics. Any kind of change needs time to be accepted and so it goes with the acceptance of these plastics. We have grown up all our lives being accustomed to using readily available traditional plastics that are convenient and cheap to use. Thus, the idea of introducing an expensive alternative, just because it is beneficial from environmental point of view, is unappealing.

Breaking down the factors that might play a role in determining the market for these plastics, one can come up with the following issues.

#### *Achieving total biodegradability*

Terms like “disintegrate,” “decompose,” “degrade,” and “biodegrade” all hold different meanings. When we talk about biodegradable plastics, we often assume them to be easily able to degrade by the effects of the nature over time. However, we may have to rethink the matter because the kind of biodegradable plastics that exist in our ideal imagination would be “green plastics.” Many biodegradable plastics are made from a blend of starch derivatives and conventional petroleum-based polymers. Even though the starch molecules in them are broken down by bacteria when exposed to suitable environments like warm and moist soil, a countless number of small pieces of plastics are still left

behind. These plastic pieces cover only a slightly less mass compared to the original product. Furthermore, these tiny pieces of plastics left behind simply occupy space in the soil and will pile up over time. They do not contribute to providing nutrients to the soil and sometimes may yield toxic effects adversely affecting the organisms in the soil and plants. Thus, achieving total biodegradability in biodegradable plastics making it “green” would be the first step to insuring a good future for them (Kissell 2005).

Due to cost barrier, many so-called biodegradable plastics are only semi-biodegradable. Polyhydroxyalkonate (PHA) biopolymers are completely biodegradable. These are not produced widely enough to be used in the manufacture of biodegradable plastics However, it is to be noted that there can be many possible blends of polymers that enable the final product to be more easily biodegradable.

Scientists have made many interesting recent developments in the field. One of them is the invention of biodegradable plastics that can be tossed into sea water. Every day, great amounts of shipped materials are disposed in sea water where they linger for years and years affecting sea life adversely. Researcher Robson Storey, a polymer scientist at University of Southern Mississippi, points out the importance of such biodegradable plastics because they are sustainable and are useful from environmental point of view as well. When exposed to seawater, the new plastics can dissolve in as few as 20 days (Choi 2007). These plastics are made of polyurethane modified to incorporate a biodegradable compound known as PLGA. This is similar to what has been used in medical sutures over the years. Hence, it has been a tested and tried material. These



plastics are going to be denser than sea water and will sink instead of floating which is going to prevent the washing up on the shores and coastlines.

Talking about additives that can increase the biodegradability of plastics, there are many possible approaches which are as follows (The Solutions For Plastic n.d.).

#### Modification of existing materials

Thin matrix of conventional polythene is filled in with starch to prepare partially biodegradable plastic bags. Microorganisms feed on the starch when the bags are dumped leaving behind polythene film structure which soon disintegrates. In order to develop fully biodegradable plastics, scientists have been involved all over the world. In the US, Warner Lambert is involved in development of starch-based fully biodegradable plastics. It is going to be composed of 80% starch and additives like plasticizers which will be used to improve processing and also to make them tougher. The remarkable aspect of these newly developed plastics will be their versatility in use. They can be used in disposable items like cups and trays to making capsules for drugs.

#### Chemical co-polymerization of known biodegradable materials

Using known biodegradable materials in combination with additives to enhance biodegradability has been another goal for scientists involved in the field all over the world. The Sekisui Chemical Group is a company operating in about 20 countries with over 200 companies and is based in Japan. This company has developed a new plastic by co-polymerization of two different biodegradable chemicals based on aliphatic polyester derivatives. This plastic is based on polyester which is decomposed with the help of enzymes like lipase to

products like water and carbon dioxide causing no further contamination as in other biodegradable plastics. This plastic is also claimed to be stronger than polyethylene having faster biodegradability. It has been claimed that a film of 100 micron thickness of this plastic is totally decomposed in soil in just two months (The Solutions For Plastic n.d.). Even though these plastics already have high biodegradability, their biodegradability is always controllable based on the conditions of polymerization. Another advantage of this plastic is that it is a thermoplastic and is easily recyclable. Another company called Tubiz Plastics, which is a Belgium based subsidiary by Rhone Poulenc, has developed a new biodegradable plastic by the name of “Bioceta” which is simply based on cellulose diacetate. They use additives that not only plasticize but also accelerate degradation by microorganisms.

#### *Use of biopolymers for making plastics*

Scientists have also come up with other alternatives which include genetically engineering micro-organisms and plants to produce polymers for biodegradable plastics. These plastics are named bioplastics. Their biodegradability, however, depends on factors like the microbial activity of the environment and surface area to which they are exposed. Despite their biodegradability, the PHAs still have good resistance to water and moisture vapor, and are stable when being used or stored.

#### *Awareness in people about their advantages over traditional plastics*

No matter how much involvement scientists show in the field, not much can be achieved unless people are aware enough to realize the differences between these two types of plastics and make the right choice. Hence, public

awareness plays a vital role in determining the market of biodegradable plastics. According to a survey taken among 500 people in April 2007, 70% of Americans were unaware of the fact that plastics are made of crude oil. 40% also believed that all plastics are biodegradable. With the right kind of information, people are willing to make choices that are beneficial for the environment. With simple facts and figures, we can get a point across and make people think and care more. It takes approximately 2 million barrels of crude oil to make plastics each day and only six percent of plastics are recycled according to the U.S. Environmental Protection Agency (Raising environmental awareness 2007). Such facts and figures can help people realize why they should choose biodegradable plastics over traditional plastics.

Not just from an environmental point of view, plastics production involves great health risks as well. Chemicals released in plastics production can cause birth defects and damage the nervous system, blood, kidneys, etc. Even the plastics used in our households can release harmful toxins especially in case of fire. Health hazards of plastics will be discussed more under the particular topic.

Pop Sustainability is a non-profit organization launched in 1998 in New York City. It has been involved in raising awareness in people about adverse effects of traditional plastics and advantages of biodegradable plastics. New York City government has endorsed and participated in a public private sector effort to raise awareness and educate NYC citizens about biodegradable plastics. Pop Sustainability has undertaken a full scale awareness and action campaign targeting young people and college students to publicly support the adoption of bills in favor of biodegradable plastics with media coverage to get the point across to general audiences.

### *Response from governments to their use and regulation of laws related to them*

For the market of biodegradable plastics to foster, government involvement is crucial. All the new moves and involvements in the field, if backed by government mandates, can yield the best results and also ensure greater public participation. A news article published in “The Times of Malta” in February 2009 announced the government of Malta waiving the eco tax on biodegradable plastics. The aim of the tax is to eliminate, or reduce, the 40 million plastic bags used by the Maltese every year. The eco tax, to be introduced on March 1, would impose a hefty €0.15 on each bag (Xuereb 2009). The production of biodegradable bags is regulated by strict European laws.

The government of the Papua New Guinea has recently placed a ban on the use of plastic shopping bags. The importation, manufacturing, sale, and use of non-biodegradable plastic shopping bags will be banned as of March 31, 2009. This is one of the most recent developments from the government sector in the field. Environment and Conservation Minister Benny Allen said in that notice that the environment policy was enacted into law under the Environment Act 2000 (PNG Government bans plastic bags 2009).

In the U.S., almost all plastic six-pack rings for beverages have been made of photodegradable LDPE plastic since the early 1990's. This is not entirely helpful because photodegradable plastics do not solve a lot of problems. They require 6-8 weeks of sunlight to degrade and won't degrade if buried. However, at least 16 states-including Massachusetts, New York, and Rhode Island, have passed laws that require six-pack holders to be biodegradable (which are marked by a small diamond between the rings).

The Biodegradable Plastics Society of Japan (BPS) and the International Biodegradable Products Institute of the United States (BPI) have announced the signing of an agreement. This will mainly act towards cooperating in the development of comparable tests and standards for biodegradable plastic products. Eventually, this will result in the recognition of each other's certifications, facilitating the approval process for manufacturers. Biodegradable plastics are evolving on a global basis and such actions speak for this.

#### *Areas where they can be used*

The market for biodegradable plastics also depends on the possibility of their use in various areas/fields. The greater the number of fields they can be used in, the better their market will turn out to be. They are suitable in many areas and with the development of biodegradable plastics with differing structures, properties and degradation behaviors, many potential areas for their use have been developing. Starch based plastics are suitable in agricultural areas where no inorganic residues will occur from their use. On the other hand, biodegradable plastics with suitable pro-degrading additives are suitable for using as food waste bags because they are integrated until they undergo composting. Take-away food containers, thermoformed biscuit trays, and plastic food wrap are better off being substituted by biodegradable plastics, because at present, they are not collected and sorted for mechanical recycling. Hence, if biodegradable plastics are used in their place, they can be assimilated in compost easily.

Another important market for biodegradable plastics can be laminated paper products. Paper products used at present like hamburger wrappers and

disposal cups are coated with polyethylene layer that is biodegradation-resistant. If biodegradable plastic coatings were used on them, their degradability could be enhanced.

Wraps and bags for food scraps, food residuals have a potential area for the use of biodegradable plastics. Conventional plastics are a significant contaminant in organics processing and they reduce the marketability of the compost produced. Biodegradable plastics can be successfully used as films in fresh food wrapping and plastic wraps in catering services. A major advantage that can result from this would be that the food wasted in these areas can be directly diverted to commercial composting facilities. That is, there is no need to sort out the food wastes from the plastics.

Similarly, consumer packaging would be another potential area for the use of biodegradable plastics. Such packaging materials are not mechanically recycled as of yet, and hence would be successfully substituted by biodegradable plastics. Drinking straws, bread bags, food preparation gloves are the commonly used plastic materials in everyday lives which can be replaced by biodegradable plastics.

We often neglect landfill and its importance. By choosing biodegradable plastic films as daily landfill covers, landfill life can be greatly extended. Currently, usually soil is used as landfill cover to discourage flies but it is to be realized that using soil for the daily cover can lead up to 25% loss of available landfill space (Nolan-ITU Pty Ltd 2002).

## Examples from the Real World

### Interviews with Faculty Members from the Foreign Countries

The interviews with faculty members provided us information of the recycling programs prevalent in different countries and how people think and behave regarding plastic wastes and environmental issues. Faculty members from Turkey and European countries, Germany, Italy, Netherlands, Switzerland, and Denmark, told us that the recycling programs in their countries are mostly run by the government and that people are required to take recyclables to recycling centers and sort them into right bins, unlike curbside recycling programs. On the other hand, faculties from Japan and India mentioned that recycling programs are run by individuals or companies in their countries. Exchanging recyclables with other products is common in these countries. Also Professor Zhou, from China, mentioned that the recycling program in Shanghai is almost impossible to launch, since there is not enough space in residents' apartments to fit in recycling bins for different materials. Most of the faculty members were not sure about more efficient recycling program between the U.S. and their respective countries, as they are both quite different. For example, the curbside program in the U.S. is more convenient for people, since they do not have to go to recycling centers, however if people go to such centers, they can learn a lot more about sorting recyclables by themselves.

One of the questions we asked to all Faculty members was whether people use more plastics in the U.S. or in their home countries. Most of the Faculty members answered that people use more plastic materials in the U.S. compared to their home countries. One of the main areas where Americans use more plastics was in grocery

bags. Most of the countries do not give out plastic shopping bags for free charging a few cents similar to the U.S. Also most of them said people generally use more plastics in the U.S. on packaging. For example, bottled water in plastic containers is not common in China and India since many people boil tap water before drinking. In European countries, water comes in glass bottles to make recycling easier. Also most of the grocery stores in Europe have containers placed outside for people to drop off any unnecessary plastic bags to recycle them.

Lastly from the interviews, we gathered information on whether people in their home countries participate more on recycling programs in general and if they were more aware of plastic wastes compared to the people of the U.S. Most of the faculty members answered that peoples' participation and awareness on the matter is more except in case of a few countries like China, India, and Turkey. In European countries, government and social organizations run recycling programs and set goals and policies for recycling. Also, people are more aware about the limited resources they have including the small land area, which makes the idea of landfill not very practical. As a result, countries are encouraged to come up with viable solutions. For example, one of the towns in Japan had bad pollution problem, but now despite its small geographical size, it has one of the best recycling programs in the country. Many faculty members also agreed that educating people on the matter is important for recycling programs to run efficiently. People in most of foreign countries are encouraged to educate themselves about plastics pollution and recycling programs since they have to be able to sort out recyclables themselves and can be fined if it is not done properly. In countries like China, recycling programs are not as well developed and people are not used to participating in recycling. However, they are more aware of the plastic wastes and pollution caused by them as large population



poses a possible threat. On the other hand, most of the faculty members feel that people in the U.S. are not as aware as the people in their countries. However, recycling has become part of lives of people in the U.S. and they still participate without much knowledge and awareness on the specifics of recycling.

### Recyclemania

As the college campuses form small cities nowadays, there are large amount of resources consumed and MSW produced. Even though the campuses have their own recycling and waste minimization programs, there is still a large potential to reduce further. Thus, Recyclemania started in 2001 to raise the awareness of waste management and recycling program among college students and faculties. The colleges in the States compete to encourage each other and at the end of 10 weeks long competition, the schools are ranked by recycling and trash data according to four basic rules, which are Stephen K Gaski Per Capita Classic, Gorilla Prize, Waste Minimization, and Grand Champion. Stephen K Gaski Per Capita Classic looks at how much trash they recycle per person by dividing the total weight of recyclables by population. Recyclables for the competition include paper, cardboard, MSW, bottles and cans. Gorilla prize compares the total weight of recyclables regardless of the population. For waste minimization, they look at who can generate the least amount of both trash and recyclables and for grand champion, they compare the recycle rate by dividing the weight of recyclables by the weight of recyclables and trash combined (Recyclemania n.d.).

### WPI

Mainly through the Sustainability, WPI focused on and established a number of programs for waste minimization and recycling efforts on campus.

One of the policies the Sustainability is focusing on is the Materials Management, where they try to reduce the waste and recycle more. Targeted materials for the policy include paper, bottles, cans, corrugated cardboards, mixed electronics, consumer hazardous waste and chemical waste. For each category, there are instructions for preparation and the location, where they need to be taken, and contaminants that cannot be taken in. Beginning in March, 2008, Sustainability established the bottle and can recycling, where recyclable containers can be thrown into the appropriate bins located in residential halls and academic buildings (WPI Sustainability 2009).

In addition, we conducted two interviews with Facility System Manager and the director of Chartwells Service to focus and obtain more detailed information on the recycling of plastics. On the campus, there are two full time recyclers, who sort through the recycling items and put out bottles for the curb side. Local recyclers, from "Institutional Recycling Network," also take recyclables from the campus to the recycling center in NH. In addition, WPI is part of many collaborations and competitions among the colleges for the recycling. WPI, for the first time, participated in the Recyclemania and the survey with other colleges in the States to compare the recycling programs. In addition, there are other collaborations with Worcester Consortium colleges to improve the recycling programs.

Another interview we conducted was with the director of Chartwells Service, where we assumed that the large amounts of plastics are consumed daily. Campus center is one of the places where most plastics is consumed, from the plastic silverwares and plates for food. According to the interview, the consumption has been also increasing for years in small percentages. Due to

environmental concerns, they tried alternatives like replacing plastic plates and silverwares with china dishes and metal silverwares. However, many were thrown in the trash or stolen. Nowadays, they are trying to make a transition to using biodegradable plastics, based on starch. However, there are other concerns regarding other options, such as financial costs and properties of the biodegradable plastics, as the food service is provided by the company and they cannot only think about the environment.

WPI participated in the Recyclemania for the first time in 2009, starting in January. Prior to the actual competition, the Sustainability team held a Precyclemania for three weeks during the B term among the residential halls as a preparation for Recyclemania. Two separate categories, mixed paper and co-mingled cans, glass, and plastic bottles, were collected in each residential hall and house. Two volunteers from each residential hall meet the Precyclemania committee, who would measure recyclable containers or bags for each category and make sure the recyclables are taken away by Custodial Service, for three assigned days. The per-capita measurement (lbs/capita), used for the ranking, was calculated by dividing the weight of the recyclables by the population of the residential halls (WPI Sustainability 2008).

## Methodology

For this project, our research was primarily done by reading online sources, such as newspaper articles and data from different organizations. Although there is information available in books about the traditional plastics, the concept of biodegradable plastics being relatively new, it was easier and more convenient to look for online sources, where contents are updated regularly. Also, data on plastics consumption and recycling were easily found on websites of environmental and chemistry- related organizations on their annual reports.

As part of our research, we also conducted unstructured interviews with Faculty members of WPI. To get an idea of recycling and awareness in foreign countries compared to the U.S., we choose Faculty members from foreign countries to interview and contacted them. To cover a broader range for better comparison, we contacted few professors from countries where the recycling program is known to be well organized, such as in most European countries, and a few professors from countries where the recycling programs are not up to the mark yet, such as China and India. We prepared a set of questions focused on recycling programs for plastics and awareness in people about plastic waste as well as comparison between their home countries and the U.S. on the recycling program and consumption of plastics in general. In addition, we asked specific questions to some of the Faculty members from what we have learned about the recycling program in their home countries through research.

To add to our information of how it all works in the real world, we also conducted interviews with people involved in recycling program and the consumption of plastics at WPI. First, we had an interview with a manager from Chartwells to get

an idea of plastics consumption at the campus center and other dining areas on campus. Our interview questions focused on the areas of plastics consumption and also on the trend of plastic consumption on the campus. We also focused on how other alternative options could be implemented to reduce the use of plastics. In addition to this, we also conducted an interview with a coordinator of the Sustainability team at WPI. Our interview questions were on the recycling program on the campus and the efforts in our school to reduce the plastics. This interview gave us an opportunity to learn about how collection of wastes and recycling works at WPI and also about the ongoing participation in Recyclemania.

## Analysis

### Chemical Decomposing

Chemical decomposing is a very effective solution to plastic pollution, since the non-biodegradable property of plastic is the main cause of plastic pollution. However, no technology has been developed yet to set up an economical and effective large-scale plastic decomposing facility. But chemical decomposing is still a field that has a great potential to develop in the future.

According to our researches, there are mainly two ways to decompose conventional plastics. Decomposing plastics by microorganisms is one of them. Daniel Burd, a Canadian high school student, found out that there are three kinds of microorganisms in the earth from a landfill that can break down the molecules of plastic bags. However, since this is a relatively new discovery, it is not applied industrially yet. Its economical applicability still needs to be discussed, but according to Burd, this decomposing method is possible to be applied on an industrial scale. Another way to decompose plastics is by combustion. This is a relatively easy and inexpensive way compared to using microorganisms, however, odor and toxic gases produced during combustion is a big problem. Currently, some companies have already applied this method, and Wheelabrator Technologies Inc. is one of them. In Wheelabrator's clean energy plants, waste is burned and heat generated from combustion is turned to electricity with emission air control. These waste-to-energy plants not only handle municipal waste environmentally, but also provide electricity to households and businesses. However, these plants are not just for plastics, but are for all

municipal wastes. Moreover, for both decomposing methods, prior waste management still needs to be done. Analogous to recycling, if plastic waste is not managed properly and fed to decomposing facilities, it is highly possible that those plastic materials will still end up in landfills or in the oceans.

### Reduced use of plastics

Reducing consumption of plastics is the most direct way to reduce plastic waste. According to our research and interviews with international Faculty members, a large amount of plastic material consumed in the U.S. is unnecessary and can be reduced. Therefore, reducing consumption of plastic is an applicable solution to plastic pollution for the U.S.

In our interviews with international Faculty members, almost all of them agreed that they used more plastic materials in the U.S. than in their own countries. In developing countries such as India and China, people consume fewer plastic materials mainly out of economic concern. Since their countries are not as industrialized as the U.S., there are fewer resources for everyone. Therefore, they have to consume less or reuse what they already have. For example, people in China do not usually buy bottled water, but boil tap water to drink instead, and people in India will reuse plastic bags they get from stores. But it is interesting that in Western European countries, people also consume fewer plastics, while their countries are as developed as the U.S. This fact reveals that the lifestyle of Americans is the main contributor to the large consumption of plastic materials. One of our interviewees, Professor Dollenmayer who has been to Germany many times, reflected that the popular fast food culture of

Americans is one of the sources of unnecessary plastic consumption. It is true that in this fast world such grab-and-go food is convenient, but very often, the food and beverages are over packaged, or even if customers do not need to carry the food with them, disposable containers and cutleries are the only option. Moreover, it is very hard to manage the waste generated from fast food packaging. Thus, such plastic waste will usually end up in the landfill or ocean. Similarly, bottled water is another source of unnecessary consumption of plastics, since in the U.S., tap water is usually safe to drink, but at the same time, Americans consume more bottled water than people in any other country in the world. These cases show that there is a great possibility for the U.S. to reduce the amount of plastic materials, and experience can be gained from the European Union members. Regulations on packaging can be applied to producers. As Professor Brisson mentioned in the interview, in Germany, manufacturers have to pay a certain amount for packaging, which is usually more expensive than the regular price, so that they need to minimize the size of packaging. Also, recycling bins for packages are usually located at the door of stores, and consumers can recycle unwanted packages conveniently. In addition, European Faculty members mentioned that education is a very important factor. Since people are more educated and more aware of plastic pollution, they will be more willing to use reusable containers and shopping bag.

However, reducing consumption of plastics is not easily carried out, and it takes a long time to see the effect, since it requires a change of lifestyle. Moreover, in the U.S., there are also differences among the states, which make it difficult to apply restrictions and education. In addition, reducing consumption of plastics will impact the economy significantly, due to the massive size of the



plastic industry. Also, conventional plastics are still necessary in many aspects, and reducing the use of plastics can only slow down, but not stop, plastic pollution.

Nevertheless, reducing plastic consumption is still necessary and worth trying. Charging for plastic bags in stores and supermarkets will be a very good starting point. IKEA's success in its plastic bags tax policy proves that this is practicable in the U.S. Although today some stores will give customers a few cents as reward for bringing their own shopping bags, but usually its not noticeable to a lot of customers. On the other hand, charging for plastic bags can call customers' attention more easily, and, according to the IKEA case, customers would rather stop using plastic bags than pay extra money for them. Also, IKEA reflected that customers understood and supported their decision, which means that going green might help stores earn good reputation from customer

## Recycling

Among the existing solutions to the problems of plastics, recycling is one of the most convenient and easiest ways for everyone to participate in. There are various ways to participate through government programs or programs run by environmental organizations. More than 80% of the U.S. population has access to the curbside program run by the government (EPA 2007, 2006 MSW Characterization Data Tables). To make it more convenient for consumers, the curbside program requires no sorting of recyclables but allows everything to be thrown into the bin. In addition, there are recycling centers available at the stores in the States with active Bottle Bill.

Also as consumers, the recycling only requires one easy step of putting plastic wastes in right bins by each individual. Unlike other possible solutions, where

adjustments in lifestyle are sometimes necessary to reduce or replace uses of plastics in households, it can be done easily. Separating the plastic waste from other waste will prevent plastics to be land filled and will allow it to be recycled with other plastics of the same kind.

From the information we gathered about recycling programs and interviews we had about recycling programs in foreign countries, we could say that there is still room for improvement in recycling in the U.S. One of the things we noticed is that countries with good recycling systems and the states even in the U.S. that have enforced “Bottle Bill” are all geographically located near the places where negative impact of plastics on the environment is more noticeable. Many European countries with good recycling programs and awareness do not have enough land space to land fill wastes or are surrounded by oceans, where plastics are accumulated on shores. Also in the U.S., states like California, Oregon, Massachusetts and other states with “Bottle Bill” are mostly located by the ocean, where plastics in the water accumulate on shore affecting the ocean environment negatively. In these places, the effect of plastic wastes on the environment is observed explicitly by many consumers which drive national and state governments to take necessary actions. One of the ways to encourage consumers to recycle would be to publicize and educate more people about plastic waste and its threat to the environment.

During the interviews, most Faculty members mentioned the importance of education and awareness in the matter. Unlike the curbside program, in most European countries, consumers are required to take recyclables to the center and sort them out themselves. Because consumers are required to sort recyclables themselves, it is likely that they are more educated and aware about the plastic waste and recycling. On the other hand, the curbside programs require no sorting to make it

convenient for consumers. However, this causes confusion as people take it as they can put all recyclables in the bin while the company cannot process certain materials and have problems in the recycling process. For example, plastic grocery bags are excluded from the curbside program and consumers need to take them to stores to recycle, but some people think that all plastic materials can go in the bin. Although the zero-sorting curbside program encourages consumers to participate more in the recycling program, people are likely to be more educated about the recycling and sorting materials when they are directly involved in the process. Also, because they are required to do recycling and sorting themselves, it is obvious that most people participate out of their awareness of the negative impact plastics have on the environment, unlike in curbside recycling where people do it because it is in a way compulsory.

Another option for improvement would be introducing financial incentives. The “Bottle Bill” runs based on granting financial incentives for recycling bottles. However, there are only few states with active Bottle Bill and the Bill itself is limited only to certain beverage bottles. Also while the curbside and recycling centers run free, there are costs associated with throwing the trash away. People are required to purchase their own trash bags and the bigger volume of trash means they have to spend more on buying trash bags. The curbside is offered for free by government, but because the cost of trash bags is not as expensive, many people seem to put everything in the trash bag. Although not applicable in the U.S., in Germany where they are required to sort trash themselves, the company can charge for anything sorted in the wrong basket when they are picking up recyclables (Hamermesh 2008). More systems with financial incentives and increasing the cost of not recycling would definitely encourage more consumers to participate in recycling plastics.

However, once the plastic waste leaves the hand of the consumers, it seems to pose several problems in the recycling. Despite the consumer's effort to recycle plastics, there are confusions about what happens afterward as there were rumors about trash being sent to Eastern Europe from the interviews we had. Also only small amount of plastic thrown into the bin can actually be recycled due to how they were originally made. The company's manufacturing containers are not responsible for the waste disposal and the open loop system of recycling poses problem as manufactured products are not suitable for entire recycling process designed by companies. In addition, when the plastics are manufactured originally, there can be variety of shapes and colors from different chemical and additives added. Because of the contamination, only limited amount of plastic entering the recycling bin can be actually recycled and made into new products.

Thus, from the economical and environmental point of view, recycling plastic is not always as favorable as it seems. The biggest problem associated with the recycling is making products with inferior quality, also known as downcycling. Because the additives and chemicals in the plastics and polymer chains are broken during the process of recycling, downcycling is unavoidable for the case of plastic. Trying to avoid downcycling, businesses cannot make much profit causing them to add more chemicals and additives to retain original strength of plastics which eventually leads to serious environmental threats.

### **Biodegradable Plastics**

The incorporation of biodegradable plastics in everyday life is a progressive thought and approach to a greener, healthier, and a better

environment. It is believed that biopolymers were not initially made with the intention of serving as plastic materials. Rather, they were invented to be used as cellular components having the ability to survive in a given environment to an organism. The progressive development of several biopolymers over the years has, however, stirred the plastic industry.

Being informed and concerned customers, the prospect of introducing biodegradable plastics in life is promising and progressive. Going over what has been already stated in the paper before, use of biodegradable plastics greatly reduces the dependence on fossil fuels. That is one of the primary reasons why we greatly advocate the idea of these plastics. We have responsibility towards our future generation and it all begins with taking good care of our planet. Even though fossil fuels are available to us at present, we are responsible for proper use and management of these resources. Biopolymer researchers are in tune with the fact that replacement material for plastic manufacturing should soon be required.

Even though economic issues regarding biodegradable plastics often come up as the biggest hindrance, it is to be realized that cost is dependent on availability and use. If conventional plastics are to be completely banished, the demand and production of biodegradable plastics will grow causing their prices to become reasonable. At the present time, it is only an option over traditional plastics, but if it is to replace traditional plastics completely, people would have no other option but to use them. Not only will their use solve the problem of limited landfill space, but it will also address the problem of ever-increasing hike in the price of crude oil. Incorporating biodegradable plastics in everyday use would not only take the pressure off fossil fuels but also encourage agricultural

producers who are interested in exploring and developing the natural fiber processing industry. A lot of income from agriculture can be generated if biodegradable plastics can be made mainstream.

Aside from the obvious economic and environmental benefits, biodegradable plastics are progressive from scientific point of view as well. Genetic engineering of plants that mainly deals with modifying plants to produce genes that eventually produces plastics is a raging scientific topic. Many interesting researches and developments have been made in connection with this subject. Biodegradable plastics, thus, provide a good scope for scientific research and studies on genetic engineering. Genetic engineering of plants serves the purpose of complete utilization where plants, in addition to being utilized as food, can also be used for industrial applications.

In addition to being useful for everyday life purposes, biodegradable plastics also have a great scope to be used in medicinal field. Hence, the market of these plastics looks very promising. Biodegradable sutures used in medicine have been approved since the 1960s. When used as an implant, a biodegradable medicinal device will not require second surgical intervention for removal. This makes surgery a lot safer, and reduces the likelihood of infections. If their production can be made mainstream, they have a great possibility of expansion over many areas over the years.

It is increasingly being realized that plastics are the biggest source of pollution in the environment, because when improperly disposed, they can cause a lot of adverse effects on all living beings. For examples, in seas, plastic ropes, nets, and many other wastes produced by humans, are known to entangle aquatic life. These organisms have also been found to have choked on this plastic

debris. Plastic pollution in land is equally degrading to microorganisms to plants and to humans eventually. Thus, plastics are a major source of pollution and making a transition to biodegradable plastics will be the first step to achieving a cleaner, safer and a better future.

What sets biodegradable plastics one step ahead of conventional plastics is the fact that they can be manufactured by using renewable biomass instead of biofuels. As pointed out earlier, this is a huge advantage because when we say “renewable biomass”, it also includes “agro-industrial” wastes that are not only cheap, but their conversion solves another problem by turning waste materials into useful products. This makes production of biodegradable plastics possible even in the countries that lack the scope for crop expansion. In return, they are being benefitted economically and ecologically,

However, biodegradable polymer technology can at present only offer a limited range of materials. It is due to this limitation that biodegradable plastics have not been able to go mainstream yet. However, countries including the US and Japan are now focusing on the technological development of biodegradable polymers, so that they can be expanded in their range and used more widely. Also, the cost of manufacturing them needs to be addressed first and foremost because in reality, cost always comes first before other priorities. Efforts have been made in this context. For example, in Australia, the Cooperative Research Centre (CRC) for International Food Manufacture and Packaging Science is looking at how basic starch, which is rather cheap to produce, can be used in a variety of blends with other more expensive biodegradable polymers in order to produce a variety of flexible and rigid plastics. These are being made into 'film' and 'injection molded' products such as plastic wrapping, shopping bags, bread

bags, mulch films and plant pots. More of such research and efforts need to be incorporated by every country for the industry of biodegradable plastics to really blossom and succeed. The day when we will be using plastics that degrade in our yard in a matter of months is not far away if we, as responsible people of the modern 21<sup>st</sup> century, give it a serious thought.

## WPI

### Sustainability and Chartwells

In our interviews with faculty members, we included questions about recycling system in WPI. Most of them think that the recycling system is acceptable. There are containers for recycling papers in all the offices, but some of the Faculty members reflected that recycling containers for bottles or plastic containers are not always accessible for them. The Sustainability Group at WPI has not made much effort to improve the recycling system in WPI, but since it is a very new department, there are still many possible improvements that can be made in the future. On the targeted materials list for the recycling policy, the only plastic product listed is plastic bottles. However, according to our interviews with the manager of Chartwells, as well as with some European faculty members, a large amount of plastic is consumed in the campus center without being recycled. Although Chartwells has already replaced some containers with biodegradable products, our researches have shown that biodegradable products still need to be recycled, or it will take a long time to degrade in the nature. But from our observations, no recycling container has been set up in campus center for those containers, and all of them get mixed up



with other regular trashes. Other than recycling all plastics that are used, which might not always be economical and practical, reducing use of plastic is a better solution. Recently, reusable mugs are made available in the campus center food court. With the purchase of a mug for \$3.99, a \$1.5 coupon and a 5% discount for future drink refill are offered, which creates a financial incentive for customers to purchase those mugs. This is a very good starting point, and more efforts like this should be made. Replacing dishes and cutlery with reusable ones should be reconsidered, although Chartwells has tried it before but failed. A good way to start is to replace some fraction of the dishes with reusable ones, so that consumers can have their own options. Also, researches need to be conducted to find a better way to manage the reusable dishes, so that they are not stolen or broken as easily.

### Recyclemania

The Recyclemania competition creates a very efficient incentive for students to recycle, since they get to compete with their peers. During the competition, the Recyclemania has certainly helped to bring some positive changes to WPI. In order to win over our competitors from other schools, WPI has been improving its recycling system for the competition, which is beneficial to the community in the long run. There are more accessible recycling containers on campus, and there are signs on regular trashcans reminding people not to put recyclables in. At the same time, more activities related to recycling were held this year, like in WPI bookstore, a green section was set up, where products made from recyclates are available. Students and staff at WPI participated more

in recycling during the eight competition weeks, and thus are more aware of the importance of recycling.

However, there are limitations of the Recyclemania. The only acceptable plastic product in Recyclemania is plastic bottles (including detergent bottles), which means that many other plastic products are excluded. Ideally, this competition will help people to form a habit to recycle, but there is no guarantee for that. Therefore, the importance of recycling needs to be emphasized, but it should not be just for the sake of winning a competition.

According to the Recyclemania results, WPI ranks in the middle in Massachusetts, which indicates that there is still room for improvement. Since this competition just ended recently, it is hard to tell if it brought WPI long-term benefits. However, as we can see, the Recyclemania did bring good changes to WPI during the competition weeks, regarding enthusiasm and participation of students, and, therefore, is worth participating in.

## Conclusion and Recommendations

Plastic takes up large part of society, from plastics used for furniture, electronics, to small households needs like containers and grocery bags. Since plastic first became available to consumers, it became widely used, due to the advantages it provides, such as lightweight, durability and its ability to mold into any products with chemicals and additives. However, there are also a number of disadvantages that plastic poses, including health problems starting from manufacturing to consumption and negative environmental impacts created by accumulation of plastic wastes.

Today, the management of plastic wastes has become one of the most challenging problems in our society. It seems even serious if we think about the future generation that has to deal with continuously growing amount of plastic wastes accumulated in the environment. In the course of this project, we did an extensive amount of research on plastics and their types, their impacts on the environment, economy, and many other factors. Based on all of the information we gathered and comparisons we have made, we determined that there is no one best alternative to the plastics problem we have, but different solutions should be combined for the best result.

The alternative that has the most potential in the future is biodegradable plastics. Even though the idea of biodegradable plastics is fairly new, with changing times and needs, they are most likely to be one of the most viable options to replace traditional plastics. There are a number of challenges related to biodegradability that need to be addressed like achieving complete biodegradation. Our research showed that developments have been made, and are being carried out in achieving biodegradability by modifying existing materials, copolymerization of known

biodegradable materials, and using biopolymers from genetically modified plants. By addressing some of these complications biodegradable plastics have along with creating awareness in people about their advantages over traditional plastics, biodegradable plastics can soon be introduced in all major areas of everyday life.

Even though biodegradable plastics might appear to have promising future, from our researches we determined that it cannot replace all the areas where plastics are currently used. One of such reasons is that in some places where plastics are expected to have a long lifetime, biodegradable plastics may pose problems because their biodegradability is not always controllable. In addition, for some areas where plastics are used, other solutions can produce better results than biodegradable plastics. For example, biodegradable plastics are not tolerable to heat and cannot replace all plastic silverwares and dishes. However, there are other options of reducing the use of plastics by replacing them with china dishes and metal silverware. Also, one of the areas where most plastics are used is probably in grocery bags. Biodegradable plastics can eventually replace the traditional plastic grocery bags. However, from interviews and other researches, we concluded that the use of plastic grocery bags can be reduced more easily by using financial incentives and encouraging people to bring reusable tote bags. Lastly, one other area where use of plastics can be reduced easily without using biodegradable plastics would be bottled beverage containers. Bottle beverage containers can be recycled easily if people are educated and aware that they need to be placed in proper recycling containers. However, there are other obstacles to recycling water bottles as the bottles and caps are usually made with different types of plastics. Also, additives are usually added when the bottles are manufactured, and labels and glue are also used in packaging. Such impurities in water bottles might contaminate the recycling streams and

therefore cause downcycling. Thus, if the manufacturers take appropriate steps and make the containers easier to be recycled by recycling companies, it would help reduce the plastic waste in the environment. Combinations of these solutions will definitely help reduce plastic wastes in areas where biodegradable plastics cannot or do not have to replace traditional plastics and will also help reduce the plastic wastes until biodegradable plastics are good enough to be used extensively.

Last, but not the least, we concluded that educating people on this matter is very important in order to reduce plastic uses and wastes. Although we knew about the problems of plastics and alternatives at the beginning of the project, we did not know about the magnitude of the problems and the possible solutions. There are alternatives and solutions available already to reduce plastic use and lessen the negative impact it has. However, it cannot work efficiently unless people are aware and educated about it. Also from the interviews with faculty members from other countries, where less plastic is used and recycling participation is higher, we can conclude that educating people from early on about plastic waste and recycling programs is very important. For example, there are a number of bins available for recycling plastic bottles on campus, but we can still find large number of plastic beverage bottles thrown away in regular trash bins. In addition, there are signs at local grocery stores that inform people about financial incentives for bringing one's own bag. However, we still see that most people are unaware of the system and majority of them receive plastic grocery bags from the store. Thus, for these solutions to work efficiently and create best results, one of the most important steps is to educate people and make them aware of the problems.

This project enabled us to look at all important aspects of use of plastics, and their impacts on various facets of life. Based on our research, biodegradable plastics

have a promising future from what they have to offer. Therefore, if traditional plastics can be replaced in every possible field, then, the lingering issue of plastic wastes and threats they seem to pose will be resolved. Also, as much as the use of plastics is reduced by introducing papers or other less harmful alternatives, the better our environment will be in the coming years.

## Appendix

### Interview Summaries

#### Professor Brisson (Humanities & Arts; Germany)

2:30 - 3:00 pm Friday, December 7<sup>th</sup>, 2008, Friday

By Seonhee Park and Ningwei Li

- When did you come to the U.S? Do you visit your home country frequently?

She came to the States in 1993 and she visits Germany every 2 years usually. The most recent visit was last summer.

- How much do you know about the recycling program in your home country?

There are different bins for paper, glass, and plastics (including yogurt cups, shampoo bottles etc.). Yellow bins are for cans, green are for newspapers and cardboards etc. Glasses are separated according to colors such as brown, green and white but could've been changed. Gray bins are for remaining household goods including trash and junk. Brown bins are for compostable and organic materials and kitchen scraps. Hazardous materials such as batteries and paints are collected and disposed separately in a special place.

Sometimes there are green dots or arrows on wrapping materials for recycling. It means companies have to pay certain amount for wrapping materials. This shows government's attempt to reduce amount of wrapping in the first place. Also in the supermarkets, there are bins on the way outside to take out the wrappings of the products so they can dispose. People also generally bring their own shopping bags; however, it costs about 50 cents or less to get a plastic bag. Also, people have to fill up the plastic bags themselves without any help from the supermarket staff.

- Do you think the recycling program in your home country is more efficient?

She thinks it's more efficient in Germany. Since they don't have a lot of space, they need to reduce the landfills and need ways to incinerate, burn or recycle a lot of trashes. So in Germany, people are more aware of recycling and trashes are transported to different places since there is too much to recycle.

- Do you think people participate more in the recycling program in your home country than in the U.S?

In Germany, people have education about pollution from very early on. There are programs related to recycling from as early as kindergarten. As a result, people do not waste a lot of plastics, such as in wrapping.

- How far do you participate in the recycling program here?

Recycling programs vary from place to place. In Rockport, where she lives, the recycling is pretty good and cardboard and other trashes are being collected.

However, in Worcester, everything is collected in one bin.

In cafeterias, they always use plastic containers and throw them out after just one use. She brings her own lunch in reusable containers and has mugs for drinks.

- Do you think you are consuming more plastics in the U.S. than in your home country?

There are more materials available in the States. For example, aluminum is made from hard mine labors but people use it only once and throw it out. She thinks it could be replaced by something more environmental friendly such as wax papers.

- Do you think people in your home country are more aware of the plastic waste than in the U.S.?

The people in the U.S. are more aware of pollution but they don't do recycling and are not up to their mark on their habits of recycling. Also the lifestyle of people of America is affluent and they have no experience of scarcity of resources. It needs



to begin from education to change certain aspects of their lifestyles. There also needs to be financial incentives (example of oil and gas prices and taxes).

- What do you think about the recycling in WPI?

Since her first year in 2005, there have been changes in the recycling program in WPI as they started separating different materials. One of the examples is the special parking spot for hybrid cars but it's rarely being used. Also they started having separate bins for paper and batteries at the campus center. Still, they could work on reducing the overall use of plastics containers.

### **Professor Dollenmayer (Humanities & Arts, Germany)**

5:30 - 6:00 pm Thursday, December 18<sup>th</sup>, 2008

By Seonhee Park and Ningwei Li

Notes: Prof. Dollenmayer got back from Germany just before our interview. Since we got information about recycling in Germany from Prof. Brisson, this interview mainly focused and reflected on his recent visit to Germany and universities.

- How do you think the German recycling programs are better than the ones in America, and why?

German people are conscious of not wanting to produce waste. There are a lot of recycling containers everywhere, and people use them. There are also a few German laws about recycling. For example, customers can take the packages (the wrapping plastic bags) at the store and throw them into a container, and the store has to recycle them.

Also, there is not a lot of fast food packaging available. For example, they usually drink coffee out of ceramic coffee cups, while people in the States tend to bring drinks around in plastic or paper cups. In Germany, there is not a big culture of fast food.

For soft drinks and water bottles, they are recyclable plastic bottles with code.

There used to be returnable bottles in Germany, but not anymore. Aluminum and glasses are still available. In fast food stands, they try to minimize the packaging of food. For example, if you are getting a sausage, it usually comes on a small piece of paper. Plastics are not common in fast food packaging.

He thinks the major reason is that Germany is more densely populated and less space to landfill trashes.

- How much do you know about the recycling program in German colleges?

In student cafeteria, food does not come in packages such as paper, plastic or Styrofoam. Mostly they use glasses and ceramic plates that can be washed afterwards. In all public buildings, there are timed light switches in hallway, so that light turns off automatically after a certain period of time. Now most of the new buildings are green buildings, which have to meet certain green requirements in EU. Germany is leading its way in EU to make good laws regarding the environment.

- Do you think you are consuming more plastic in the U.S. than in Germany?

He thinks so, and he thinks it is a cultural thing. Germans do not like synthetic products, they like natural products like wood and cotton. For example, they prefer wooden toys rather than plastic toys, and they tend to use less synthetic materials in house ware. In Germany, they hardly ever use plastic spoons and forks. Silverwares are available.

For grocery shopping bags, people usually will bring their own bags, and it costs half a euro for a plastic bag. In general, they use less plastic packaging in Germany than in the States.

He also mentioned that in hotels in the States, they just started to encourage customers to reuse the towels, while it is standard in Germany.

- Do you think the recycling program in Germany is more efficient?

In Worcester, we bring out a recycling bin and trucks will come and pick it up. In Germany, they have recycling centers and you have to bring trash there by yourself.

He thinks actually recycling bin will work better, since it is easier and more convenient for us.

- What do you think about the recycling program in WPI?

He thinks that it is not extensive enough. He wishes there was less packaging, and he thinks that they are not making a big effort to make people do recycling, not making effort at all to change the way it works in campus center. They do not try to reduce the packaging they use and they do not try to raise the awareness of using less packaging.

- How do you think the recycle in the States can be improved?

Recycling needs to be developed from bottom up, also needs political leadership making priorities and encouraging the recycling. Every part of the society should start focusing on the recycling instead of the small groups of the society making the efforts.

### **Professor Fehribach (Mathematics; Delft, Netherland)**

2:00 - 2:30 pm Friday, December 12<sup>th</sup>, 2008

By Seonhee Park, Ningwei Li, and Dilasha Mahat

- When did you visit Netherlands? How long did you stay there?

He stayed in Delft for about a year in 1999 (9 years ago).

- How much do you know about the recycling program in Netherlands?

Recycling was typical in every household and one of the major differences was that the garbage disposal was unusual. At the time he was there, they recycled paper and glass but not plastics (plastics were thrown into dumpster with

garbage but there was generally less plastic packaging). There was a large dumpster for garbage and recycling. Paper was recycled in the bin and glass was taken to a glass bank, which is about 3 x 3 x 2 metal/steel container weighed in tons with one small opening. Once in a while, a big truck would come in and pick it up and replace with empty glass banks. Recycling and garbage dumpsters were in parking space on little shops within walking distances (Delft is a very small medieval town and everything was within walking distance).

- Do you think the recycling program in Netherlands is more efficient?

It was cheaper to use recycled aluminum than from mine during 70s.

- Do you think people participate more in the recycling program in Netherlands than in the U.S?

Most people participate in Netherlands though not everyone. There is no enforcement or regulations for not recycling (no fines etc.), but people do it because it's good for environment and is convenient for them. In the States, it varies from place to place. Where he lives, there is a high compliance of recycling and it is easy to recycle.

Homogeneous society with similar views and ethics makes it easier unlike in the U.S. where there are lots of different types of people and strong sense of individualism.

- Do you think you are consuming more plastics in the U.S. than in Netherlands?

It is almost surely true. More products are in plastic containers (milk in plastic jugs/cartons). In Netherlands, grocery bags were not given out for free. It was about 5 Dutch cents (about 2 US cents), it was sturdier and could be used as many times before being thrown away. Also, there were no water bottles (people drink water off the water fountains), most soft drinks were in glass containers and aluminum. However, there is almost no use of glasses in the States.

## Mr. Hutson (Physics, Lab Manager; Switzerland & Germany)

2:00 - 2:30 pm Friday, December 5<sup>th</sup>, 2008

By Seonhee Park and Ningwei Li

- How long did you stay in Switzerland?

He stayed in Switzerland for six years, from 1994 to December, 1999

- How much do you know about the recycling program in Switzerland?

He said that they had no choice about recycling. There were designated bins for paper, cans, glass, plastics and cooking oils (all kinds of used oils). Every town has one place with all the bins (devices with various slots) and there were paper dumps in apartment garages. Everyone was obligated to take appropriate measures. There were different bins for white, brown and green glasses (can be just white and colored) and batteries were collected separately (he took batteries to the university he attended where they collected). Not all kinds of plastics were recycled and resin 1 was collected separately etc. There was no general trash but possible exception would be in Germany, where he also spent a few years, where dump and trash such as furniture and junk were separated.

- Do you think the recycling program in Switzerland is more efficient?

He is not sure since he doesn't know what happens after he throws them out. In Germany, there were rumors about all trashes being collected and shipped to the Eastern Europe. He remembers there is a recycling company in Netherlands that achieves 100% recycle rate. There was an extensive article about the recycle company in Netherlands in National Geographic in late 80s.

- How far do you participate in the recycling program here?

There is a green bucket for recyclable items and wastes like Styrofoam cannot be placed in the bucket. Papers have to be separated and large items are taken to someone who can take care of them. He brings batteries to school.

- Do you think you are consuming more plastics in the U.S. than in Switzerland?

Not sure but in general, yes. For example, people use glass bottles for water in Switzerland and they can be recycled afterwards unlike plastic bottles in the States. Not much difference in some packaging such as cooking oils is found. He carries his own shopping bags that are not plastics but paper and tote bags. Almost everyone carried their own shopping bags in Europe but it's less common in the States.

- Do you think people in Switzerland are more aware of the plastic wastes than in the U.S.?

There are no other choices because of social organizations and drive to collect wastes. And they are trying to control the trash. There is not that much difference. The people in the U.S. also have awareness of pollution and are aware of the cost of plastic bags. Europeans are more religious about doing things they were asked to do and it's more functionally organized. In the U.S., it is less organized and a little chaotic because there are people from varied backgrounds and lifestyles. For example, German government sets goals of certain percentage to be recycled by a certain period of time and people will try to achieve that goal. Suppliers come up with their own solutions and it has evolved over decades. It builds up by bits and pieces. Also in Europe, sometimes sellers ask the buyers if they can reuse the shipping boxes for shipping. However in the U.S., sellers presume they are doing the right thing already.

**Joseph Kraskousakas (Director of Chartwells Dining Services)**

10:00 – 10:30 am Monday, January 26<sup>th</sup>, 2009

By Seonhee Park, Ningwei Li, and Dilasha Mahat

- In which area, are plastics consumed the most?

Campus center is the place with the most consumption of plastics in WPI.

- How many plastic containers and packaging materials are consumed in WPI?

There are a total of three dumpsters for plastic bottles and cans in WPI, but he was not sure about other materials.

- What is the trend in the consumption of plastic materials in WPI over the years?

He thinks that the consumption is increasing over the years. In campus center, it has been steadily going up for 7 years in small percentages. They have tried alternatives over the years. Recently, they are making transition to using starch-based biodegradable plastics (He sent us additional brochure on the biodegradable plastic they are using). In WPI, recycling has gotten more priority over the years. The amount of recyclable items will be increasing.

- Are there any regulations on using packaging materials or distributing the food regarding the plastic materials in WPI?

No.

- Are there any alternative options to replace the plastic dishes, spoons etc.?

Yes. They now have salad containers made out of biodegradable plastics. But since most of the biodegradable plastics are not heat tolerant, they cannot use them for soup, hot drinks containers, or silverwares.

5 years ago, they also tried to using reusable silverware and china dishes at the campus center. Some people actually liked the idea, but after about half a year, most of the dishes were gone. They were either thrown to the dumpsters or stolen. But it is not a bad idea to reintroduce them and they might try it again.

- Are there any financial concerns regarding reducing the use of plastics?

Definitely there is a big impact on the cost. Usually it cost 10 – 25% more if they use biodegradable plastics or china instead of traditional plastics. For on campus activities that require catering from the dining services, they can decide which one to use.

- What is your opinion on using plastic containers and packaging? Which, plastics or other alternatives, do you think is better?

As a manager of a company, he thinks the cost is still a very important factor in making decisions. If there is a big difference between the costs, they are hesitant in making decisions although the one solution is more environmentally friendly or better. However, it is still progressive to think about taking right steps, especially about using and recycling plastics.



**Miss Kumar (Chemistry, Senior Laboratory Instructor; India)**

2:00 – 2:30 pm Friday, January 30<sup>th</sup>, 2009

By Seonhee Park and Ningwei Li

- When did you come to the U.S? Do you visit your home country frequently?  
She has been in the States for 24 years but she has visited India in recent years.
- How much do you know about the recycling program in your home country?  
She does not know much about the recycling program in India. As far as she knows, the government just started to encourage people to do more recycling. But there are stores owned by private companies where they can take plastic containers and newspapers to sell. Also, people usually reuse plastic plates and containers. But they do that mainly out of financial concerns, not for environmental reasons.  
Also there are individuals who buy old newspapers and sell them back to the companies to earn money.
- Do you think the recycling program in your home country is more efficient?  
She thinks that because of financial concerns, people usually reuse as much as they can. For example, they usually will use both sides of the paper before they throw it away.
- Do you think people participate more in the recycling program in your home country than in the U.S?  
She thinks people in India participate more in recycling but mostly out of financial reasons.
- How far do you participate in the recycling program here?  
She recycles paper and plastic containers.

- Do you think you are consuming more plastic in the U.S. than in your home country?

Yes, she thinks she consumes more plastics in the States. For example, milk usually comes in recyclable glass bottles in India. But in the States, it mostly comes in plastic containers.

Usually in stores, they don't charge for plastic bags. In some old stores, they do not give out plastic bags and customers have to bring their own bags. But in new westernized stores, they give out plastic bags for free just like in the States. And there is definitely an increase of plastic usage in India with Westernization. But people usually reuse the plastic bags.

- Do you think people in your home country are more aware of the plastic waste than in the U.S.?

People in India are not aware of plastic wastes as much. But because they can't afford to use once and throw it away, people reuse more materials.

- What do you think about the recycling in WPI?

She thinks WPI is doing a good job in recycling paper. But she's not sure about plastics, since sometimes she cannot find containers to recycle plastics.

### **Professor Masamuse (Mathematics; Japan)**

By e-mail

- When did you come to the U.S? Do you visit your home country frequently?

He's from Japan and his recent visit was in this winter.

- How much do you know about the recycling program in your home country?

He said there is one or two days a week in which they can dump bins, cans, and PET bottles, which are labeled "recycle recourses" to recycle.

There are also companies in Japan collecting the old news paper or magazines from the households in the neighborhood of the company, and as a return, giving them tissue papers.

He also recommended the website about the recycling at the town called Minamata. The town was once famous for its pollution, but nowadays it is considered to be the town with the best recycling program in Japan (<http://www.minamatacity.jp/eng/index.htm>).

- Do you think the recycling program in your home country is more efficient?

He said it's difficult to answer and that there are two approaches to develop the recycling (first is to educate the people to recycle and second is to develop the market of second hands).

He is not sure about which recycling program is better since the information he has on the recycling in poor. He said Japanese people know how to participate but do not know how much it helps the environment or economy.

- Do you think people participate more in the recycling program in your home country than in the U.S?

Yes. In Salisbury, where he lives, there is no regulation for dumping and there is no difference in dumping trash and recycling resources. However, there are many websites in Japan for people to sell and buy used stuff. If this can be considered one form of recycling, Japanese people are using this system very efficiently.

- How far do you participate in the recycling program here?

He brings cans and plastic bags to stores.

- Do you think you are consuming more plastics in the U.S. than in your home country?

He's not sure. But he thinks that most Japanese people think that dumping is not good. Also for example, they use wooden chopsticks.

- Do you think people in your home country are more aware of the plastic wastes than in the U.S.?

Yes, he thinks so.

- What do you think about the recycling in WPI?

He knows that when we dump the trash, we separate papers from the rest. He thinks there are more things we can do and suggested yard sale.

### **Professor Padir (Electrical & Computer Engineering; Turkey)**

3:00 - 3:30 pm Monday, December 15<sup>th</sup>, 2008

By Seonhee Park, Ningwei Li, and Dilasha Mahat

- When did you come to the U.S? Do you visit your home country frequently?

He came to the States in 1997 and has been visiting once a year. The last time he visited was summer of 2007.

- How much do you know about the recycling program in your home country?

There are two categories: one in big cities and one in rural/small cities. Usually people are more educated in urban area and the city's municipality runs the recycling program. It's not mandatory but voluntary and it is still a very new concept. People will take trash to places where they recycle and there are bins in the central place. It's convenient and mostly within walking distances. In rural areas, he is not sure if there's any recycling. However, since Turkey is attempting to join the EU, the government is trying hard to reach the EU standard.

- Do you think the recycling program in your home country is more efficient?

The States is more efficient since they are more aware of the need to do it and participate more.

In Turkey, people do not care a lot about trashes on the street and recycling is not mandatory for individuals. Also people became more environmentally sensitive but not as well as in the States or Canada.

- Do you think you are consuming more plastic in the U.S. than in your home country?

In Turkey, everything is in plastic containers. Plastic bags are posing a big problem and garbage is causing problems (there are landfills full of plastics in Turkey). Also, soft drink containers are made of plastics, thus causing the increase of plastic usage compared to glasses.

- Do you think people in your home country are more aware of the plastic waste than in the U.S.?

Educating people is necessary to increase the effort in big cities and it will take time in rural areas. The awareness of plastic wastes in Turkey varies among individuals. Some people do not care at all, but some of them care and put a lot of effort in recycling. In extremes, there are people composting for gardens but it is not yet wide spread.

- What do you think about recycling in WPI?

In WPI, there are two bins in the offices for paper and garbage. It is a good effort I think.

### **Prof. Pietroforte (Civil & Environmental Engineering, Italy)**

10:00 – 10:30 am Thursday, February 5<sup>th</sup>, 2009

By Seonhee Park, Ningwei Li, and Dilasha Mahat

- When did you come to the U.S? Do you visit your home country frequently?

He came here a long time ago, back 1983. He goes back to Italy twice a year.

- How much do you know about the recycling program in your home country?

In Italy the major source of plastic solution are plastic bags from supermarkets. In many supermarkets now, you need to pay about 5 or 10 cents for plastic bags.

Most supermarkets give out biodegradable plastic bags, but you still have to pay.

You don't have to pay for the real cost. It is just an incentive. 80% of the people bring their own bags.

In all major cities, the trash collection is categorized. People separate them and put them in different containers. On the street, there are containers for plastics, glasses, and metals. Trucks come and empty containers. However, he doesn't know about how it works in the countryside.

- Do you think the recycling program in your home country is more efficient?
- He said that there is no doubt that recycling is impacted by how people behave. He thinks we should look at how much garbage is produced around the world. Among all countries, US consume twice as much plastic per person than Sweden, which is as rich as US. Also, he usually cooks in Italy instead of buying fast food. He recommended us to look up data on consumption of plastics in different countries. Data might be available from a reliable, international source such as United Nations.

- Do you think people participate more in the recycling program in your home country than in the U.S?

No. He thinks Italians have not yet incorporated good habits of cleaning up or recycling. They are free-willed people who do not like to abide by rules.

- Do you think you are consuming more plastic in the U.S. than in your home country?

Yes, of course. In Italy, he uses detergents that come out in boxes. Here, is usually a liquid contained in a plastic bottle. In Italy, he tends to cook. He goes to open markets and buys fresh produce. Therefore, he uses very few containers and plastics.

- What do you think about the recycling in WPI?

They have bins for recycling paper. But considering the widespread consumption of sodas, he doesn't know if they are recycled or not. Magazines are wrapped in

plastics. There is a lot of stuff that are wrapped in plastics, but they are always thrown away in trash as far as he knows. WPI can definitely improve that. Also, he commented on never seeing any recycling sign for recycling plastic bowls in cafeteria. Students just throw them away.

**Mr. Thomsen (Director of Office of International Students and Scholars; Denmark)**

1:30 - 2:00 pm Monday, December 8<sup>th</sup>, 2008

By Seonhee Park and Ningwei Li

- When did you come to the U.S? Do you visit your home country frequently?  
He came to the States in 1984 and visits frequently, once or twice a year. Last time when he was in Denmark was in October 2008.
- How much do you know about the recycling program in your home country?  
There are a lot of environmental related projects at the IQP center in Denmark. The recycling program in Denmark runs with the assistance of municipal organizations. There is no any national policy and hence it varies from place to place. In grocery stores, you are only allowed one bag (biodegradable paper bag). You will have to pay if you want to have more. In recycling centers, there are containers/bins for paper, glass, metal and plastics. In cities, there are recycling centers within walking distances and people are expected to take the recyclable materials to the center and sort them there. In rural area, people usually drive to recycling centers on Sunday. They put stickers on the cars to show that they are from a particular area. People are encouraged to do rough sorting.
- Do you think the recycling program in your home country is more efficient?  
In Worcester, we have to buy trash bags, and trucks come to pick up recycling bins. He is not sure which one is more efficient since these two countries do it in different ways.

- Do you think people participate more in the recycling program in your home country than in the U.S?

Yes, he thinks people in Denmark participate more, the recycling in Denmark started very early.

- Do you think you are consuming more plastic in the U.S. than in your home country?

Yes, he thinks so. In the States, people consume too many plastics bags.

Everything comes in plastic bags while plastic bags are not durable enough. For example, they wrap newspapers with plastic bags. It may be necessary on rainy days, but they do it every day. In Worcester, if kitchen supplies are broken, people tend to buy new ones and throw old ones in trash. However, used household items are always broken down and recycled in Denmark.

In terms of shopping bags, they have plastic bags with different qualities in Denmark. Usually it costs 2 dollars for each plastic bag. However, people usually bring their own reusable tote bags.

In Denmark, they mainly use glass bottles for drinks with higher deposit. They are very durable, so that they can be cleaned and used like new bottles. Cans for beers and sodas were not allowed in Denmark. But Denmark lost in a court case in the EU, now they have more cans for soft drinks and beers.

- Do you think people in your home country are more aware of the plastic wastes than in the U.S.?

Denmark is very focused on environmental issues. It is one of the leading countries in alternative energy. Heating is usually done by district heating (huge facilities that makes heat, steam and distribute to households in very well insulated pipes. They are designed so that they can burn many kinds of fuels-oil, natural gas, agriculture wastes, Christmas trees after Christmas etc.)



He thinks that one of the major reasons is the size of the country. Since Denmark is not big, they don't have enough space for landfills. Therefore, they have to find a way to reduce and recycle the trash. Also, Denmark is surrounded by ocean, therefore people can actually have visible image of how plastic pollutes the ocean. Moreover, in general people in Denmark are more educated in terms of environmental protection, and they have a longer history of being aware of environmental problems.

**Liz Tomaszewski (Sustainability Coordinator and Manager of Facilities Systems)**

1:30 – 2:00 pm Monday, January 26<sup>th</sup>, 2009

By Seonhee Park, Ningwei Li, and Dilasha Mahat

- How is the recycling of plastics conducted on the campus?

There are two recyclers who work fulltime on the campus. Their job is to sort through the recycling items. Bottles are put out on the curb side. Local recyclers from “Institutional Recycling Network” take care of the recyclable wastes. They bring the wastes to the recycling center located in Nashua, NH.

- What is the result or outcome of the recycling efforts on the campus?

They have implemented new efforts to encourage recycling on the campus. They introduced events like Precyclemania and Recyclemania in residential dorms. This year (2009), WPI joined Recyclemania for the first time. This competition begins in January. WPI also held Precyclemania in preparation for Recyclemania and it was successful.

- What is the trend in the success of plastic recycling rate in WPI over the years?

WPI is well positioned in comparison to other schools in the field of plastics recycling. WPI participated in a survey with 200 other institutions from the

states. The process ended on January 19<sup>th</sup> and the main purpose was to compare recycling programs in different schools. IN addition to efforts made in recycling, researches and IQPs related to Sustainability encourage participation of students.

- What are the sources of plastic waste? And what are the percentages of each category, such as packaging, lab equipment etc.?

Notes: She told us that she will email us data on this

- Is there any cooperation with other local colleges or organizations in carrying out the recycling in WPI?

WPI collaborates in a competitive manner with other schools. In the Recyclemania, other colleges from the States participate and colleges from the Worcester Consortium are participating as well. Our effort is to improve our standing in the field o plastics and wastes recycling and better ourselves with time.

### **Professor Zhou (Chemical Engineering; China)**

2:00 - 2:30 pm Tuesday, November 18<sup>th</sup>, 2008

By Seonhee Park and Ningwei Li

- When did you come to the U.S? Do you visit your home country frequently?  
She came to the States in 1997 from the central part of China, Wuhan. She used to visit China every four or five years, but now she visits every one or two years.
- How much do you know about the recycling program in your home country?  
When she went to Shanghai last June, department stores no more gave out plastic bags and it was inconvenient. There are not that many recycling programs and since you have to pay extra money for plastic bags, it is an incentive to reuse.

- Do you think the recycling program in your home country is more efficient?  
From her discussion with relatives in Shanghai in recycling business, people realized how much plastic waste they are producing and realized the need to recycle, but there is a limited resource and lack of recycling efficiently.  
Since most of the apartments in Shanghai have limited space, it might be hard to set up different recycling bins for different materials.
- Do you think people participate more in the recycling program in your home country than in the U.S?  
No, since people have been participating in the recycling program when they are young, it is part of their everyday life in the U.S.
- How far do you participate in the recycling program here?  
She participates regularly on curbside program in her town.
- Do you think you are consuming more plastic in the U.S. than in your home country?  
Yes, mainly on packaging. For example, she drinks bottled water in the States, while in China, she boiled tap water before she drank it.
- Do you think people in your home country are more aware of the plastic wastes than in the U.S.?  
She thinks that people in the States are not as aware of plastic pollution as the people in China, because people in China actually see the problem and know that it should be changed, although this awareness has just started. On the other hand, people in the States do recycling without the awareness of the plastic pollution problems since recycling has already become a part of their life.
- What do you think about the recycling in WPI?  
WPI seems very serious about recycling and puts emphasis by putting recycling bins in every academic building. Also the sustainability project in WPI focuses on the recycling.

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