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Research article

Case study of economic and environmental analysis of five post-consumer plastic sortation methods

Matthew Franchetti (Corresponding author)

Department of Mechanical, Industrial and Manufacturing Engineering
The University of Toledo
2801 W. Bancroft Street, Toledo, Ohio, 43606, United States
Tel: 1-419-530-8051 E-mail: matthew.franchetti@utoledo.edu

Connor Kress

Department of Mechanical, Industrial and Manufacturing Engineering
The University of Toledo
2801 W. Bancroft Street, Toledo, Ohio, 43606, United States

Abstract

The study explores the economic benefits and environmental impacts of post-consumer sortation systems for plastic recycling collected from community drop off sites. The purpose of this study was to compare five different configurations of current and emerging technologies from an economic, energy, and emissions standpoint using LCA via a case study in in Northwest Ohio, USA. The technologies studied included electrostatic systems, differential methods, surfactant methods, infrared scanning, and ultrasound scanning. Using LCA and cost-benefit analyses, these scenarios were compared in a standardized manner. The findings from the case study indicated that infrared scanning offers the highest economic benefit and the differential method offers the lowest environmental impact in terms of greenhouse gas emissions.

Keywords: Plastic recycling; LCA; economic analysis

Introduction

Since 1960, the US Gross Domestic Product (GDP) has increased from $520.5 billion to $14.6 trillion in 2010 [1]. As the United States has grown more productive and as more goods are being consumed, more waste is being generated. Of this waste stream, plastic refuse is problematic for society and has experienced low recycling rates.

For example, the US generated 31 million tons of plastic waste in 2010 and of that total, only 8% was recycled [2]. A cost benefit analysis of the existing plastic sortation and recycling methods is necessary to better understand and promote the increased recycling of these materials. Technological advances in the recycling field have increased the efficiency and productivity of sortation processes. By using a standardized approach, the various methods of plastic recycling technology can quantified and compared from an economic and environmental perspective.

Overall recycling rates have expanded 28% in the past 20 years; a trend that is expected to improve plastic recycling rates as well [3]. With increased demand for lower cost plastics and increased environmental concerns, recycling is both a government service and profitable business venture. These aspects are expected to be greatly influenced by the US’s Recycling Works Program which establishes a 75% solid municipal waste recycling goal for 2015 [4]. The program also dictates that 30% of all waste in the United States will be recycled, both by the manufactures and the consumers. This sets the precedent for major growth in the recycling industry in the next several years in the US. Along with possible subsidies from the federal government, the program is expected to generate 1.5 million new jobs in both recycling and post-manufacturing waste recovery [4]. A challenge that must be addressed to reach these higher levels is related to modern technologies and the need to justify large amounts of initial capital. Questions need to be answered such as “if federal/state government subsidized capital for these operations, what technologies would they use?” and “how would decision makers know that those technologies are superior to currently used methods?”. This research work and case study intends to address these questions via a case study that explores and compares the actual cost and environmental impacts of implementing five emerging and current technologies in a common scenario in Northwest Ohio, USA.

The goal of this study was to compare the cost, energy, and global warming implications of the use of five emerging plastic sortation technologies for the Lucas County Solid Waste Management District (LCSWMD) located in Toledo, Ohio, USA. The LCSWMD is a government agency that works to divert materials from landfill disposal in Northwest, Ohio, USA. Five scenarios were considered; (1) electrostatic separation; (2) “sink/swim” differential method [5]; (3) surfactant coated plastics [6]; (4) infrared optical scanning [7]; and (5) ultrasonic scanning. Internal rate of return (IRR), payback period and LCA methods were used to compare the technologies. The technologies were evaluated for manufacturing and operation life cycle phases of five hypothetical design scenarios. This paper focuses primarily on the techniques used in modern recycling for the sortation of consumer plastic wastes to build a detailed guide for analyzing plastic recycling methods and to determine the most cost effective methods. Numerous studies have been conducted related to LCA models for plastics sorting [8 - 12] but a literature review indicated that no comprehensive economic analysis has been conducted in the field. This study aims at filling this knowledge gap by comparing several of the most promising plastic sortation technologies from an economic and environmental standpoint using life cycle assessment (LCA) via a case study.

Materials and Method

This paper examines five current and emerging post-consumer plastic sortation technologies. The purpose of the sortation processes are to separate comingled plastic containers into the six plastics types (1-6) that are to be baled and sold to plastic recyclers. Similar parameters for each technology were analyzed based on economic and environmental impacts. The first sortation technology analyzed is electrostatic separation. The next two methods are a direct comparison of a common technique, using relative density in a liquid to separate plastics. The variant for these two technologies is the presence of a surfactant. The last technologies discussed in the paper are methods of scanning plastics in order to quickly sort them, using other machines, and modeled infrared and ultrasonic scanners. Electrostatic separation is designated as Scenario 1. “Sink/Swim” Differentials and Surfactant aided separation are the Scenarios 2 and 3, respectively. Lastly, infrared scanning is Scenario 4, and ultrasonic is Scenario 5. The study examines each scenario and evaluates the method in terms of profitability, carbon footprint, and amount of energy consumed. Of the parameters analyzed for this paper, cost and global warming potential are emphasized.

Region description

Toledo, Ohio is a metropolitan city located in the Midwestern portion of the US with approximately 295,000 residents. The city encompasses 218 square kilometers and the average temperature is 20 degrees Celsius (range of temperatures from -5 degrees Celsius to 30 degrees Celsius). This study was conducted using data and parameters from the Lucas County Solid Waste Management District (LCWMD) drop-off sites in Toledo, Ohio, USA. The LCSWMD operates and maintains 20 drop off sites that collect recyclable materials from the community including newspaper, cardboard, plastics, aluminum cans, and glass bottles. Annually, the facility collects and sorts 8,700 metric tons of materials that are baled and transported to various recyclers. Of the 8,700 metrics tons, approximately 90% or 7,850 metric tons are mixed plastics.

Functional units and plastic volume estimate

A LCA approach that combined waste management and prevention was applied for this study [13]. This approach allowed for the examination of both recycling and waste prevention, but allowed the method to focus on plastic recycling methods. The functional unit for this study was the annual management of mixed plastic waste collected by the LCSWMD (7,850 metric tons per year). For the life cycle inventory of the operation phase, it was necessary to estimate the plastic generation rates. For the analysis of the four scenarios, this total amount of annual plastic waste was used in calculations. The amount of annual plastic collection is shown in Table 1.

Table 1: Annual plastics waste collected by the LCSWMD

Waste category	Metric tons per year
Polyethylene terephthalate (PETE)	4,760
High-density polyethylene (HDPE)	1,550
Low-density polyethylene (LDPE)	930
Other	610
Total	7,850

Electrostatic Separation – Scenario 1

This technology was developed in the 1990's as an example of an electrically based solution to sorting plastic [14]. Through statically charging particles using friction, then exposing them to an electrostatic field, an electromotive force is induced.

A simple tribo-electric separator consists of six components: a feeder system, a blower, a cyclone shaped tunnel for the tribo-electric friction to occur, assorted containers for collecting sorted plastic bins, and two vertical-plate electrodes along with their accompanying DC power supply [14]. The tribo-electric separator is typically installed with a climate control system, which regulates temperature and humidity. In operation, the feed is distributed in a current of air provided by the blower and introduced into the cyclone through its tangential entry. The air current is used to accelerate the mixture into the cyclone and rub it against the inner lining. After a certain period of frictional charging time (named as rubbing time), the oppositely charged plastics fall down freely in the area between the electrodes. The particles are drawn to either the positive or negative electrode according to the polarity of the charge, and separated by falling in different collecting bins.

"Sink/Swim" Differential Method – Scenario 2

The method of sink/swim sorting of plastics is one of the older procedures used for recycling [12]. The principle is very simple; mix the plastics in a large container filled with a liquid of known density. After some time, the plastics will either float or sink based on the density. This has been used since the 70's and is a well-documented technique [12]. In recent years, the system has grown largely in scale, due to increasing demands and further technological advancement of the practice.

Although this method is very straightforward in concept, the mechanics could be considered complex. Ideally, all of the plastic variations involved have prominent differences in density. The larger the contrast, the more accurately the plastic is sorted. Unfortunately, waste plastic densities do not differ significantly, as displayed in Table 2 [15].

Table 2: Density ranges for the differential method

Material	Density Range (g/cm3)
Polypropylene	0.916-0.925
Low-density polyethylene	0.936-0.955
High-density polyethylene	0.956-0.980
Bulk polystyrene	1.050-1.220
Polyvinyl chloride	1.304- 1336
Polyethylene terephthalate	1.330-1.400

In recycling, there is a narrow window for the process to work, so often containers are pressurized [16]. This allows for slight changes in pressure, resulting in a diminutive modification of the density. The ability to minutely alter the density of the fluid creates a large amount of regulation over the process. By having an exact measure of the density of the liquid in relation to the desired plastic being sorted, much higher results are achievable. A simple computer based algorithm can separate the waste plastics by changing the pressure in the tank. This also significantly reduces the likelihood of having to adjust liquids to isolate alternative plastics.

Surfactant Based Separation – Scenario 3

The use of surfactants to effectively sort plastics on a large scale is also relevant. This method is similar to the "Sink/Swim" system. When using this technique, the materials to be separated are first treated with a surfactant and then suspended in water [16]. Because of a reaction with the surfactant material, plastics that would normally sink in water are suspended in the mixture. Air is then introduced into the system via pump. The air bubbles adhere to some particles depending on their resin type, causing the particles to float to the surface. Materials that are not affected by the bubbles sink to the bottom. Collection systems at the top and bottom of the tanks can then collect the now isolated materials.

The first noticeable benefit is that no advanced technology is essential. Second, the chemicals used are common in chemical processing and do not pose any substantial environmental hazards. Third, froth-flotation can separate certain plastics, such as PET from PVC, which has instituted a crucial problem to the conventional sink-float separation establishments.

Near-Infrared Scanning – Scenario 4

Infrared scanning of plastics is an existing technology in the recycling community, and has become one of the most common methods of sorting plastics [9]. It's used to sort nearly every type of plastic, and it can operate at large volumes. Using infrared scanners, the plastic is examined, and then it removed from the feed.

Infrared scanning operates on the concept that plastics can be analyzed using near-infrared scans that examine both density spectrometry and resin color [16]. It recognizes the density spectrometry by exposing the plastic sample to infrared light, then processing the returning wavelength [7]. It also uses simple high speed cameras to look for resin color. After identifying the type of plastics, it is marked optically, then that plastic is then removed from the system. Typically this is done instantly using compressed air to push the plastic off the line. During operation, the line moves rapidly, using an advanced computer system to track the plastics until their eventual removal from the machine [7].

Ultrasound Scanning – Scenario 5

Ultrasonic scanning of plastics for recycling purposes is a more recent practice to the marketplace. This technology sorts plastics using ultra-sonic waves in water to determine density of plastic samples. The plastics are then removed from the processing line based on the results. This is typically done using mechanical arms to grab plastics and is a highly technical method of sorting. Ultrasound scanning uses some of the same routes of technology utilized by other scenarios. Unlike other technologies, however, it can accurately describe plastic densities in non-clear liquids, such as ferro-fluid, whereas many optical methods would be useless. The ultrasound scanning method also builds a 3D-image of the objects, something which no other technology has employed.

Mechanics

Mechanics for this scenario are based on sound propagation. First, the waste plastic is ground up into small pieces, roughly 20 mm. They are then submerged into a water-filled processing line, roughly 100 mm deep. The plastics are scanned using multiple ultrasonic waves at various wavelengths, which produce an accurate image of the plastics. Using mechanical means, the plastic is removed from the line.

Theory and Calculations

Life cycle assessment method

The five scenarios were analyzed using LCA to allow for a standardized comparison. LCA is a method to access the environmental impacts of product or service through all of the associated life cycle phases from raw material acquisition, manufacturing, distribution, usage, transportation, and disposal [13]. The functional unit for the study was the processing of 7,850 metric tons of mixed plastics. Economic Input-Output Life Cycle Assessment (EIO-LCA) provides a comprehensive estimate of a sector's or a group of sectors' energy demand and emissions. In this study, the EIO-LCA method was used to estimate the energy demand and carbon dioxide equivalence emissions (CO2EE) for manufacturing and operating phases of the five scenarios [17]. EIO-LCA is based on the U.S. Department of Commerce annual input-output model of U.S. economy from 1997, and considers the interactions between 480 commodities or services in the United States [17]. EIO-LCA was used to factor in the direct and indirect effect of the resources related to each of the scenarios.

Life cycle inventory of the manufacturing phase

Costs of all inventory items were obtained from local and US vendors. All scenarios were analyzed for a ten year life. A ten year project life was selected based on the equipment class life for each scenario as established by the US Internal Revenue Service for these types of equipment [18].

Life cycle inventory of the operation phase

The LCA inventory of the operation phase for each scenario involved the analysis of annual mixed plastics generation in Lucas County at the primary functional unit. In terms of system boundaries, the plastic waste generation depicts only waste that is disposed of at the 20 LCSWMD community drop office sites located throughout Lucas County. Climate change was the primary impact category considered for this study. Energy usage for the scenarios was based on the energy requirements for the processing equipment.

Economic analysis

Internal rate of return (IRR) and payback period analyses were used to evaluate the economic implications of selecting the alternative scenarios. When comparing which project to invest, IRR is often preferred over other investment criteria by financial officers [16]. Conventional approach is to invest in only in projects with positive

IRR. In this study, IRR of Scenarios 2, 3, and 4 were calculated with respect to the cash flows of Scenario 1 using Equation 1:

$$NPV = \sum_{t=0}^{n} C_t /((1+r)\exp t) = 0$$

Equation 1

In this method, the net present value (NPV) is set equal to zero and one solves for r to determine IRR. Where, NPV = net present value; t = time (years); r = discount rate (for this analysis, r is calculated as the IRR after setting NPV equal to zero); Ct = cash flow of evaluated scenario minus the cash flow of standard scenario for year t. Discounted payback period is another financial criterion used to determine whether to invest in a project. IRR method is often preferred over a discounted payback period, since the payback period ignores the cash flows after the cut-off time of the project.

Results and Discussion

Calculations and assumptions

The costs, energy consumption, and emissions for the five scenarios are displayed in Table 3. A ten year project life was used in the calculations for each scenario based on the expected life of the equipment and US Internal Revenue Service class life and recovery period [17]. The model assumed that comingled plastics were delivery once daily from the 20 drop off sites throughout Lucas County to the processing facility (the distances of the drop off sites to the facility range from 5 km to 20 km) at fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. For each scenario the separation of materials will be completed onsite by the staff using manual means. The initial separation of will be conducted by the patrons of the drop off sites. Any incorrectly sorted material will be identified and removed by the facility staff.

Scenario 1, the electrostatic system, required the purchase of an airflow regulator, blower, flow meter, tribo-cyclone, power supply, and collection bins. The comingled plastic waste is transported once per day to the material processing facility from the 20 drop off sites. Two local vendors were contacted to provide estimates to manufacture and install the equipment to process 7,850 metric tons of comingled plastic wastes generated per year in the region. The average total cost in purchase and install the system were estimated to be $3.1 million, which includes cost of the building and purchase of equipment. The annual operating costs of Scenario 1 are $1.8 million, which includes transportation costs, cost of two 20 cubic meter capacity hauling trucks, fuel for the trucks, building utilities, and annual salaries for ten labors and two administrators. In terms of revenue, the process would generate $2.35 million per year at an average per metric ton price of separated plastics of $300 for the 7,800 metric tons generated. Energy usage related to transportation for Scenario 1 was based on diesel fuel consumption during transportation to the facility at a fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. Emission factors for fuel consumption were calculated at a rate of 2.68 kg of CO2 per liter of diesel. Per year this resulted in energy usage related to transportation of 0.084 GJ per year and 0.840 GJ over the ten year timeframe. In terms of energy usage and emissions to manufacture the system, the team estimated 1.48 GJ of energy and 288.01 MTCO2EE were needed to manufacture and install the system based on quotes from the vendors. In terms of operations, the system would require 0.046 GJ of energy per year to operate and emit 8.95 MTCO2EE per year (the energy and CO2 emissions would be generated by the local coal burning power plant). This resulted in net energy usage of 1.94 GJ and 377.52 MTCO2EE over the ten year life of the system.

Scenario 2, the differential method system, required the purchase of four separation tanks, four pumps, screens, and pipes/fittings. Two local vendors were contacted to provide estimates to manufacture and install the equipment to process 10,000 metric tons of comingled plastic wastes generated per year in the region. The average total cost in purchase and install the system was $2.75 million. The annual operating cost of the system was estimated to be $1.75 million based on the wages and benefits for ten laborers and two administrators to operate the system and system maintenance/material/energy costs. In terms of revenue, the process would generate $2.35 million per year at an average per metric ton price of separated plastics of $300 for the 7,800 metric tons generated. Energy usage related to transportation for Scenario 1 was based on diesel fuel consumption during transportation to the facility at a fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. Emission factors for fuel consumption were calculated at a rate of 2.68 kg of CO2 per liter of diesel. Per year this resulted in energy usage related to transportation of 0.084 GJ per year and 0.840 GJ over the ten year timeframe. In terms of energy usage and emissions to manufacture the system, the team estimated 1.35 GJ of energy and 262.71 MTCO2EE were needed to manufacture and install the system based on quotes from the vendors. In terms of operations, the system would require 0.042 GJ of energy per year to operate and emit 8.17 MTCO2EE per year (the energy and CO2 emissions would be generated by the local coal burning power plant). This resulted in net energy usage of 1.77 GJ and 344.44 MTCO2EE over the ten year life of the system.

Scenario 3, the surfactant aided system, required the purchase of two separation tanks, two pumps, screens, pipes/fittings, and an application/removal tanks for the surfactant. Two local vendors were contacted to provide estimates to manufacture and install the equipment to process 10,000 metric tons of comingled plastic wastes generated per year in the region. The average total cost in purchase and install the system was $2.6 million. The annual operating cost of the system was estimated to be $1.85 million based on the wages and benefits for ten laborers and two administrators to operate the system and system maintenance/material/energy costs. In terms of revenue, the process would generate $2.35 million per year at an average per metric ton price of separated plastics of $300 for the 7,800 metric tons generated. Energy usage related to transportation for Scenario 1 was based on diesel fuel consumption during transportation to the facility at a fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. Emission factors for fuel consumption were calculated at a rate of 2.68 kg of CO2 per liter of diesel. Per year this resulted in energy usage related to transportation of 0.084 GJ per year and 0.840 GJ over the ten year timeframe. In terms of energy usage and emissions to manufacture the system, the team estimated 1.38 GJ of energy and 268.55 MTCO2EE were needed to manufacture and install the system based on quotes from the vendors. In terms of operations, the system would require 0.044 GJ of energy per year to operate and emit 8.56 MTCO2EE per year (the energy and CO2 emissions would be generated by the local coal burning power plant). This resulted in net energy usage of 1.82 GJ and 354.17 MTCO2EE over the ten year life of the system.

Scenario 4, the infrared scanning system, required the purchase conveyor belts, infrared scanners, control modules, air jets and gripper system are then activated to propel each piece of plastic into its respective sorting area as it exits the line. Two local vendors were contacted to provide estimates to manufacture and install the equipment to process 10,000 metric tons of comingled plastic wastes generated per year in the region. The average total cost in purchase and install the system was $2.8 million. The annual operating cost of the system was estimated to be $1.7 million based on the wages and benefits for ten laborers and two administrators to operate the system and system maintenance/material/energy costs. In terms of revenue, the process would generate $2.35 million per year at an average per metric ton price of separated plastics of $300 for the 7,800 metric tons generated. Energy usage related to transportation for Scenario 1 was based on diesel fuel consumption during transportation to the facility at a fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. Emission factors for fuel consumption were calculated at a rate of 2.68 kg of CO2 per liter of diesel. Per year this resulted in energy usage related to transportation of 0.084 GJ per year and 0.840 GJ over the ten year timeframe. In terms of energy usage and emissions to manufacture the system, the team estimated 1.41 GJ of energy and 274.39 MTCO2EE were needed to manufacture and install the system based on quotes from the vendors. In terms of operations, the system would require 0.047 GJ of energy per year to operate and emit 9.15 MTCO2EE per year (the energy and CO2 emissions would be generated by the local coal burning power plant). This resulted in net energy usage of 1.88 GJ and 365.85 MTCO2EE over the ten year life of the system.

Scenario 5, the ultrasound system, required the purchase conveyor belts, ultrasound emitting/receiving equipment, control modules, air jets and gripper system are then activated to propel each piece of plastic into its respective sorting area as it exits the line. Two local vendors were contacted to provide estimates to manufacture and install the equipment to process 10,000 metric tons of comingled plastic wastes generated per year in the region. The average total cost in purchase and install the system was $3.3 million. The annual operating cost of the system was estimated to be $2.35 million based on the wages and benefits for ten laborers and two administrators to operate the system and system maintenance/material/energy costs. In terms of revenue, the process would generate $2.35 million per year at an average per metric ton price of separated plastics of $300 for the 7,800 metric tons generated. Energy usage related to transportation for Scenario 1 was based on diesel fuel consumption during transportation to the facility at a fuel economy rate of 4.25 km/liter and 38.7 MJ per liter. Emission factors for fuel consumption were calculated at a rate of 2.68 kg of CO2 per liter of diesel. Per year this resulted in energy usage related to transportation of 0.084 GJ per year and 0.840 GJ over the ten year timeframe. In terms of energy usage and emissions to manufacture the system, the team estimated 1.54 GJ of energy and 299.68 MTCO2EE were needed to manufacture and install the system based on quotes from the vendors. In terms of operations, the system would require 0.046 GJ of energy per year to operate and emit 8.95 MTCO2EE per year (the energy and CO2 emissions would be generated by the local coal burning power plant). This resulted in net energy usage of 2.00 GJ and 389.2 MTCO2EE over the ten year life of the system.

Table 3: Cost, energy, and carbon footprints comparisons

	Scenario 1 Electrostatic	Scenario 2 Differential	Scenario 3 Surfactant	Scenario 4 Infrared	Scenario 5 Ultrasound
Cost	$	$	$	$	$
Initial investment cost of system	3,100,000	2,750,000	2,600,000	2,800,000	3,300,000
Annual operational cost of system	-1,800,000	-1,750,000	-1,850,000	-1,700,000	-1,750,000
Annual revenue from system	2,350,000	2,350,000	2,350,000	2,350,000	2,350,000
Net annual cost benefit	550,000	600,000	500,000	650,000	600,000
Payback period (years)	5.64	4.58	5.20	4.31	5.50
Internal rate of return	12%	17%	14%	19%	13%
Total cost benefit over 10 year life	2,400,000	3,250,000	2,400,000	3,700,000	2,700,000
Energy	GJ	GJ	GJ	GJ	GJ
Initial system mfg/installation energy use	-1.48	-1.35	-1.38	-1.41	-1.54
Annual operational energy use of system	-0.046	-0.042	-0.044	-0.047	-0.046
Total energy net/loss over 10 year life	-1.94	-1.77	-1.82	-1.88	-2.00
Carbon Emissions	MTCO2EE	MTCO2EE	MTCO2EE	MTCO2EE	MTCO2EE
Initial system mfg/installation emissions	288.01	262.71	268.55	274.39	299.68
Annual operational emissions of system	8.95	8.17	8.56	9.15	8.95
Total emissions over 10 year life	377.524	344.442	354.172	365.848	389.2

Economic analysis

All five scenarios had an economic life of ten years as displayed in Table 3. Scenario 5 had the highest initial investment cost and Scenario 3 had the highest operational costs due to equipment and operational (surfactants) requirements respectively. From an economic standpoint, Scenario 4 represented the most preferred scenario with a payback period of 4.31 years and an internal rate of return (IRR) of 19%. Over the ten year life of Scenario 2, the total cost benefit was estimated to be a positive $3.7 million. Scenario 2 also had the lowest operational costs of the competing scenarios. By comparison, Scenario 5 (ultrasound) represented the least preferred scenario with a calculated total economic benefit of $2.7 million versus the cost benefit of $3.7 million from Scenario 4. From a pure economic standpoint, all scenarios had a positive cost benefit over the ten year period, an IRR greater than 12% and a payback period of less than six years.

Energy analysis

The order of scenarios based on lowest to highest net energy requirements over the ten year system life was: Scenario 2 > Scenario 3 > Scenario 4 > Scenario 1 > Scenario 5. The energy requirements over the ten year life of each scenario ranged from 1.77 GJ to 2.0 GJ. Scenario 2 (differential method) was the least energy intensive (1.77 GJ) over the ten year life of the system because the equipment requirements (pumps) required less energy for operation versus the electrostatic and scanning methods required in the other scenarios. Scenario 5 (ultrasound) was the most energy intensive (2.0 GJ) over the ten year life due to the mechanical and electronic equipment needs.

Environmental analysis (carbon emissions)

The ten year carbon emissions for each scenario ranged from 344.4 MTCO2EE to 389.2 MTCO2EE. In the ten year operational life, the carbon footprint was lowest for Scenario 2 (differential) at 344.4 MTCO2EE (Table 1). These greenhouse gas emissions were associated with the use of diesel fuel to transport the plastic wastes to/from the processing facility and energy requirements to operate the equipment (derived from a coal fired power plant). Ranking of the scenarios based on greenhouse gas emissions over the system life from lowest to highest was Scenario 2 > Scenario 3 > Scenario 4 > Scenario 4 > Scenario 5. Initial manufacturing emissions were similar for all scenarios ranging from 262.7 MTCO2EE to 299.7 MTCO2EE. The differences in initial manufacturing emissions were related variations in the needed equipment for each scenario and the distance to transport the materials. Operational emissions were similar for all scenarios ranged from 8.17 MTCO2EE to 9.15 MTCO2EE per year. These operational emissions were the result of the energy required to operate the systems using electricity from the local power utility (coal burning power plant).

Conclusion

In this study the cost, energy, and CO2EE implications of emerging post-consumer plastic separation technologies for recycling were compared for the first time in literature and studied in a standardized format via a case study. The analyses were representative of sorting 7,850 metric tons of post-consumer plastic waste collected from 20 drop off sites. The economic implications of the alternative scenarios were analyzed using IRR and payback period calculations. The Input-Output LCA estimates provided comprehensive and nationwide averages of energy and CO2EE effects for the scenarios modeled in this study. The study indicated that all five scenarios had a positive IRR and payback period ranging from four to six years. Based on total system cost over the ten year system life, Scenario 4 (infrared) was most preferred with a total cost benefit of $3.7 million, an IRR of 19%, and payback period of 4.31 years (Table 3). From an environmental standpoint, Scenario 2, showed the lowest CO2EE over the 10 year system life at 344.4 MTCO2EE. All scenarios indicated similar emissions ranging from 344.4 to 389.2 MTCO2EE.

This study indicated that all five scenarios had positive economic performance. In considering alternatives, Scenario 4 (infrared) was the most preferred system in terms of cost and had average carbon equivalent emissions. Future research is necessary to evaluate the relative performance of these scenarios using a greater system boundary via experimental testing. These results suggest that emerging technologies to sort post-consumer plastic wastes are beneficial terms of cost, energy, and greenhouse gas emissions. Additionally, these results provide a ranking a several sortation methods that may be considered for public or private implementation.

References

[1] World Bank. Gross Domestic Project., 2012. Retrieved June 19, 2012, from http://data.worldbank.org/indicator/NY.GDP.MKTP.CD

[2] US EPA. Wastes – Resource Conservation: Plastics. (2012). Retrieved June 19, 2012, from http://www.epa.gov/osw/conserve/materials/plastics.htm

[3] National Association for PET Container Resources. 2010 Report on Post-Consumer PET Container Recycling Activity. Association of Postconsumer Plastic Recyclers, 2nd Print.

[4] Recycling Works. Federal Policy Recommendations. Recycling Works! Campaign: A Jobs, Energy and Climate Solution. Recycling Works, 2011. Web. 27 Aug. 2012.

<http://www.recyclingworkscampaign.org/federal-policy-recommendations/>.

[5] Powell, J., 1995. The PRFect Solution to Plastic Bottle Recycling. Resource Recycling, 14, 25-27.

[6] Florestan, J., Mermilliod, N., and Marfis, IC., 1994. Recycling of Plastics: Automatic Identification of Polymers by Spectroscopic Methods. Resources, Conservation and Recycling, 10, 67-74.

[7] Scott, D. M. 1995. A Two-Colour Near-Infrared Sensor for Sorting Recycled Plastic Waste. Measurement Science and Technology. 6, 156-159.

[8] Jenseit, W., Stahl, H., Wollny, V., Wittlinger, R., 2003. Recovery Options for Plastic Parts from End of Life Vehicles: an Eco-efficiency Assessment, Oko-Institut e.V.

[9] Wollny, V., Dehoust, G., Fritsche, U., Weinem, P., 2001. Comparison of Plastic Packaging Waste Management

Options – Feedstock Recycling versus Energy Recovery in Germany, Journal of Industrial Ecology. 5, 49-63.

[10] Baitz, M., Kreibig, J., and Byrne, E., 2004. Life Cycle Assessment of PVC and of principal competing materials. The European Commission, PE Europe GmbH.

[11] Tukker, A., 2002. Plastics Waste - Feedstock Recycling, Chemical Recycling and Incineration, iSmithers Rapra Publishing, Shropshire, UK, Vol. 13.

[12] Craighill, A., and Powell, J., 1996. Life cycle assessment and economic evaluation of recycling: a case study, Resources, Conservation and Recycling. 17, 75-96.

[13] Cleary, J., 2010. The incorporation of waste prevention activities into life cycle assessments of municipal solid waste management system: methodological issues. International Journal of Life Cycle Assessment. 15, 579-589.

[14] ERA Technology Ltd. Electrostatic Recovery of Paper and Plastics Packaging Wastes (ELREC). 2011. Rep. no. BRPR-CT96-0247. N.p.: European Community under the Industrial & Materials Technologies Programme.

[15] Atland, Brian L., 1995. Optimization of the High-Pressure, Near-Critical Liquid- Based Microsortation of Recyclable Post-Consumer Plastics. Resources, Conservation and Recycling. 15, 203-217.

[16] Al-Salem, S.M., Lettieri, P, Baeyens, J., 2009. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Management. 29, 2625-2643.

[17] Hendrickson, C.T., Lave, L.B., Mathews, H.S., 2006. Environmental Life Cycle Assessment of Goods and Services: An Input Output Approach. Resources for the Future, Washington, D.C.

[18] Internal Revenue Service, 2013. How to Depreciate Property. Publication 946.