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SUSTAINABILITY ASSESSMENT OF FLEXIBLE PACKAGING

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December 11, 2009

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Executive Summary

Introduction

Environmental consiousness, energy efficiency, and thoughtful use of carbon-based resources are key aspects of corporate social responsability goals among several corporations. Meeting such goals requires balancing the performance, cost, design, and environmental impacts of innovations, while staying relevant and competitive in a global marketplace. With the growing interest in sustainability and impacts across the "triple bottom line" — economic, environmental, and social/societal aspects — most manufacturers of products face tough choices when selecting the packaging systems that offer the best blend of performance, cost, and environmental impact.

Flexible packaging offers significant advantages relative to alternatives such as paper, paperboard, rigid plastics, aluminum, or glass. The advantages include:

- Lower package mass, and lower energy consumption in manufacture and transport to the consumer, and
- The ability to create distinctive packages through direct printing, allowing manufacturers the ability to capitalize on product and company branding initiatives.

There are also some perceived hurdles associated with end-of-life of flexible packaging including:

- The difficulty of recycling or reusing these materials either because of package construction or lack of development of a recycling infrastructure, and
- The public perception that plastics are energy-intensive package materials, especially the process of acquiring raw materials and manufacturing packages.

Objectives

The Flexible Packaging Association (FPA) commissioned this sustainability study with focus on two primary areas:

- Understand the life cycle energy consumption and carbon footprint of flexible packages compared to alternatives, and
- Explore the options for management of flexible packages at the end of their useful lives.

The energy consumption and carbon footprint assessment was further broken into assessing energy consumption across the life cycle of a package, carbon footprint across the same life cycle, and the potential for energy recovery at package end-of-life through routing of packages to waste-to-energy facilities. The end-of-life assessment examined conditions that promote recycling of flexible packages, and conditions that promote waste-to-energy.

Section 2 of this report presents the life cycle energy and carbon footprint assessment of flexible packaging and alternatives. The case studies used in this assessment are presented in Appendix A of the report. Section 3 of this report presents Battelle's findings on the end-of-life options for

flexible packaging, specifically recycling and waste-to-energy. A short synopsis of results from these two sections is presented below in this Executive Summary.

Energy, Carbon Footprint, and Energy Recovery Assessment Results

Battelle conducted an assessment of the energy consumption, carbon footprint, and potentially recoverable energy for a select number of flexible packages. We also conducted similar assessments for a select number of alternatives to flexible packages. The packages covered a wide variety of applications including raisin packages, beverage packages, salty snack packages (chips, pretzels or similar), whole cuts of meat, and parcel mailers.

Battelle performed a streamlined life cycle assessment that focused on energy consumption and combustion emissions. Other environmental and sustainability impact categories were not included. The purpose of focusing on energy consumption and emissions was to understand how package manufacture, delivery, and use contributed to energy consumption for the various packages. In particular, Battelle sought to determine if any energy consumption or carbon footprint advantages might be attributable to flexible packages.

Figure ES-1. Example system and life cycle stage boundary definition.

Using the total life cycle energy consumption (from raw materials in the ground through ultimate disposal as an indicator) flexible packages were found to offer energy savings of 30 to 87 percent over the alternatives assessed for similar product applications. If only energy consumption during the steps from manufacture of the packages through ultimate disposal is included, flexible packages generally offer a similar percentage energy savings. An exception was found when comparing the pellets-to-grave energy consumption of flexible drink pouches with aluminum cans where, because of the energy advantages of recycling aluminum relative to production of virgin aluminum, aluminum cans are significantly more energy advantageous than flexible drink pouches.

Battelle's assessment of the carbon footprint, the amount of carbon released to the environment during manufacture and use of a product, match those for the total energy consumption. Because energy consumption and carbon footprint are tightly linked through the combustion process, the relative results are almost identical to those for total energy consumption.

Lastly, Battelle evaluated the potential energy value of the packages assuming that each would be combusted for energy recovery at the end of its useful life. Here, packages with combustible content, such as paper and plastics, fared much better than more durable materials such as glass

Table ES-1. Summary Results of Energy Use, Carbon Footprint, and Potential Energy Recovery of Flexible Packaging Systems

Case Studies	Packaging Alternatives Compared	Total Energy Consumption (MJ)	Pellets to Grave Energy Consumption (MJ)	Carbon Footprint (kg CO_2)	Potential Energy Recovery (%)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [3][4]	2.16	1.48	0.13	44.2
	Paperboard Box with Inner Poly Bag [3][4]	1.95	1.46	0.16	20.5
	Stand-up Flexible Pouch [4]	1.06	0.22	0.049	48.1
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure[1][3][4]	14.2	3.46	0.88	0
	Plastic PET Bottle and Cap [1][3][4]	12.7	2.46	0.42	42.8
	Aluminum Can [4]	4.17	0.62	0.32	0
	Stand-up Flexible Pouch [4]	1.89	0.99	0.10	27.3
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [2][3]	4.80	1.19	0.23	23.5
	HDPE Flexible Pouch Mailer [2]	3.37	0.64	0.11	40.0
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [4]	0.27	0.09	0.011	38.7
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	5.96	2.42	0.27	35.4

[1] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine.
[2] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[3] Assumes no Reuse of Package
[4] Values exclude transportation and preparation for beverage or dried fruits, *etc*.

and aluminum. Packages with large mass, such as the paper and paperboard products, typically offered a greater potential absolute energy recovery. However, when comparing potential energy recovery with the total energy consumption, we generally found flexible packages to be superior. This is because of the low energy consumption for flexible packages during the package life, coupled with the high energy content (energy per unit mass) of the plastic which can be reclaimed at the end of its life. For complete details of the assessment see Section 2 and Appendix A of the report.

To summarize, Battelle believes flexible packages, in almost all configurations, offer several advantages over the alternatives. Flexible packages offer lower total energy consumption across the life cycle. As a result of the lower energy consumption, flexible packages offer a lower carbon footprint across the life cycle. Because of the lower total energy consumption coupled with the high energy content of the plastic materials upon combustion, flexible packages offer the advantage of reclaiming a higher percentage of the energy consumed by combusting the packages at end-of-life and recovering the energy for subsequent use by society.

End-of-Life Options for Flexible Packaging Results

Battelle evaluated two end-of-life options for flexible packaging: 1) recycling and 2) waste-to-energy (WTE). The evaluation is based on the currently available infrastructure and technologies available for collection, handling, and processing of municipal solid waste in the U.S. In addition, international case studies and references on handling waste streams close to the flexible packaging waste point of generation are analyzed and presented.

Battelle first reviewed the status of municipal solid waste (MSW) in the U.S. and found that plastic waste contributed over 12% of the total waste generated in 2006. About 10% of the plastic waste was recycled. Based on our research of the current infrastructure and technology for managing the municipal solid waste coupled with consumer habits, the majority of flexible packaging in the U.S. ends up in a landfill. While evaluating the end-of-life options, Battelle reviewed the historical development of waste recycling programs and WTE plants across the U.S. and studied the drivers and barriers that led to the success or failure of these initiatives.

Battelle reviewed the status of infrastructure and technology currently in use for recycling and explored a few very innovative programs that sort plastic and flexible packaging waste streams and convert these into new value-creating products having direct application in society. Several such examples within the U.S. are presented in this report. Europe is known to be further ahead than the U.S. on such recycling initiatives and management of MSW, so Battelle gathered insights from recycling programs in Europe and Asia. The report presents these findings in greater detail.

Battelle conducted similar evaluations of drivers, barriers, infrastructure, and technology to better understand the status of the WTE option for flexible packaging in the U.S. as well as internationally in Europe and Asia. The U.S. EPA's ruling to classify WTE facilities as renewable energy facilities, and the greater impetus of the new U.S. administration on development of renewable energy sources could potentially boost this end-of-life option for flexible packaging, which has historically been victim of the "NIMBY" or "Not In My Back Yard" syndrome. Section 3 of this report provides several examples of the current and future technologies in WTE that could make WTE facilities more prevalent and more acceptable in the U.S. The U.S. currently has 89 WTE facilities with almost all of them using MSW as their primary feedstock. Similar to the recycling assessment, Battelle reviewed the state of WTE in Europe and Asia and once again found that these regions were further ahead in the WTE area. Technologies enabling the WTE businesses in the U.S. and Europe are included in this report.

Please note that the objective of the evaluation of the end-of-life options in Section 3 is to provide FPA with a compilation of the findings, not to make specific strategic recommendations.

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List of Acronyms and Abbreviations

Btu	British Thermal Units
DOE	United States Department of Energy
DSD	Duales System Deutschland
EPA	United States Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
FPA	Flexible Packaging Association
HDPE	High Density Polyethylene
IWSA	Integrated Waste Services Association
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LDPE	Low Density Polyethylene
LLC	Limited Liability Company
MACT	Maximum Achievable Control Technology
MMT	Million Metric Tons
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
MSW-DST	Municipal Solid Waste Decision Support Tool
NIR	Near Infrared
NSWMA	National Solid Wastes Management Association
O&M	Operation and Maintenance
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polylactic acid
PP	Polypropylene
PS	Polystyrene
PURPA	Public Utility Regulatory Policies Act
PVC	Polyvinyl chloride
QF	Qualified Facilities
RCP	Research Commercialization Proposal
RDF	Refuse Derived Fuel
RFP	Request for Proposal
TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
TCLP	Toxicity Characteristic Leaching Procedure
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
WRAP	Waste & Resources Action Program
WTE	Waste-to-Energy
YCRRC	York County Resource Recovery Center

1.0 Background

1.1 Introduction

Environmental consiousness, energy efficiency, and thoughtful use of carbon-based resources are key aspects of corporate social responsbility goals among several corporations. Meeting such goals requires balancing the performance, cost, design, and environmental impacts of innovations, while staying relevant and competitive in a global marketplace. With the growing interest in sustainability and impacts across the "triple bottom line"— economic, environmental, and social/societal aspects — most manufacturers of products face tough choices on selecting the packaging systems which offer the best blend of performance, cost, and environmental impact.

Flexible packaging offers significant advantages relative to alternatives such as paper, paperboard, rigid plastics, aluminum, or glass. The advantages include:

- Lower package mass, and lower energy consumption in manufacture and transport to the consumer, and
- The ability to create distinctive packages through direct printing, allowing manufacturers the ability to capitalize on product and company branding initiatives.

There are also some perceived hurdles associated with end-of-life of flexible packaging including:

- The difficulty of recycling or reusing these materials either because of package construction or lack of development of a recycling infrastructure, and
- The public perception that plastics are energy-intensive package materials, especially the process of acquiring raw materials and manufacturing packages.

1.2 Scope and Objectives

The FPA asked Battelle to conduct a sustainability study of flexible packaging to help its member companies understand the sustainability attributes of their products. This study is part of an overall strategy to communicate the benefits of flexible packaging to a wide audience, including product manufacturers, the regulatory and legislative community, retailers, and the general public. The study focuses on assessment of such pre-selected indicators of sustainability such as life cycle energy consumption, carbon footprint, and the management of end-of-life options for flexible packaging systems.

To assess the life cycle energy consumption or savings and carbon footprint of flexible packaging, Battelle used a streamlined life cycle assessment (LCA) to evaluate a limited, pre-selected number of flexible packages and some alternatives. The study results focus on the trends in flexible packages' energy consumption, potential energy recovery, and carbon footprint results relative to the alternative package systems rather than results for individual packages. Battelle assessed the results across the selected set of package systems, looking for advantages for one package system over others for energy consumption, potential energy recovery, and carbon

footprint. Battelle then analyzed the results in detail to better understand the causative processes or operations that drive these benefits.

Battelle also addressed how flexible packages might be handled at the end of the use phase of their life cycle. Battelle explored current and future technologies that might be employed to reduce the volume of plastics waste. Battelle looked at practices in the U.S. and in Europe, China, Japan, and parts of Asia. Battelle sought to understand the infrastructure in and why the practices were different based on geography, social pressures, economics, and regulations. From this collection of data, Battelle identified the most promising approach for the flexible packaging industry to achieve its maximum value in the U.S.

1.2.1 Study Design

1.2.1.1 Energy and Carbon Footprint Assessment

A standard LCA (ISO 14040 series) is a very detailed and rigorous process. A typical LCA includes resource consumptions items other than fuels, as well as emissions other than global warming emissions. An LCA also encompasses a large number of environmental impacts, such as toxicity impacts, land use, and habitat destruction. Sustainability typically includes looking at social and economic impacts; the "triple bottom line" of environment, economics, and society; geographical and socioeconomic distribution of labor and environmental impacts; and changes in wealth and social class distribution.

The scope of this study focused on energy and carbon footprint to the exclusion of other environmental impacts and sustainability indicators; a process called a streamlined LCA.

Within this streamlined framework, Battelle followed ISO guidelines and practices per the ISO 14040 series of standards for conducting LCAs. The streamlined LCA covered all life cycle stages from acquisition of raw materials through ultimate disposal of wastes. Because Battelle focused on energy consumption and carbon footprint, the

Some Terms We Will Use

System – The set of processes or activities necessary to perform a service or produce a product.

Life Cycle Assessment (LCA) – A holistic assessment of the environmental emissions and resource and energy consumption of a system of processes or activities and the potential environmental impacts of those emissions or consumption. It is holistic because it includes activities from cradle (extraction of resources from the earth or biota) to grave (ultimate disposal of the expended resources back into the earth).

Life Cycle Inventory (LCI) – A component of an LCA that tabulates or prepares a numerical accounting of the emissions or energy and raw materials consumption of a system.

Life Cycle Stage – A subset of the processes or activities in a life cycle, such as those required to collect and process raw materials, or those required to collect and dispose of expended materials. Typical stages include: Raw Materials Extraction, Intermediate Materials Processing, Product Manufacture, Product Use, and Waste Management. These names might change depending upon the product or process being assessed.

Streamlining – The acknowledged omission of certain elements of an LCA in order to focus efforts or attention on the understanding of limited or narrow issues or consequences. An LCA can be streamlined by omitting certain life cycle stages or selected processes that are considered to be incidental, or by focusing on certain flow streams, such as energy, carbon, or toxic releases.

effort focused on preparing the life cycle inventory (LCI – a numerical accounting of flows among system operations), and especially those flows that crossed the system boundaries.

Note: The carbon footprint was calculated as the sum of the global warming emissions for the system using the U.S. Environmental Protection Agency's (EPA) TRACI Global Warming Emissions method within the GaBi software (Version 4.3), including a few very minor non-carbonaceous emissions.

The emphasis was on U.S. practices for manufacturing, packaging, and end-of-life management of packages. To the extent that other countries have similar infrastructure, the results should be extensible. As packaging operations (including manufacture of materials, manufacture of packages, sourcing of packaged goods, or preparing a packaged product) move to overseas locations, it would be useful to validate any assumptions from this study against local conditions and local infrastructures. However, data for many countries (such as many of the lesser developed countries and China) is not readily available.

FPA's interest was in flexible packaging systems for food, which is a high-volume, high-value market. According to FPA, flexible packaging for food accounted for over 57 percent of flexible packaging shipments. In the past, FPA has begun to address the environmental impacts of flexible packaging by comparing the mass of flexible packaging, including food and non-food packaging, over the alternatives; the implication being that lower package mass translates into lower energy consumption. Battelle used these comparisons as a guide in selecting package systems for further assessment.

From this pre-selected set of package alternatives, Battelle and FPA then selected those with high volume, high value, and/or high visibility to the consumer as candidates for assessment. This focused approach helped develop the data requirements, identify data sources, establish data collection and analysis approaches, and facilitate understanding of the life cycle trends and drivers. The packages assessed and their general attributes are shown in Table 1. *Note: The general attributes of the flexible packaging systems under each of the case studies are important because the assessment was performed on a limited number of package systems covering a variety of attributes. The results were generalized to the flexible packaging in that specific segment. Battelle recommends that the readers understand how their package compares to those assessed to learn how the results from this study might apply to their flexible packaging products.*

Table 1. Packages Assessed

Case Study (Example Products)	Alternatives Compared	General Attributes
Case Study 1: Dry Goods • *(Dried fruits, Nuts, Cereals, Snack foods)*	• Paperboard canister with plastic lid • Paperboard box • Stand-up flexible pouch	• Contains dry goods • Is reclosable / resealable, • Provides oxygen exclusion for product protection during distribution, shipping, and storage • Provides package/brand visibility at point of sale • High volume package • Consists of several layers
Case Study 2: Beverages • *(Juices, Wine, Water, Non-carbonated beverages)*	• Glass bottle • Plastic PET bottle • Aluminum can • Stand-up flexible pouch	• Contains wet goods or liquids • Good for single use • Non-reclosable with exceptions • Provides oxygen exclusion, • Provides package/brand visibility • Is a high volume package • Has multiple layers
Case Study 3: Parcel Mailer • *(Shipping Containers)*	• Kraft paper mailer • LDPE flexible mailer	• Good for single use • High volume package
Case Study 4: Whole Muscle Meat Cuts • *(Ribs, Roasts, Whole Poultry, Hams)*	• Shrinkwrap PE film	• Contains wet goods • Good for single use • Provides oxygen exclusion • For high value product
Case Study 5: Salty Snacks • *(Chips, Pretzels)*	• Flexible salty snack bag	• Contains dry goods • Good for single use • Provides atmosphere preservation • Is a high volume package • Provides package/brand visibility • Consists multi-layers

1.2.1.2 End-of-Life Assessments

For end-of-life scenarios, FPA was most interested in assessing recycling and waste-to-energy as options for managing flexible packaging. Battelle assessed the current state, defined an achievable future state, and analyzed the gaps between these two states. The project primarily focused on practices and both regulatory and socioeconomic factors in the U.S.; but recognizing the global presence of several FPA members, insights or information on global conditions were evaluated, especially where these conditions differ from U.S. practices. In defining the future state, Battelle evaluated global conditions for plastics and packaging end-of-life in general, with specifics on flexible packaging end-of-life options to understand the drivers and barriers to the

recycling and waste-to-energy options from a political, social, economic, and environmental perspective. For many countries, useful information was not available in a timely manner or was not available at all.

The two major focus areas, 1) energy and carbon footprint and 2) end-of-life options, are addressed in the following sections of this report. Details of the assessments and supporting documentation are presented in the Appendices. Each of the following major sections addresses scope and objectives, and assumptions that were specific to that assessment, as well as the approach and results.

2.0 Energy and Carbon Footprint Assessment of Flexible Packages

The objective of the energy and carbon footprint assessment was to prepare a scientifically and technically sound assessment of the energy consumption and the potential for energy savings of flexible packages and their alternatives.

2.1 Technical Approach

2.1.1 Streamlining the Life Cycle Assessments

Streamlined LCAs for flexible packages were prepared by Battelle or summarized from previously published literature. For select cases, a comparison of flexible and alternatives packages was made to better understand the energy consumption and carbon footprint advantages of flexible packages, at what point in the life cycle stages these advantages might exist, and the potential magnitude of any energy savings. LCA practices in accordance with ISO 14040 guidelines were used to construct comparable systems incorporating all life cycle stages to prepare the streamlined assessments.

2.1.2 Selection of Data Sources

Before start of the project, FPA had indicated their inability to provide any data for this assessment. Because of this, publicly available LCIs (complete assessment of package systems), or LCI data (data collected and formatted for easy use in an LCI) were used, whenever possible. Candidate LCIs and LCI data were evaluated to see whether the scope, data quality, and impact criteria were consistent with the objectives of the current study. Studies with comparably unaggregated data presented by life cycle stage or by unit operation were selected, and their data were aggregated for each alternative. We were able to find LCIs for mailers (Franklin Assoc., 2004), and some of the beverage containers (Franklin Assoc., 2006), which we used to form the basis of all or part of these assessments.

Note: For the streamlined LCIs that Battelle constructed, we used the database provided with the GaBi software (Version 4.3) for process models except as detailed below. We used process data for U.S. practice as our primary choice, North American process data as our secondary choice, and European process data as a third choice, but only when the data were representative of U.S. practices and technology. One exception to this order was for transportation, where we used the

European LCI module included with GaBi because it was more detailed than the available US LCI data. (These models were supplied to FPA on a CD with the final report.)

2.1.2.1 Package Manufacture

Battelle was unable to find publicly available data on the energy consumption for manufacturing flexible packages and approaching the FPA members was not an option. Battelle simulated a medium-size package production plant with the help of a plastic packaging equipment manufacturer very familiar with package production manufacturing facilities. The simulated plant had to be representative of all the different types of flexible packaging systems evaluated in this assessment. This simulation model was used to estimate the manufacturing phase energy consumption. Because the package plant design firm who collaborated here is knowledgeable in selecting and sizing equipment, Battelle believes that these data are a reasonable estimate of the energy required to manufacture packages. The plant simulation mirrored the capacity of a known raisin packaging plant in the U.S. that, as measured by pounds of pellets consumed, falls in the middle of the range of equipment available for package manufacture. *Note: Because of knowledge of plant design of the vendor, Battelle's estimate for the margin of error in the per-package energy consumption is less than 30 percent of the calculated value. This margin of error is consistent to engineering practices for preliminary engineering assessments.*

2.1.2.2 Packaging of Product

Energy consumption for packaging of the product was estimated from Department of Commerce, Bureau of the Census, Census of Manufacturers data (2007 Economic Census), and was generally assumed to be within 10 percent per unit mass of product for each package. However, details specific to packaging of particular products were lacking from this source, and alternative sources of data were not found. The packaging energy consumption value was calculated by dividing total energy consumption for an industry by the production, and thus represents only a rough estimate.

2.1.2.3 Package Descriptions

A detailed description of construction materials for one dried fruit or nut package and one salty snack bag were provided by FPA members. A description of construction materials for a beverage pouch was derived from the package descriptions, other LCIs, and information available on the Internet. In general, all of the flexible packages were similarly constructed; they are multi-layer and a large portion of each is polyethylene. The differences lie in the number and thicknesses of layers, which is a function of the material to be contained, the environment to be maintained within the package, and the overall package size. The beverage pouch, because of the required strength to contain the relatively dense liquid, had the greatest mass of package per unit product. Details of package life cycles assessed and the information assembled by Battelle are provided in Appendix A.

2.1.3 Validation of Data Sources

Prior to using any data, Battelle validated the data by performing checks on the reasonableness of the energy consumption and carbon footprint data, and by verifying the calculated energy consumption and inherent energy against accepted bounds and alternative references. For example, the approximate energy value of a unit mass of most packaging materials is known. This value can be compared with both the total energy consumption and the energy value of the

collected package materials at end-of-life. *(Note: In more than one instance, the energy value of the mass of package going to disposal was more than the claimed total energy consumption. From this Battelle deduced there must be errors in the dataset and sought an alternative.*) Battelle also cross-checked U.S.-origin LCI data with European-origin LCI data (included with the GaBi LCI software or contained in other LCIs) to see if the results were similar or different. For processes in which similar manufacturing operations are used, the data are expected to be very similar.

2.1.4 General Assumptions

Because of the large number of flexible packages and alternative packaging materials, Battelle realizes that any discussion of energy consumption or carbon footprint based on package-specific LCIs could suffer from being too specific to one package and not applicable to other packages with similar attributes, unless the differences among alternatives were small. For this reason, Battelle viewed specific packages as representative systems and projected plausible assumptions for other packages. Battelle recognizes that the results would not be specific to any package system, but if the assumptions are representative, the significance of trends and drivers should be accurately portrayed. *Note: It is the significant trends and drivers that are of most interest when assessing the advantages of flexible packages in general, which is one of the objectives of this effort.*

Battelle assumed no differences in energy consumption due to package type during warehousing, grocery store display, or during use of the product by consumers in their homes. This assumption can be justified because Battelle did not find any reason to believe that package alternatives require different handling or storage requirements during the operations stated above. Each appears to be designed as a complete substitute for another, and the product in one package can be swapped onto the grocer shelves for product in another package alternative. This assumption would not be valid if, as an example, product in package A could be placed on the shelf without requiring refrigeration, while product in package B required refrigeration.

2.1.4.1 Transportation Distances

The transportation distance from the package manufacturer to the point of use could vary widely for each package alternative and product combination. By choosing to model a specific package system, the study could have unknowingly chosen a system that favored one package type over any of the others. Consequently, a constant transportation distance was chosen that was representative of all product systems and based upon either U.S. Department of Energy data (DOE, 2008) or data from a study on accessibility to grocery stores for store to home distances (Sharkey, *et al.*, 2006). The transportation assumptions are as follows:

Table 2. Transportation Distance Assumptions

Transportation Segment	Distance, miles
• Package manufacture to point of packaging	• 500 miles via over the road diesel truck
• Point of packaging to grocer warehouse	• 500 miles via over the road diesel truck
• Grocer warehouse to grocery store	• 50 miles via over the road truck
• Grocery store to home	• 5 miles via passenger
• Trash pickup, from curbside to materials recovery facility (MRF)	• 50 miles via single unit diesel truck
• MRF to the landfill	• 500 miles via over the road truck

These values will not be exact for any package-product combination, but are representative of the average package-product combination.

Battelle calculated the potential error that might be included because of invalid estimates of transportation distances. For diesel trucks, the potential error is approximately 1.5×10^{-7} MJ per gram of package per mile transport. As an example of the error, for the raisin package, if the MRF to landfill distance is decreased from 500 miles to 50 miles, the change in total energy consumption (and relative error) is:

- 7.5×10^{-4} MJ (0.07 percent of the total energy) for the flexible package
- 2.6×10^{-3} MJ (0.1 percent of the total energy) for the paperboard canister
- 3.8×10^{-3} MJ (0.2 percent of the total energy) for the paperboard box.

Given the low relative error of the results compared to the differences among alternatives, these generalized assumptions are considered a valid approach.

2.1.5 System Boundaries

Figure 1 illustrates the global life cycle stages and operations included within each assessment. For assessments prepared by Battelle, a 5 percent cut-off rule was employed: any materials that contributed less than 5 percent of the mass to a process were ignored, as were any upstream processes that might have been linked to these materials. This is a higher exclusion cutoff than found in many more rigorous LCIs, where a 1 percent cutoff is more common. This rule excluded from the assessments most or all of the adhesives, inks, dyes, paints, and coatings. *(Note: The mass of these materials was small, and Battelle expects the types of materials to be similar for each of the package alternatives–having similar energy consumption and carbon footprint–thus Battelle does not expect the omission of these materials to alter the trends found.)* Detailed system diagrams for the Battelle-prepared systems are included in Appendix A with the detailed results.

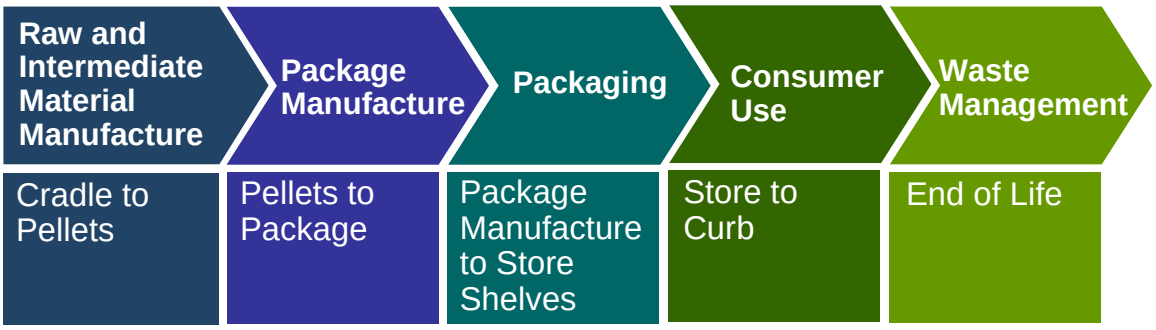

Figure 1. Example System and Life Cycle Stage Boundary Definition.

Changes other than primary packaging were also not included in the systems. These changes might include:

- Increased transport density due to decreased weight,
- Changes in secondary and tertiary packaging, and
- Alternative handling or storage options.

For any specific package-product combination, it might be desirable to prepare a more rigorous LCA, including a lower exclusion cutoff, as well as the secondary and tertiary packaging to get a much more detailed picture of the preference for one package alternative over another.

One issue that Battelle tried to incorporate into the systems was the differences in loss of product that could be attributed to different packages. Flexible packages have been demonstrated to extend the shelf life of products. For products such as meat, where the energy intensity of production is very high, reduction in spoilage or waste could be a differentiating factor in favor of flexible packaging, especially if the system shows large reductions in energy consumption. However, Battelle did not find a sound, technically defensible study that clearly delineated the reduction in product waste that could be attributed solely to flexible packaging. The studies Battelle found compared flexible and alternative packages and discussed potential shelf life enhancements from these packages. There was also a significant amount of ambiguity in the definition or destination of "spoiled" products. Some meat products were found to be re-trimmed or re-dressed and re-packaged; others were sold at markdown for quick sale; still others were transformed into alternative products (*e.g.*, steak trimmed and processed into ground beef) or products not for human consumption (*e.g.*, being processed into pet food as protein or meal). Each of these scenarios raises interesting LCA method or boundary condition issues that the project team was unable to resolve in a timely and defensible manner. For these reasons, while Battelle acknowledges that potential for energy savings is associated with packaging, no attempt was made to include a quantitative assessment of such findings.

2.1.6 Construction of LCI Models

Battelle constructed LCIs for seven of the packages assessed: all three raisin packages; the whole meat cuts package; two of the beverage containers: aluminum cans and the flexible pouch; and the salty snack bag. In addition to the LCI module data supplied with GaBi, Battelle created LCI process modules for package manufacture, product packaging, warehousing, retail shops, and home use.

Not specifically included in these models is package printing. Referring to Allied Development LCI (2008) data on package manufacture, the error by not including printing is about 0.00014 MJ per flexible raisin package. The values for other flexible packages should be similar. The relative error by not including printing is insignificant at approximately 0.013 percent of the total energy consumed.

2.2 Results and Discussion of Energy Use and Carbon Footprint of Flexible Packages

Tables 3 through 7 summarize results of the assessment for each of the packaging alternatives: Total or System Energy Consumption, Pellets-to-Grave Energy Consumption, Carbon Footprint, Recoverable Energy at End-of-Life, and Percentage of Recoverable Energy at End-of-Life. The Total Energy Consumption includes all operations from extraction of raw materials from the ground through ultimate disposal; the Pellets-to-Grave Energy Consumption includes all operations from manufacture of packages through ultimate disposal. It excludes all operations required to manufacture pellets or the equivalent material such as paper pulp, aluminum ingots, or glass cullet. The Carbon Footprint is the summation of global warming gas emissions across the entire life cycle (cradle-to-grave), of which the primary constituent is CO_2 from combustion

of energy carriers (fuels). The Recoverable Energy at End-of-Life shows the amount of energy that could be recovered from each package system assuming complete collection and combustion in waste-to-energy facilities. The Percentage of Recoverable Energy at End-of-Life is the percentage of the Total Energy Consumption that could be recovered upon combustion of waste packaging materials.

2.2.1 Total Energy Consumption

Table 3 shows the Total Energy Consumption for each package alternative. Details are presented in Appendix A. For each of the comparison cases, the flexible package is the lowest energy consuming package alternative. The flexible packages offer from 30 to 87 percent lower energy consumption than the next lowest alternative. Experience at Battelle, gained through sensitivity analysis of LCI systems, indicates that differences among alternatives of greater than 10 percent can be considered significant. Franklin Associates (2006) also uses a similar value for judging significant differences among systems, and presents a statistical justification for this value. Given a 10 percent threshold, the flexible packages are better than any of the alternatives compared.

Table 3. Total or System Energy Consumption for Flexible Packages and Alternatives

Case Studies	Packaging Alternatives Compared	Total Energy Consumption (MJ)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [(3)(4)]	2.16
	Paperboard Box with Inner Poly Bag [(3)(4)]	1.95
	Stand-up Flexible Pouch [(4)]	1.06
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure [(1)(3)(4)]	14.2
	Plastic PET Bottle and Cap [(1)(3)(4)]	12.7
	Aluminum Can [(4)]	4.17
	Stand-up Flexible Pouch [(4)]	1.89
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [(2)(3)]	4.8
	HDPE Flexible Pouch Mailer [(2)]	3.37
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [(4)]	0.27
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	5.96

[(1)] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine.
[(2)] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[(3)] Assumes no Reuse of Package
[(4)] Values exclude transportation and preparation for beverage or dried fruits, *etc.*

Detailed results of our life cycle assessments and information gathering (provided in Appendix A) show that the primary energy-consuming operation for each of the package alternatives is the conversion of raw materials into package precursors: plastic pellets, paper pulp, glass cullet, or aluminum sheet. Conversion of raw materials ranges from 13 to over 75 percent of the total energy consumption. The percentage of energy associated with conversion of raw materials tends to be higher for plastics, aluminum, and glass than for paper.

2.2.2 Energy Consumption without Raw Materials Conversion

FPA asked specifically about the energy consumption for the various packaging alternatives without regarding energy required to convert raw materials. Table 4 contains the results for this energy tabulation.

Table 4. Pellets-to-Grave Energy Consumption for Flexible Packages and Alternatives from Package Manufacture through End-of-Life (without raw materials conversion)

Case Studies	Packaging Alternatives Compared	Pellets to Grave Energy Consumption (MJ)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [3][4]	1.48
	Paperboard Box with Inner Poly Bag [3][4]	1.46
	Stand-up Flexible Pouch [4]	0.23
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure[1][3][4]	3.47
	Plastic PET Bottle and Cap [1][3][4]	2.48
	Aluminum Can [4]	0.62
	Stand-up Flexible Pouch [4]	0.99
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [2][3]	1.19
	HDPE Flexible Pouch Mailer [2]	0.64
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [4]	0.09
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	2.42

[1] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine
[2] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[3] Assumes no Reuse of Package
[4] Values exclude transportation and preparation for beverage or dried fruits, *etc.*

The results are similar to those found for the Total Energy Consumption where the flexible package alternatives generally are the lowest energy consuming package alternative. An exception was found when comparing the pellets-to-grave energy consumption of flexible drink pouches with aluminum cans where, because of the energy advantages of recycling aluminum, aluminum cans are significantly more energy advantageous than flexible drink pouches. (Recycling aluminum requires about 1/20th the energy to produce virgin or new aluminum.)

Detailed analysis of the data presented in Appendix A shows that the primary energy-consuming operations are Package Manufacture and Packaging. These operations account for 50 to 97 percent of the Pellets-to-Grave Energy Consumption. *(Note, for this range, we have not included the mailer packages as we do not have data on package manufacture.)* The percentages tend to be on the lower end for the packages with the greatest mass per unit product (*e.g.*, glass bottles, PET bottles, aluminum cans), and highest for the lower mass per unit product packages.

Table 5. Carbon Footprint for Flexible Packages and Alternatives

Case Studies	Packaging Alternatives Compared	Carbon Footprint (kg CO_2)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [(3)(4)]	0.13
	Paperboard Box with Inner Poly Bag [(3)(4)]	0.16
	Stand-up Flexible Pouch [(4)]	0.049
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure [(1)(3)(4)]	0.88
	Plastic PET Bottle and Cap [(1)(3)(4)]	0.42
	Aluminum Can [(4)]	0.32
	Stand-up Flexible Pouch [(4)]	0.10
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [(2)(3)]	0.23
	HDPE Flexible Pouch Mailer [(2)]	0.11
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [(4)]	0.011
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	0.27

[(1)] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine.
[(2)] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[(3)] Assumes no Reuse of Package
[(4)] Values exclude transportation and preparation for beverage or dried fruits, *etc.*

2.2.3 Carbon Footprint

FPA also inquired about the carbon footprint of the various package alternatives. Carbon footprint and energy consumption are alternative indicators of the use of energy resources. These indicators are generally, but not always, proportional. Any differences will arise due to the energy carriers used within a system. For example, manufacture of plastics tends to be fueled by combustion of carbonaceous fuels, where manufacture of aluminum tends to be fueled by hydroelectricity. When looking at energy consumption, plastic pellets may look to be more environmentally beneficial. However, when looking at carbon footprint, aluminum may be the more environmentally beneficial material, because of the very low carbon footprint associated with hydroelectricity. *(Note, the values for aluminum represent the carbon footprint associated with hydroelectricity production and consumption. If the hydroelectricity were not used for aluminum production it would likely be placed into the grid, thus many people assessing the carbon footprint of aluminum production would attribute the* ***marginal*** *electricity production that the hydroelectricity replaces to aluminum production, which would most likely be coal combustion for electricity production. Under this scenario the aluminum's carbon footprint is much larger.)*

The carbon footprint results are presented in Table 5. The results match those for Total Energy Consumption presented in Table 3, where the flexible package is always the most preferable option as it presents the lowest carbon footprint.

2.2.4 Potential Energy Recovery

As Battelle began to examine the end-of-life options described in Section 3, Waste-to-Energy was one alternative that seemed to have widespread use overseas, and appeared to offer some advantages to the U.S. Many package materials are combustible materials. If we as society use and discard the package, we have wasted the energy value of the molecules. The use of this energy value is only deferred for the period of time the package is in use. By capturing this energy value after the useful life of the package, we can make use of the molecules twice, once as a package and once as energy, decreasing our impact on the environment. For this reason, Battelle computed the energy value of the packaging waste streams.

Battelle identifies these values as the Potential Energy Recovery because in order to capture the energy calculated society would need to first collect or aggregate all of the package waste stream, allowing none of the packages to be diverted to a landfill, composting, or be lost in the environment. Society would also need to combust all of the packages in a waste-to-energy plants, of which currently there are only about 90, with a current utilization of about 10 percent of the U.S. waste disposal.

The results are presented in Table 6. Potential energy recovery is a function of both the materials of construction and the mass in the package. Plastics tend to have much higher energy values per unit mass than paper, while aluminum and glass, not being combustible, have no energy value upon combustion. (In fact, if aluminum or glass are combusted they may have a negative energy value as they will absorb heat from the combustion process.) Packages with higher mass tend to offer a greater potential energy recovery than those of lower mass. The results in Table 6 do not always favor flexible packages, which while comprised of high percentages of plastics, tend to have the least mass per package system.

Table 6. Potential Energy Recovery for Flexible Packages and Alternatives at End-of-Life

Case Studies	Packaging Alternatives Compared	Potential Energy Recovery (MJ)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [(3)(4)]	0.96
	Paperboard Box with Inner Poly Bag [(3)(4)]	0.40
	Stand-up Flexible Pouch [(4)]	0.51
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure [(1)(3)(4)]	0
	Plastic PET Bottle and Cap [(1)(3)(4)]	5.5
	Aluminum Can [(4)]	0
	Stand-up Flexible Pouch [(4)]	0.52
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [(2)(3)]	1.13
	HDPE Flexible Pouch Mailer [(2)]	1.35
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [(4)]	0.10
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	2.11

[(1)] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine.
[(2)] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[(3)] Assumes no Reuse of Package
[(4)] Values exclude transportation and preparation for beverage or dried fruits, *etc.*

An alternative analysis is to look not at the absolute potential for energy recovery, but a relative comparison of how much of the energy consumed by the package system can be recovered at end-of-life. This relative assessment cancels out the effects of package mass. It emphasizes the efficient use of high energy content resources by showing which package preserves the molecules for a second use after the package has served its function. These relative results, presented as the percentage of the Total Energy Consumption that could be recovered are presented in Table 7. The percentage is calculated by multiplying the package material mass(es) by the energy value of the material upon combustion, and then dividing by the Total Energy Consumption (from Table 3).

Generally, the flexible packages offer the highest potential energy recovery at end-of-life. For dried fruit packages the difference between the paperboard canister with lid and the flexible package is too small to judge which is the most beneficial. Here we have a high-mass, high-energy value material package compared with a low-mass, high-energy value material package. To pick between these two packages will require an assessment (a full LCA) with a lower margin of error. For beverage packages, the PET bottle offers the highest percentage recovery of energy, owing to a combination of materials of contruction and package mass.

Table 7. Potential Percentage Energy Recovery for Flexible Packages and Alternatives at End-of-Life

Case Studies	Packaging Alternatives Compared	Potential Energy Recovery (%)
Case Study 1: Flexible Pouch, per 24 oz. raisins (Dried fruits, Nuts, Cereals, Snack foods)	Paperboard Canister with Plastic Lid [(3)(4)]	44.2
	Paperboard Box with Inner Poly Bag [(3)(4)]	20.5
	Stand-up Flexible Pouch [(4)]	48.1
Case Study 2: Flexible Beverage Pouch, per liter (Juices, Wine, Water, Non-carbonated beverages)	Glass Bottle and Closure [(1)(3)(4)]	0
	Plastic PET Bottle and Cap [(1)(3)(4)]	42.8
	Aluminum Can [(4)]	0
	Stand-up Flexible Pouch [(4)]	27.3
Case Study 3: Parcel Mailer, per mailer (Shipping Containers)	Recycled Paperboard Mailer [(2)(3)]	23.5
	HDPE Flexible Pouch Mailer [(2)]	40
Case Study 4: Whole Muscle Meat Cuts, per pound (Ribs, Roasts, Whole Poultry, Hams)	Shrinkwrap PE Film [(4)]	38.7
Case Study 5: Salty Snack Bag, per square meter (Chips, Pretzels, Tortilla Chips)	Flexible Bag	35.4

[(1)] Derived from Franklin Associates. 2006. Life Cycle Inventory of Container Systems for Wine.
[(2)] Derived from Franklin Associates. 2004. Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods
[(3)] Assumes no Reuse of Package
[(4)] Values exclude transportation and preparation for beverage or dried fruits, *etc.*

2.3 Discussion and Conclusions

When evaluating the sustainability of product alternatives, all the benefits to society that might accrue should be considered. Within the context of this assessment, focusing on energy

consumption and carbon footprint, the most beneficial alternatives would offer the lowest energy consumption, the lowest carbon footprint, and the greatest fraction of recoverable energy upon combustion in waste-to-energy facilities.

For the case studies assessed for this project, flexible packages generally have lower, if not the lowest, life cycle energy consumption values compared to the alternatives assessed. This is true when looking at either energy consumption across the entire life cycle (cradle-to-grave), or at the portion from package manufacture-to-grave. Much of this benefit is due to the inherent advantages the highly engineered, multi-layer flexible packages offer for product containment with low mass of package per unit product.

Flexible packages offer a lower, or the lowest, carbon footprint for each of the alternatives assessed. This benefit results from the low life cycle energy consumption of the flexible package alternatives.

If, at the end of the package life, waste-to-energy is a viable option for waste management, as opposed to landfilling or incineration without energy recovery, flexible packages offers the ability to recapture a larger fraction of the total system energy consumed, and make it available for use. While some alternatives, in particular the paper-based alternatives, might offer a larger absolute amount of recoverable energy, these alternatives do so at the expense of a greater net consumption of energy, *e.g.*, more of the system energy is lost to society.

To summarize the results of the assessments, the primary energy-consuming operations for flexible packages are the manufacture of package materials. Flexible packages are among the lowest energy consuming packages for each of the alternatives assessed. For the retailer and consumer, flexible packages offer lower energy consumption than the alternatives because of the lower mass of package per unit product delivered. This energy savings accrues through many processes, mostly through including reductions in transportation energy requirements and materials production and package manufacture energy reductions. The relative importance of any of these energy savings varies with the operation being performed. For example, during the grocery distribution and consumer use operations transportation energy reductions are very important. However, during package manufacture transportation is a minor contributor to energy saving, while the energy intensity of the packaging materials is of most importance.

In addition to the energy savings, the lower energy consumption associated with flexible packaging has many less direct benefits such as reduction in carbon footprint, leading to reductions in global warming. Reduction in energy consumption may also lead to lower prices for consumers, as producers and vendors accrue the benefits of lower energy consumption. These lower prices for flexible packaged goods could result in higher demand for products as consumers' disposable income increases, and they exercise their choice for convenience products, that tend to be offered in flexible packages.

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14. Wrap. 2008. Domestic Mixed Plastics Packaging Waste Management Options. ISBN: 1-84405-396-2.

3.0 End-of-life Options for Flexible Packages

3.1 Current End-of-life Options for Manufactured Goods and Products

Having served its design intent during the use phase of the life cycle, all products transition to the end-of-life or disposal phase of their life cycle where they typically become part of the municipal solid waste (MSW) stream. The product can be recycled, sent to a landfill, incinerated, composted, or can end up as litter. In recent years, the average consumer understanding and awareness of the implications of different end-of-life options has increased. The typical consumer wants to understand the post-use phase of the product and its affect on their local and global environment. Buying decisions are often influenced around these understandings.

This section of the report summarizes end-of-life options for flexible packaging: 1) recycling, and 2) waste-to-energy. The evaluation is based on the currently available infrastructure and technologies available for collection, handling, and processing of MSW in the United States. International case studies and references on handling waste streams closest to the flexible packaging waste stream are analyzed and presented.

3.2. Municipal Solid Waste in America

The EPA has collected annual or bi-annual U.S. MSW data going back to the 1960s. A collaboration between Biocycle and Columbia University[1] has collected and processed MSW data since 1989; their report is entitled, "The State of Garbage in America." Both groups use different methods to collect the data but agree on MSW trends, recycling percentages, and other factors. Both reports are referenced in this report, as each has different pieces of useful data. The EPA report includes data on the amount of different types of materials collected. The Biocycle data includes waste-to-energy as an end-of-life scenario, and breaks out landfilling/ recycling/WTE amounts according to geographical location. Figures 2 and 3 show the historical EPA data on overall MSW collected and trends in recycling.

Based on EPA data[2], Americans generated about 251 million tons of MSW and recycled 82 million tons of materials in 2006. EPA estimates residential waste (including waste from apartment houses) to be 55 percent to 65 percent of the total MSW generated. Waste from schools and commercial locations, such as hospitals and businesses, amounted to 35 to 45 percent. The amount of per capita waste generation has increased from approximately 2.6 pounds per day in 1960 to 4.5 pounds per day in 1990 and holding that value through 2006. The subsequent increases in overall waste generation since 1990 have been due to population growth.

[1] "The State of Garbage in America" *BioCycle* April 2006, Vol. 47, No. 4, p. 26
[2] http://www.epa.gov/osw/nonhaz/municipal/pubs/msw06.pdf

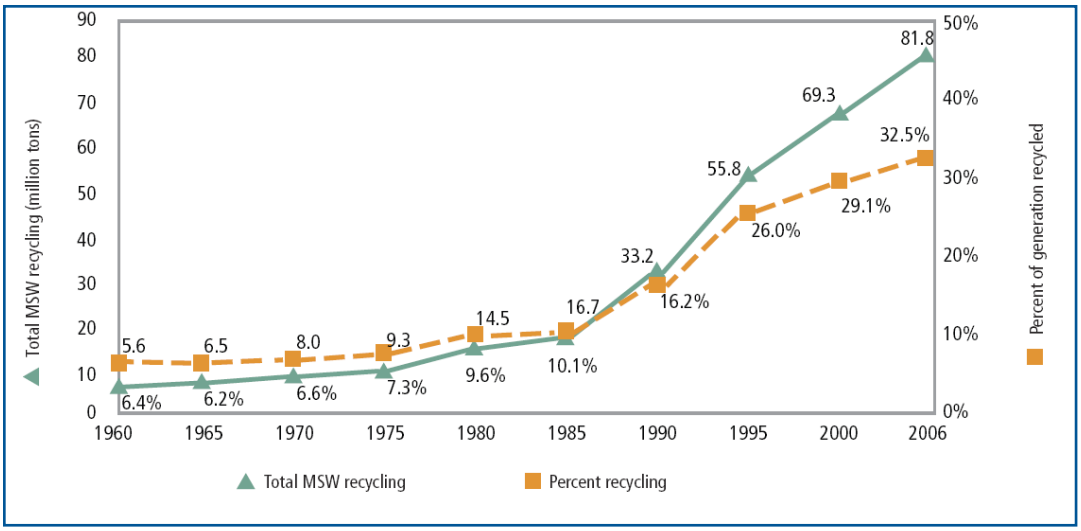

Figure 2. EPA Historical Data on Total Amount of MSW Generated and Recycling Rates.

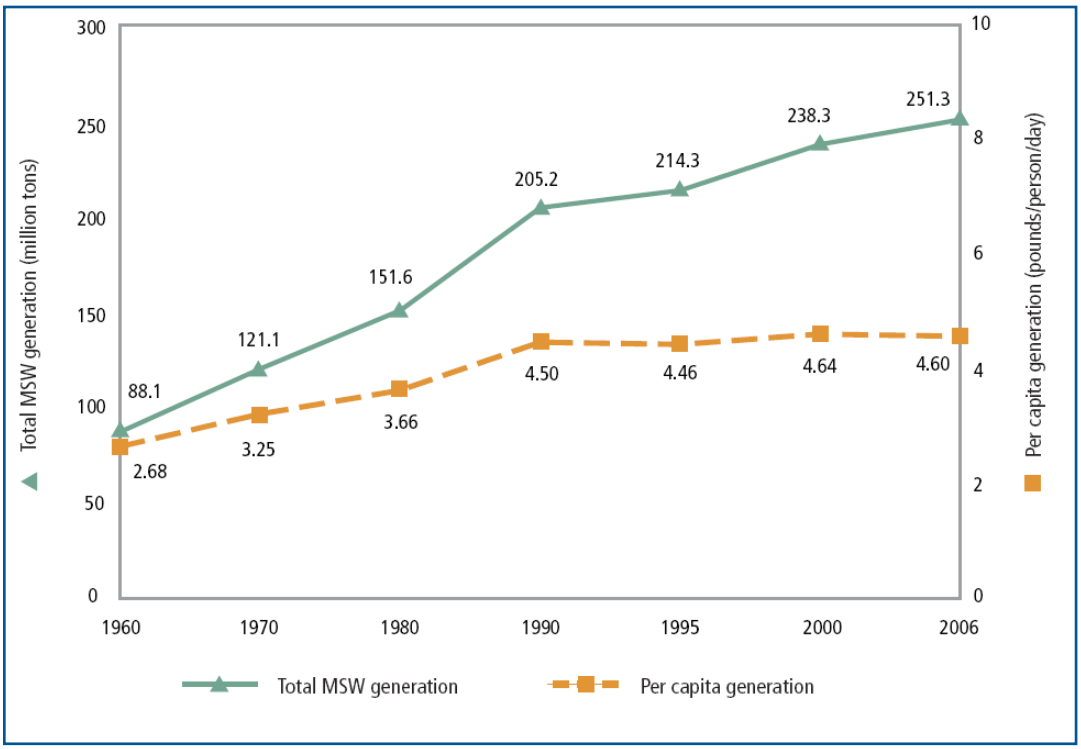

Figure 3. EPA Historical Data on Total Amount of MSW Generated, Compared Against Per Capita Waste Generation.

The EPA reports that plastic disposal accounts for 29.5 million tons of waste annually, almost 12 percent of the total waste generated in 2006. Of that 29.5 million tons, 2.9 tons are recovered via recycling. Overall, the ratio of plastics waste generation to recovery is low at 7 percent. *(Note: These numbers are for all plastics generated in all markets, not just packaging or flexible packaging.)* When moving from overall plastic waste generation of 29.5 million tons to

specifically plastic packaging, the annual waste generation is 14.2 million tons. Of that amount, only 1.5 million tons are recovered or 10.6 percent. Greater than 90 percent of all recycled plastics are high density polyethylene (HDPE) and polyethylene terephthalate (PET) bottles. Stretch film is also recycled is large amounts. The American Chemistry Council reported in 2007[3] that 783 million pounds of polyethylene (PE) film and bags were recycled. Table 8 shows historical EPA data on amount of waste generated versus end-of-life scenarios. Between 20 and 25 million pounds of greenhouse and nursery film are being recycled annually in U.S. and Canada, and approximately 80 million pounds of PET film are being recycled from x-ray films.

Table 8. EPA Data on Generated MSW Amounts vs. End-of-Life Options (million tons)

Activity	1960	1970	1980	1990	2000	2002	2004	2005	2006
Generation	88.1	121.1	151.6	205.2	238.3	239.4	249.2	248.2	251.3
Recovery for recycling	5.6	8.0	14.5	29.0	52.8	53.8	57.5	58.6	61.0
Recovery for composting	Negligible	Negligible	Negligible	4.2	16.5	16.7	20.5	20.6	20.8
Total materials recovery	5.6	8.0	14.5	33.2	69.3	70.6	77.9	79.1	81.8
Combustion with energy recovery	0.0	0.4	2.7	29.7	33.7	33.4	34.4	33.4	31.4
Discards to landfill, other disposal	82.5	112.7	134.4	142.3	135.3	135.5	136.9	135.6	138.2

Data from Table 8 can be contrasted with data from “State of Garbage in America” in Table 9.

[3] “2007 National Post-Consumer Recycled Plastic Bag & Film Report” American Chemistry Council Website, http://www.americanchemistry.com/

Table 9. Biocycle and Columbia University Data on Generated MSW Amounts vs. End-of-Life Options

Year	Reported MSW Generation (tons/yr)	Estimated MSW Generated (tons/yr)	MSW Recycled (%)	MSW Waste-to-Energy (%)	MSW Landfilled (%)
1989	260,000,000	n/a	8.0	8.0	84.0
1990	293,613,000	n/a	11.5	11.5	77.0
1991	280,675,000	n/a	14.0	10.0	76.0
1992	291,472,000	n/a	17.0	11.0	72.0
1993	306,866,000	n/a	19.0	10.0	71.0
1994	322,879,000	n/a	23.0	10.0	67.0
1995	326,709,000	n/a	27.0	10.0	63.0
1996	327,406,000	n/a	28.0	10.0	62.0
1997	340,466,000	n/a	30.0	9.0	61.0
1998	374,631,000	n/a	31.5	7.5	61.0
1999	382,594,000	n/a	33.0	7.0	60.0
2000	409,029,000	n/a	32.0	7.0	61.0
2002	482,770,983	396,381,411	26.7	7.7	65.6
2004	509,155,516	387,855,461	28.5	7.4	64.1

The regional breakout of landfilling, recycling, and WTE percentages from the "State of Garbage in America" report is outlined in Figure 4. Background reasons for why WTE is more prevalent in some regions versus others are discussed later in this report.

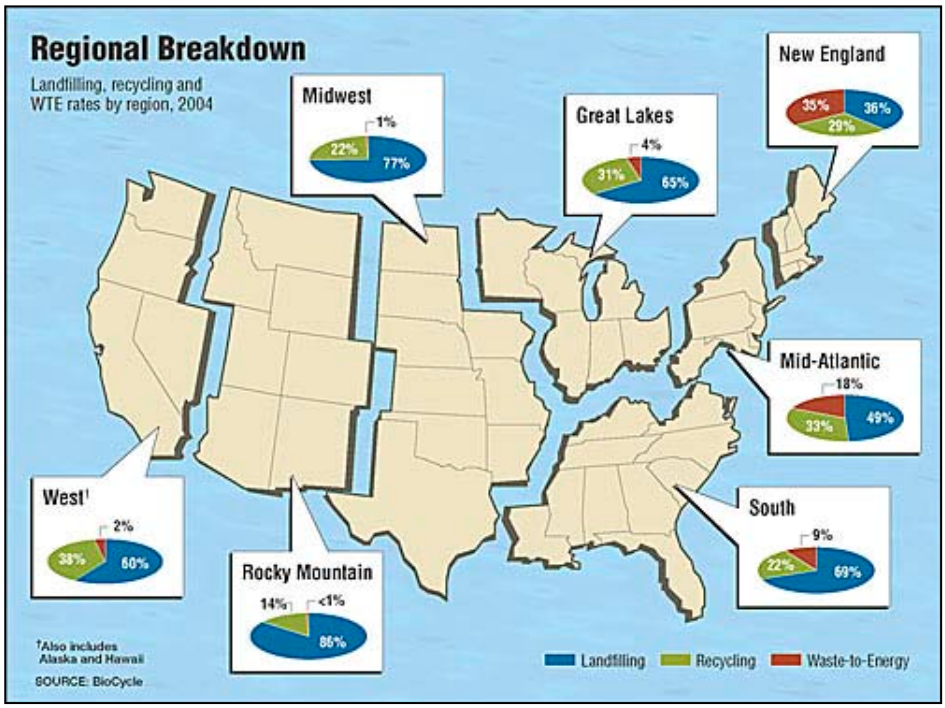

Figure 4. Biocycle and Columbia University Regional Breakout of Landfilling, Recycling, and WTE in the U.S. for 2004.

3.3. End-of-Life Hierarchies for Packaging

Across its life cycle, flexible packaging has many areas where it excels and outperforms other types of packaging. Section 2 of this report discusses how flexible packaging generally uses less

energy across its life cycle. The 2007 "Packaging Efficiency[4]" drew the following conclusions about the positive aspects about flexible packaging:

- By reducing the amount of packaging used; materials, and embedded energy, end-of-life waste and greenhouse gas emissions are reduced.
- While flexible packaging can cost more to produce, the savings in transportation energy generated across the supply chain can be used to offset this increase.
- With the interest in sustainable packaging, consumer items should be sold in flexible packaging in concentrated and dry form, as refills, and in larger sizes.

The Biocycle/Columbia and Packaging Efficiency reports document some of the benefits realized during the early stages of the life cycle. *(Note: The object of this section is to better understand how flexible packaging is compatible with two options (1) recycling and (2) waste-to-energy.)* These two end-of-life options fit into a larger common hierarchy that has been developed and adopted by several organizations that are concerned with what happens to a consumer products or packaging, when they reach the end of their life cycle. The EPA, The Sustainable Packaging Coalition, and the Australian Packaging Coalition have developed hierarchies similar to each other. These hierarchies are outlined in Table 10.

Table 10. Packaging Hierarchies from Three Global Organizations

United States EPA	Sustainable Packaging Coalition	Australian National Packaging Covenant
(1) Source reduction and re-use (2) Recycling/composting (3) Combustion with energy recovery (4) Landfill and Incineration without energy recovery	(1) Reuse of the package (2) Recycling of the packaging (3) Mechanical recycling (4) Chemical recycling (5) Managed composting (6) Waste-to-energy (7) Landfill (8) Litter/burn	(1) Avoidance (2) Re-use (3) Recycle (4) Energy recovery (5) Disposal

3.3.1 Recycling

As noted in the previous section, recycling is typically a more desirable option than WTE for end-of-life scenarios. This section of the report will investigate current recycling technology and infrastructure in the U.S. and internationally, as well as upcoming technologies. The FPA

[4] "A Study of Packaging Efficiency as it Relates to Waste Prevention" *authors of the Use Less Stuff Report.* February 2007, http://use-less-stuff.com/

understands that flexible packaging recovery and recycling has several technological and infrastructure challenges and limitations compared with other packaging materials and the intent of this research is to better understand the issues, hurdles, opportunities, and solutions for recycling.

3.3.1.1 Historical Development

The current recycling infrastructure historically has its roots in bottle deposit bills that were targeted at minimizing the amount of glass bottles and aluminum cans along roadsides in the U.S. University City, MO, was one of the first communities to offer a curbside recycling program in 1973. Currently, there are approximately 8,660 community curbside recycling programs[2].

3.3.1.2 Current Recycling Infrastructure

The flow of recycled materials from the home or business to the terminal point of the recycling process varies widely depending on the community. However, there is some commonality in the steps. Generally, at a high level, the materials are collected at the home, transferred to the materials recovery facility, sorted according to material type, and bundled and bailed for shipment to the next user. There is a trend for communities to move towards single stream recycling. A representative process is shown in Figure 5.

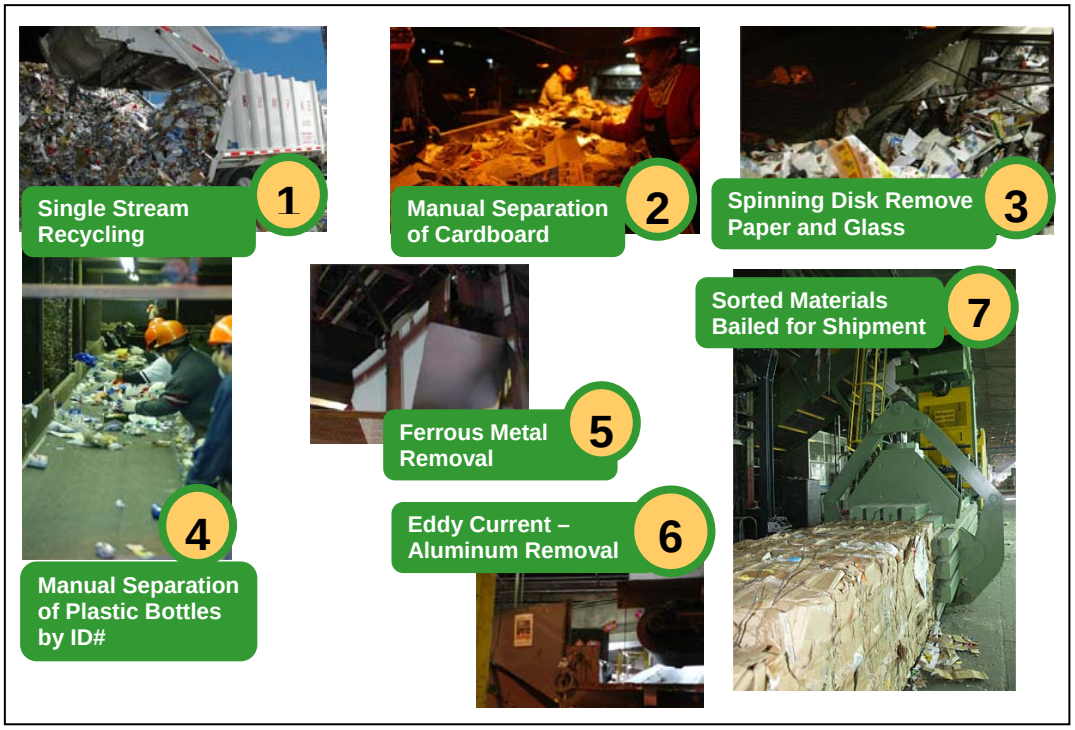

Figure 5. Single Stream Recycling of Residential Materials.[5]

Once the materials have arrived at the MRF, workers manually sift through everything, removing plastic bags, large pieces of cardboard, and other items that could damage or obstruct the sorting machines. Primary separation machines can be employed to separate fiber (paper and cardboard) from containers (plastic bottles and cans). Disc screens, trammels, and ballistic separators are

[5] www.rumpke.com

used to separate the cardboard and paper and glass. Corrugated cardboard is manually separated from mixed paper. Plastic bottles and cartons are plucked out by hand and sorted into three bins (PET #1, HDPE #2 – which together make up 90 percent of the plastic waste stream; and the third bin was everything else). Ferrous metals are plucked out of the remaining materials with magnets, and non-ferrous metals are ejected by eddy-current. Glass is separated by hand into clear, brown, amber, and green.

Interviews and research performed for this study show that there is virtually no film recovery being performed post-consumer from residential settings. Any film or flexible package that ends up in the recycling waste stream now will be sent through the entire process to the landfill. The majority of film recovery occurs post-manufacture, pre-consumer, or is based on very specific materials that are typically not contaminated and occur at designated return centers, as is the case for plastic bags.

Of all of the plastics chemistries manufactured, there are seven material identification codes that are commonly found on the bottom of packaging, as shown in Figure 6.

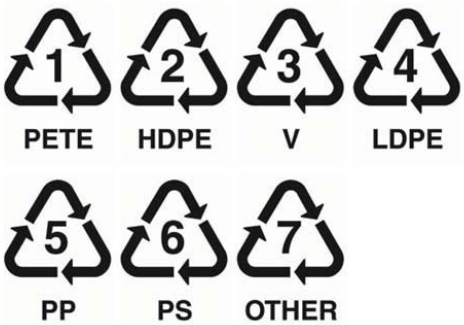

Figure 6. Material Identification Codes for Recycling.

3.3.1.3 Current Recycling Technologies

Each MRF has some common machinery and technology currently used during the recycling process. Although the majority of MRFs cannot accept film, technology is available to convert used film into recycled materials. The single most important reason for non-acceptance of films in the recycling system is because the current sorting technology cannot separate film from the waste stream. In many MRFs, the plastic materials are manually sorted from the materials stream. However, the workers are not trained to sort out any film from the combined waste streams.

Some of the current technology used in the recycling process includes:

- Grinders – same or lighter grinder can be used for bottles and film as long as blades are kept sharp. Film-specific grinders are available
- Balers – those used for corrugated cardboard work for film, but some systems are specifically designed for film
- In-feed conveyor – equipped with an electric eye sensor to determine when the hopper is full; can further facilitate efficient loading

- Washing systems – film washing systems use cold water as opposed to hot water and do not use caustics or surfactants
- Extruders and pelletizers – different feed system accommodate lighter feed stock; gravity feed is not effective for films
- Front loaders – bucket modifications are recommended to increase the volume capacity of the bucket
- Automated sorting – relies on specific gravity changes, x-ray diffraction, optical recognition and dissolution in solvents, none of which can completely fully separate any type of plastic mixture
- Clear/color sorting system – separates clear vs. colored materials (mainly plastic and glass bottles)
- Gravity sorting – separates HDPE and PP from aluminum and PET
- Electrostatic sorting – separates aluminum from PET
- Hot air – separates PP from HDPE in light stream hot air drier.

3.3.1.4 New Recycling Technologies/Developments

This section will provide an overview of new technologies for flexible packaging recycling and several other relevant industry insights.

3.3.1.4.1 Sorting Technologies

The Waste & Resources Action Program (WRAP) group from the U.K. has done several LCA and technology investigations that provide an excellent background on new technologies that could be implemented for sorting of flexible packaging from the waste stream. From their website (http://www.wrap.org.uk), WRAP helps individuals, businesses, and local authorities to reduce waste and increase recycle, making better use of resources and helping to tackle climate change.

One investigation studied mixed plastics which included all non-bottle plastic packaging sourced from the U.K. domestic waste stream and included rigid and flexible plastic items of various polymer types and colors that are typically found in household waste. It excludes plastic bottles and non-packaging items. The aim of the investigation[6] was to assess the feasibility of recycling domestic mixed plastics packaging through an appraisal of available recycling technologies, related financial implications, and environmental benchmarking.

This project used mixed plastics packaging from the domestic waste stream. This included rigid and flexible plastics packaging items of all polymer types and colors that are typically found in the household. The trial material was sourced from operational sorting facilities from which the majority of bottles and other recyclables had been removed. This feedstock still included some contamination from non-packaging plastics and other residual materials. The results of the separation trials are shown in Figure 7.

[6] "Domestic Mixed Plastics Packaging Waste Management Options" Project code: MDP017 ISBN: 1-84405-396-2 Research date: September 2007 - March 2008 Published Date: June 2008

Figure 7. Successful Separation of Mixed Plastics Waste Stream (both rigid and flexible) Using NIR and Stadler Technology

The project team evaluated four types of mixed plastics packaging recycling technology. Two of the technologies are relevant to flexible packaging, including (1) film separation (sorting flexible plastics packaging from whole rigid items) and (2) whole item separation (sorting whole rigid items by polymer or color).

The separation technologies studied included:

- Near infrared (NIR) separation technology
- Stadler and KME separation technologies.

NIR technology sorts whole rigid plastics by using sensors operating in the NIR range. Material spread out on a conveyor belt is fed underneath the sensor, which uses an NIR beam to distinguish a light intensity reading that is unique for each polymer. The unit then triggers air nozzles that separate the selected materials as programmed. The equipment can sort any of the materials listed in Figure 7 and can also sort biobased polylactic acid (PLA). NIR systems can successfully identify and remove specific polymer(s) (including PLA) from a mixed plastics packaging stream achieving more than 93 percent purity for all polymers except polystyrene (PS). TiTech manufactures IR systems that determine the color, type, shape, and position of many types of plastics, papers, and combinations thereof, and then trigger an air jet to remove the articles from the mainstream to adjacent sorted streams with 98 percent accuracy. Examples of NIR technology are shown in Figures 8 and 9.

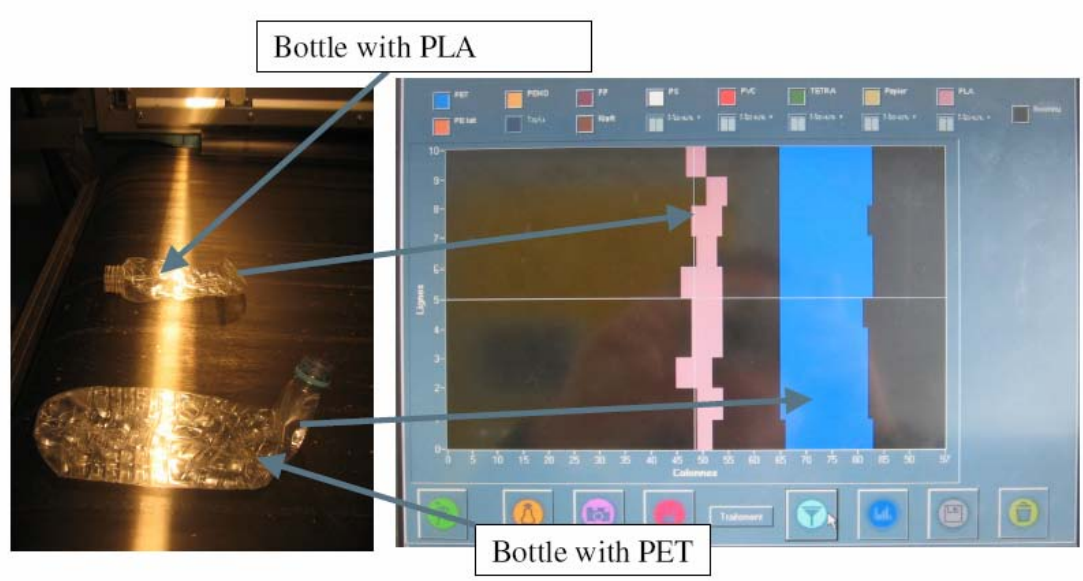

Figure 8. NIR Scan Showing the Polymer Reading

Figure 9. Three NIR Sorting Technologies

The Stadler process sorts flat flexible items from rolling rigid containers. This equipment is currently used widely to sort a paper fraction from a mixed container stream. The system uses paddles arranged in a “deck” to produce a vigorous shuffling motion. Rotational force throws flat material upwards and forwards, and the rigid items then roll down and back. The Stadler unit removed 99.5 percent of the film content from a mixed plastics fraction in the study (Figure 10).

Figure 10. Stadler Separation Technology.

Another technology used to separate plastics from a mixed stream is selective dissolution. Selective dissolution studies have shown better than 99 percent efficiency and have been used with polyvinyl chloride (PVC), PS, low density polyethylene (LDPE), polypropylene (PP), HDPE, and PET. Density separation can often achieve a higher sorting efficiency (i.e., remove more of a target material from the waste stream) than NIR sorting. However, selective dissolution tends to be a less flexible option and sometimes has high energy requirements. Selective dissolution can be cost effective for removing unbundled films from a commingled waste streams in a material recovery facility. Techniques for identifying film resin types depend on their ability to distinguish the clarity, stretch, and strength properties, feel and flexibility, and even burning characteristics of waste stream components.

3.3.1.4.2 New Uses for Old Packaging

Kraft Foods has created an exemplary new partnership with TerraCycle, an upstart recycling company, to take packages and materials that are challenging to recycle and turn them into affordable, high quality consumer products[7,8,9]. This partnership is part of a nationwide packaging reclamation program sponsored by Kraft that began last spring. The program is aimed at preventing a significant amount of packaging waste from heading to the landfills.

Through this partnership, Kraft is addressing packaging sustainability through sourcing, design, and end-of-life. The program pays schools, churches, and other nonprofit organizations to collect used packaging, such as drink pouches, energy bar wrappers, cookie wrappers, and more. The participants are paid two cents per item, which must be donated to either a school or a nonprofit organization.

The donations are made by various Kraft brands. The collected materials are sent to TerraCycle's conversion centers, which "upcycle" the packaging into tote bags, purses, backpacks, umbrellas, and shower curtains. To encourage more recycling, TerraCycle provides a free collection service

[7] http://www.terracycle.net/
[8] Kraft Foods & Terracycle, Inc. Partner On World's First Sponsored Waste Programs http://www.smallbiztrends.com/2008/08/kraft-foods-terracycle-inc-partner-on-worlds-first-sponsored-waste-programs.html/
[9] Talking trash: Kraft Foods "upcycles" to recycle. http://www.packagingdigest.com/article/CA6592204.html

to any individual or organization that participates. The participants are provided with pre-paid mailers for sending the collected materials to TerraCycle facilities.

In the upcycling process, the shipments of packaging head to one of TerraCycle's three North American conversion centers. At the TerraCycle facilities, the used packaging is hand-sorted by color, brand, and physical condition. Wrappers and other items in good condition can be hand-woven or sewn into bags, totes, and similar products.

Damaged wrappers are fused together into sheets of moisture-resistant fabric that can be made into umbrellas, shower curtains, backpacks, placemats, and more. The wrappers are washed using citrus-based, all-natural cleaners in industrial washers. Cookie packaging is treated this way. The drink pouches are sorted by color and brand and are washed in a similar fashion.

By late 2008, TerraCycle had diverted 2 million soda bottles, 10 million drink pouches, 500,000 energy bar wrappers, and nearly 1 million cookie wrappers through post-consumer and post-industrial waste streams. TerraCycle's three year partnership with Kraft could significantly boost the amount of materials TerraCycle can reuse because Kraft is collecting wrappers in some of its corporate locations as well as in schools where it runs food service. The program could eventually reach as many as 20,000 schools and upcycle as many as one billion drink pouches by 2010.

3.3.1.4.3 Converting Plastic Waste into Pre-Polymer Products[10]

Polyflow, an Akron, Ohio, company, has developed a technology that can convert feedstock from post-consumer, post-commercial, and post-industrial, mixed plastics and rubber into the pre-polymer feedstocks used in the plastics and chemical industry. The following information is from their business plan:

- Polyflow will commercialize a patent-pending alternative energy technology that enables the conversion of mixed waste polymers into monomers, the feedstock used by petrochemical companies to make polymers. A major product of the Polyflow process is styrene and the technology is an alternate and low cost route to styrene, a chemical feedstock for polystyrene and other engineering polymers. The Polyflow process reduces greenhouse gas emissions by 70 percent versus incineration and is an environmentally sound process of choice for the disposal of plastic and rubber waste. The technology has the potential to reduce the dependence on foreign oil by as much as half of the 4 percent of consumption used in the manufacture of plastics.
- Polyflow has developed a polymer technology and has demonstrated it in a 1000 lb per batch demonstration unit, but now needs to validate the continuous process required to develop a full scale plant. Polyflow will then be able to sell technology, services and plants.
- The Polyflow technology is a cracking process similar to that used in the petrochemical refineries, but at conditions that enable Polyflow to use plastic and rubber waste as a feed stock in place of crude oil. For every ton of polymer feedstock, Polyflow can produce 0.7 tons of light hydrocarbon liquid, 70 percent of which is aromatic and most is styrene monomer and raw materials for making styrene. The product is refined using common

[10] Polyflow Business Plan, obtained from Polyflow via email on 10/10/2008

distillation and extraction technology. The fact that Polyflow produces high value, light hydrocarbon is notable and the subject of Polyflow's patent application.

- Of equal importance is the fact that the Polyflow process uses as feedstock mixed plastics and rubber. Polyflow can use polymer products as feedstock that most people have forgotten are polymers, like carpet. The process can accommodate fillers and contaminants like carbon and wire from tires, fiberglass from composites, paper labels, and metal inserts and screws from e-waste. In a municipal area like Cleveland/Akron, within a 25 mile radius there is enough accessible polymer waste to feed 5 Polyflow processors.

The Polyflow reactor design is shown in Figures 11 and 12.

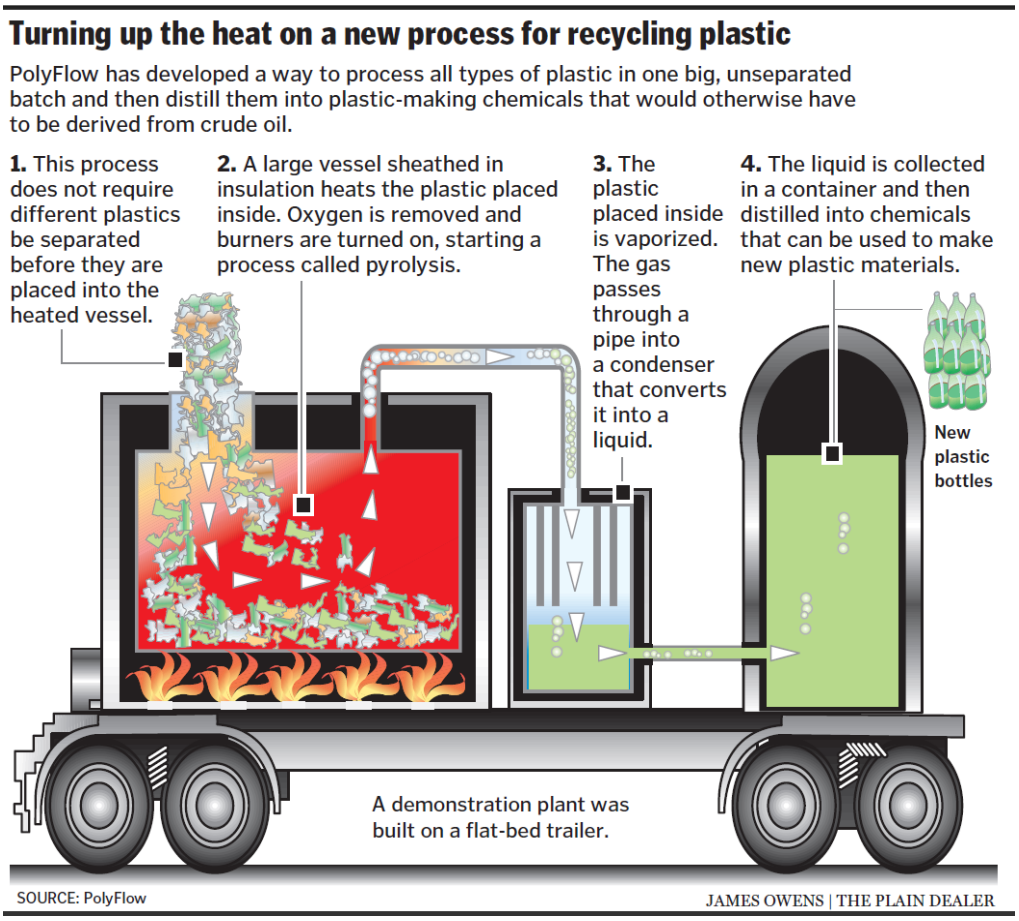

Figure 11. The Polyflow Depolymerization Process

Figure 12. The Polyflow Small-scale Process Reactor.[11]

3.3.1.4.4 Plastic Rail Ties from Waste Material[12]

An alternative to wood railroad ties, plastic ties, uses tons of plastic scrap. Plastic ties are being used in places like Chicago and New York City and in other railroads and transit systems. Polywood, Inc. has created a plastic tie that uses all plastic scrap. The ties consist of HDPE and styrene which, when combined create a thermoplastic composite material. Fibers are used to provide strength to the ties, eliminating the need for gypsum, fiberglass, or rubber. The unique tie ingredients have created a recycling market for styrene products such as Styrofoam cups and lunch trays. Prior to the market introduction of these rail ties, styrene did not have a large recycling market.

Each railroad tie uses about 200 pounds of recycled material. Railroads and transit systems are looking to the plastic ties as an alternative to wood ties. Wood ties are treated with creosote to protect them from the environment. This causes problems when it comes time to dispose of old worn out ties. On average, the Chicago Transit replaces 15,000 ties each year.

3.3.1.5 Recycling Insights from Industry

To better understand the current state of recycling flexible packages and their potential for recycling, Battelle interviewed several industry representatives. The interview survey validated our understanding of the recycling industry to be highly specialized, driven by the potential for value of recycled products and available technology and infrastructure. Most recyclers did not recover flexible packaging scrap from a mixed waste garbage stream. For example, the Rumpke Recycling facility receives flexible packaging scrap that is source separated from the generator. This stream is graded, processed and baled to shipment to an end-user. Another company, ACI Plastics, transforms large volumes of waste streams into valuable raw materials. Polymer films are shredded, reground, and pelletized for customers including resin brokers, compounders, blow-molders, extrusion shops, and injection molders.

[11] http://blog.cleveland.com/business/2008/08/it_wouldnt_be_the_first.html
[12] “Plastic Rail Ties Create Market for Scrap”http://www.americanrecycler.com/10ties.html

3.3.2. International Recycling Insights

3.3.2.1 Extended Producer Responsibilities[13,14]

Extended producer responsibility (EPR) programs are one of the significant differentiators among the recycling efforts in U.S. and Europe. These programs have existed in Europe since the early 1990s, but they have not gained traction in the U.S. In 1991, Germany legislated the manufacturer of products as the responsible party for recollecting the product and disposing it after the useful life of the product. The initial thought was that the consumer of the product would return the item to the manufacturer, who would then recycle it. The massive cost of this system led to a new format: a new company was formed with responsibility to collect and recycle the used products.

This company was called the Duales System Deutschland (DSD). The implementation of their system manifests itself as the Greendot program, where a common symbol is applied to all products that can be returned through the Greendot collection system. DSD created another collection system to add to an expensive existing system. The DSD is funded by the member companies. Initially, the fee charged to the manufacturers was based on their self-reported volume of manufactured items. This carried no incentive for light weighting of products. In households that were required to pay for their waste, the majority of the waste would end up in the Greendot collection bins, regardless of whether it had the symbol or not. Over time, German manufacturers have reduced their packaging weight while maintaining function. Since its inception, the DSD has streamlined processes and lowered costs by 40 percent.

Currently, 31 of the EU countries have adopted some form of EPR programs. They serve 500 million people and 130,000 member companies. The overall recycling rate in Germany has reached 80 percent.

Canada has also implemented an EPR, titled Stewardship Ontario, which has been in existence since 2002. In their program, industrial manufacturers pay fees that pay for recycling programs.

3.3.2.2 Recycling in Great Britain[15]

A presentation at the 2008 Global Plastics Environmental Conference outlined some testing done using some of the advanced sorting techniques. The focus was on a mixed plastics waste stream and the technologies available for implementation, especially flexible packaging. The research determined that there are several methods to separate mixed plastics waste streams, including density separation, NIR separation, and laser separation. All could be successfully used to sort the materials stream. However, justifying the economics for separating the incoming plastic materials was difficult. One of the major conclusions of the research was that energy reclamation efforts such as WTE and gasification technologies should be implemented as part of the end-of-life management schemes. This is telling, as it indicates that although the technology exists to separate the film, the overall volume of film or flexible packaging relative to the total MSW volume does not warrant additional capital or infrastructure investment.

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[13] "The Economics of Waste" Richard Porter, 2002, RFF Press
[14] "EPRs Work, but U.S. Unreceptive" Dan Hockensmith, Plastics News, September 22, 2008
[15] "Recycling of mixed post consumer plastics using advanced separation techniques"
Edward Kosior and Robert Dvorak, Nextek Limited, United Kingdom: Presentation at GPEC 2008 Conference

3.3.2.3 Interviewing Recyclers in England[16]

This English study sought to better understand the recycling habits, barriers, motivations and knowledge of residents. Due to the interview style used, the text below comes directly from the report. These interviews provide insights into issues that would need to be addressed if flexible packaging were to be implemented into the current recycling infrastructure.

Current recyclers say they would recycle more if they had:

- Collections of a wider range of materials (52 percent).
- Bigger containers (23 percent).
- More containers (20 percent).
- More space to store their containers (19 percent).
- More frequent collections (18 percent).
- Containers easier to move (16 percent).
- Bin (i.e., throw into the trash) things because they are not sure if they can be recycled (48 percent).
- Throw recyclable bathroom wastes in the residual bin (41 percent).
- Put things in the recycling even if they are not sure they can be recycled (36 percent).
- Forget to put out the recycling because they are not sure of the collection day (33 percent).
- Bin things because their recycling container is full (21 percent).
- Bin things rather than cleaning them for recycling (19 percent).

For most recyclers (95 percent) recycling has become part of the "everyday household routine." However, over half (53 percent) found it harder to recycle at Christmas; 16 percent in the winter generally; and 8 percent on vacation or in the summer generally. They are also deterred a little or a lot by:

- Fear of identity theft (16 percent)
- Having to store recyclables (12 percent)
- Having to clean recyclables (7 percent).

Less than half the sample as a whole (48 percent) understood "very well" how to use their recycling containers. About a third of recyclers said it would increase their recycling if they had better information about recycling services. Some recyclers also said that Council information had <u>not</u> helped them:

- Understand their local recycling scheme as a whole (21 percent)
- Understand the real benefits of recycling (12 percent)
- Knowing what can and cannot be recycled (12 percent)
- Knowing when the collection service operates (5 percent).

The vast majority of recyclers (90 percent), say they are "happy to be doing their bit for the environment" and 69 percent say they feel 'good about themselves' when recycling. However,

[16] "Summary Report: Barriers to recycling at home, Situational barriers" WRAP http://www.wrap.org.uk), **Project code:** CDC405-001 **Research date:** January to February 2008 **Date:** August 2008

29 percent feel they are just 'doing it because the Council is telling us' and 17 percent "do it because everyone else is doing it."

Recyclers would still be encouraged to recycle more by:

- Seeing the practical impact of recycling in their local area (86 percent)
- Feeling more appreciated by the Council (52 percent)
- Receiving an incentive for recycling (56 percent)
- Being fined for not recycling (34 percent).

3.3.3 Waste-to-Energy[17]

WTE is a term applied to the municipal solid waste (MSW) management option where the waste is taken directly to specially designed power plants that incinerate/ combust the MSW as fuel to create steam, and the steam is used to create electricity. WTE reduces trash volume by 90 percent, converting it to ash. There are currently 89 WTE facilities that operate in 27 states. The facilities are typically located where landfill space is at a premium and landfill tipping fees are high. Approximately 95,000 tons, or 13 percent, of America's trash is managed via WTE. The electricity generated is enough to supply approximately 2.3 million homes with power (data supplied from The Integrated Waste Services Association varies from the State of Garbage in America Report used here to calculate the percentage recovered for WTE).

3.3.3.1 Historical Development

WTE is synonymous with modern incineration. This technology converts waste into heat. The modern day incineration technology is sophisticated with comprehensive controls for pollution prevention and control. However, the public stigma with "incineration" and concern about impacts on health still exist.

Historically, issues stemming from community incinerators installed in communities after WWII include:

- Exhaust emissions not adequately considered in original designs
- Tall stacks used for dispersion polluting surrounding air, as opposed to air pollution control
- Original combustion furnaces utilized high excess air levels, resulting in (1) incomplete combustion (2) lower temperatures (3) high emission levels of carbon monoxide.

Most incinerators from the past did not generate electricity. These combined facts led to a "Not in My Backyard" mindset regarding incinerator locations. Figure 13 outlines some of the major milestones that have occurred in the past 35 years in the waste-to-energy industry.

[17] "FACT SHEET" from the website of Integrated Waste Services Association, the WTE industry association www.WTE.org

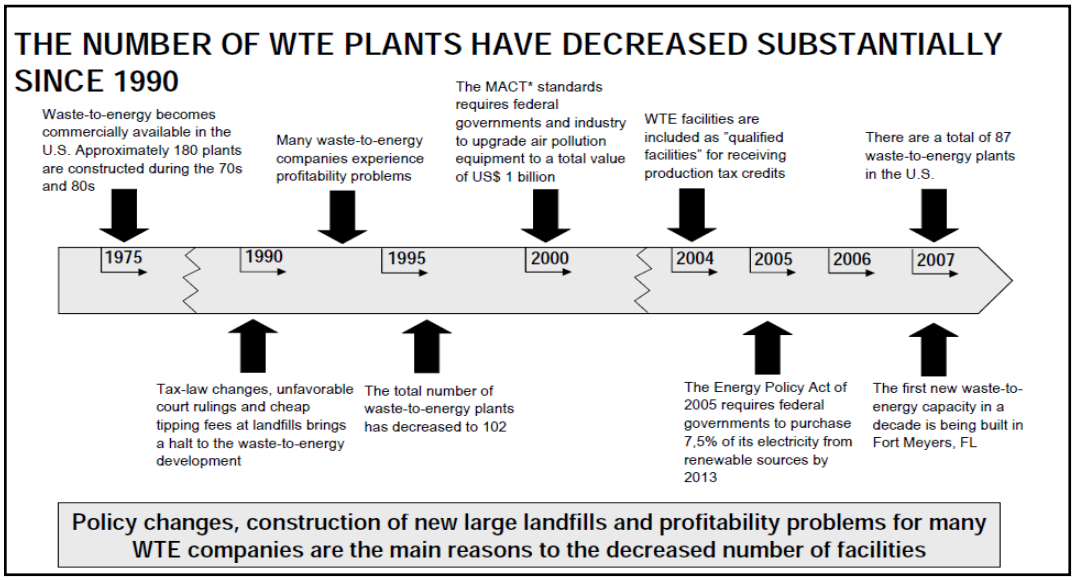

Figure 13. A Timeline of Major WTE Milestones.[18]

In the 1970s and 1980s, there were 186 MSW incinerators; in 2003, there were 112. In 1988, there were 6200 medical waste incinerators; in 2003, there were 115. There are several driving factors for the decline, including:

- Public opposition
- More recent Government emission regulations are much stricter. The cost to meet the EPA's Maximum Achievable Control Technology (MACT) standards enacted in 2000 was high, causing some plants to close down. However, the remaining waste-to-energy facilities are all in compliance with the updated regulations, at a cost of $1 billion to retrofit pollution control equipment to achieve the strictest Federal standards.
- Safe disposal of residual ash is expensive.
- Municipal waste disposal in landfills is sometimes less expensive than incineration.
- Replacement of aging incineration plants can be a political challenge.
- More public education is needed.
- Landfill space is still quite available in many locations across the U.S.

Waste disposal philosophies, including the successful implementation of WTE, need to be based on things the public understands, agrees with, and can buy into. Sustainable development and waste management is the merging of economic/social/environmental factors. Sustainable development is development that meets the needs of the present without compromising the needs of the future. WTE fits well with overall waste management guiding principles:

- Protect health and the environment – waste management must be conducted in ways that do not place a burden on future generations.

[18] **Renewable Energy in the U.S.:** Swedish Trade Council, U.S.A January 2008

- Minimize the burden on future generations.
- Conserve resources – non-renewable resources should be conserved to the maximum extent possible.

In 2004, a tax credit for new WTE facilities or new generating units at existing facilities continues the Federal Government's policy to encourage clean, renewable electricity, and promotes energy diversity while helping cities meet the challenge of trash disposal.

Global warming is currently one of the major ongoing societal discussions. Much of the discussion centers on greenhouse gas generation and management responsibility. One of the major international agreements regarding global warming and greenhouse gas management was the Kyoto Treaty. The Treaty is a multi-national agreement that mandates the signatory nations to implement emission caps and greenhouse gas trading programs to reduce greenhouse gases. The U.S. Senate has not ratified the Kyoto Treaty. America does not have a formal market in greenhouse gas credits, nor can our country participate in European or other market-trading programs designed to comply with Kyoto. But, individual organizations and companies as well as a few states are conducting some limited transactions to buy and sell greenhouse gas credits.

3.3.3.2 WTE = Renewable[19]

Currently in the U.S., WTE is considered renewable. The U.S. EPA states that WTE facilities are a "clean, reliable, renewable source of energy" and WTE facilities produce electricity with "less environmental impact than almost any other source of electricity.[20]"

Additionally, the DOE recognizes waste-to-energy as a renewable energy source and includes it in their tracking of progress toward achieving the Federal Government's renewable energy goal established by Executive Order 13123, and codified by the Energy Policy Act of 2005. The Federal Power Act defines renewable electric energy as electric energy produced by a renewable energy facility that produces electric energy solely by the use, as a primary energy source, of solar energy, wind energy, waste resources, biomass resources, geothermal resources, or any combination thereof. Further documentation includes the following:

- The Federal Energy Regulatory Commissions Regulations (18 CFR.Ch. I, 4/96 Edition, Sec. 292.204) defines biomass energy as any primary energy source which, on the basis of its energy content, is 50 percent or more biomass shall be considered biomass.
- The Biomass Research and Development Act of 2000 signed into law on June 20, 2000, defines biomass as any organic material that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes, plants, grasses, residues, fibers, animal wastes, municipal wastes, and other waste materials.
- The Federal Pacific Northwest Power Planning and Conservation Act define renewable resource to include power generated through the use of biomass.

[19] www.WTE.org
[20] Letter to IWSA from Marianne Horinko and Jeffrey Holmstead, U.S. EPA, 2/14/03, www.WTE.org

- The fuel used in waste-to-energy plants to produce clean electricity is municipal solid waste. Trash is both sustainable and indigenous – two basic criteria for establishing what is a renewable energy source.
- Twenty-three states define waste-to-energy as renewable power including Alaska, Arkansas, California, Connecticut, District of Columbia, Florida, Hawaii, Iowa, Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nevada, New Hampshire, New Jersey, New York, Oregon, Pennsylvania, Virginia, Washington, and Wisconsin.

3.3.3.2.1 Current National WTE Infrastructure[21]

WTE is used principally by more densely populated U.S. states. In 2002, the 15 states with the highest population densities accounted for 85 percent of the total tonnage sent to WTE facilities. The ten states with the lowest population densities had a total of just 0.4 percent of the WTE tonnage. Table 11 outlines the overall WTE facility count.

Table 11. International WTE Facilities

Location	Number of Facilities	Amount of MSW managed by WTE as a percent of Total MSW Generated
U.S.	89	8 to 15% (based on date from EPA and Biocycle)
Europe	400	Varies between countries
Japan	100	70 to 80%
Other Nations (China, Taiwan, Singapore	70	Varies between countries

Figure 14 displays the location of the waste-to-energy plants in the United States.

[21] "Waste in a Land of Plenty: Solid Waste Generation and Management in the U.S." Themelis, Kaufman, *Waste Management World*, Sept/Oct 2004

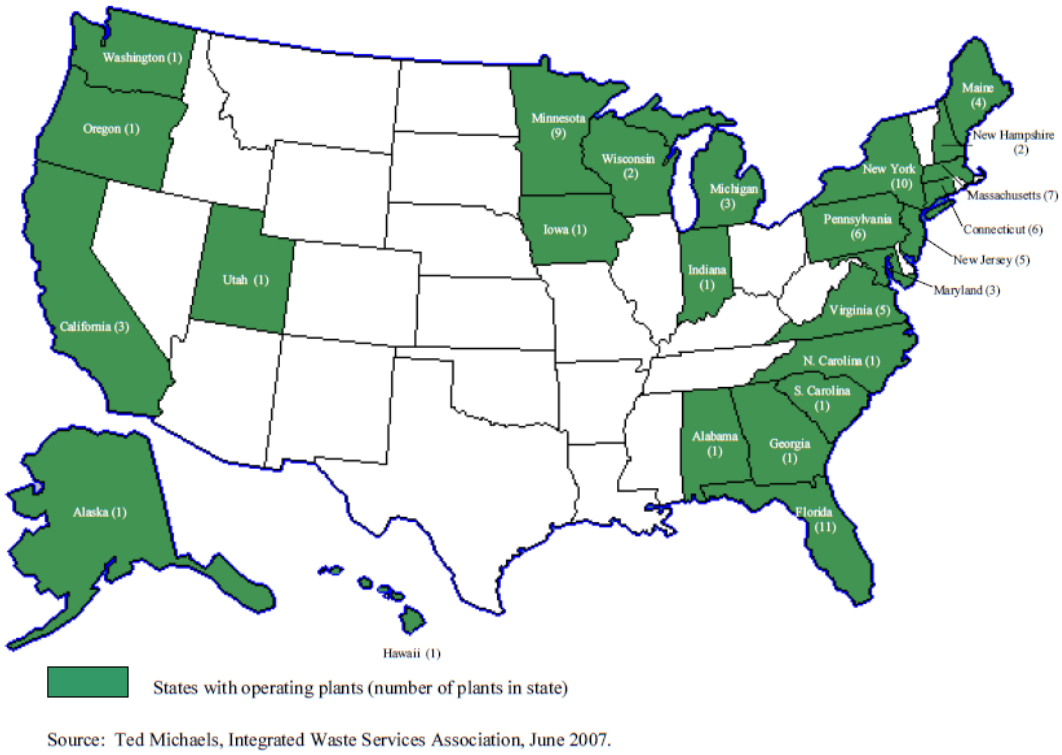

Figure 14. Operational WTE Plants in the U.S., by State. [22]

3.3.3.2.2. Current WTE Technologies[23]

As was noted earlier, WTE facilities are power generation plants that utilize municipal solid waste as the fuel of combustion. Generally, the flow of the process from incoming waste materials to sending of electricity to the grid follows this route:

- Incoming waste reception
- Storage of waste and raw materials
- Pretreatment of waste (where required, on-site or off-site)
- Loading of waste into the process
- Thermal treatment/combustion of the waste
- Energy recovery (*e.g.*, Boiler) and conversion
- Flue-gas cleaning
- Flue-gas cleaning residue management
- Flue-gas discharge
- Emissions monitoring and control
- Waste water control and treatment (*e.g.*, from site drainage, flue-gas treatment, storage)
- Ash/bottom ash management and treatment (arising from the combustion stage)
- Solid residue discharge/disposal.

[22] www.WTE.org

[23] "Summary Report: Evaluation of Alternative Solid Waste Processing Technologies", Prepared by: URS Corporation 915 Wilshire Boulevard, Suite 700 Los Angeles, CA 90017, Prepared for: City of Los Angeles Department of Public Works September 2005

This activity flow is shown in Figure 15.

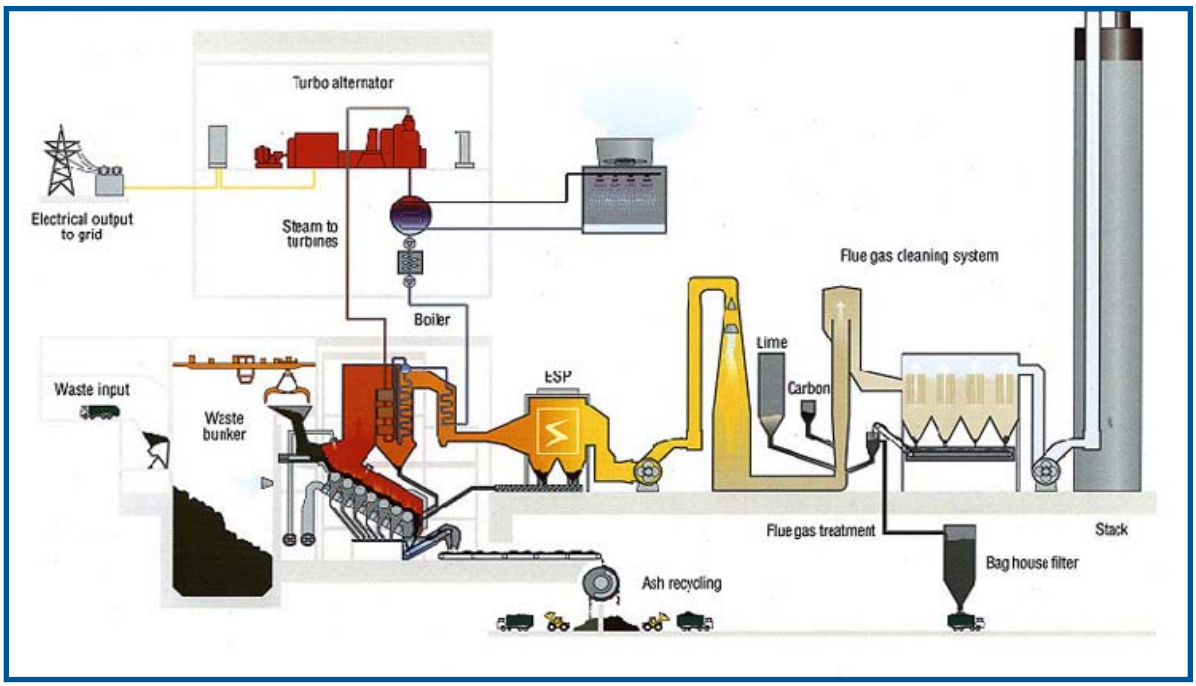

Figure 15. Activities in a WTE Facility.

Of the current 89 WTE plants in the U.S. today, only four combustion setups are used in the facilities. These are proven technologies, and are selected for implementation because of their robustness, reliability, and relative cost. Sixty of the facilities use a mass burn set up for the thermal treatment phase. A 600+ page document[24] by the European Commission and a review performed by LA County for a best technology available assessment[23] provide excellent background on each of the steps and technology options in the WTE process. Here, we will focus on: (1) thermal treatment of the material; (2) emissions control and monitoring; and (3) ash management and treatment.

3.3.3.2.3. Thermal Treatment/Combustion Options of MSW

The main thermal treatment technologies currently used are: (1) mass burn/grate incinerators; (2) rotary kilns; (3) fluidized beds; (4) pyrolysis and gasification; and (5) refuse derived fuel. Simply put, waste incineration is the oxidation of the combustible materials present in the waste stream. The waste stream is typically a highly heterogeneous material containing organic substances, minerals, metals, and water. During incineration, flue-gases are emitted that contain majority of the available fuel energy as heat. The organic substances in the waste burn when they come in contact with oxygen at their flammability temperatures. The actual combustion process takes place in the gas phase in fractions of seconds and simultaneously releases energy. Where the calorific value of the waste is high and oxygen supply is sufficient, this can lead to a thermal chain reaction and self-supporting combustion with no need for additional fuel.

[24] "Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration" European Commission August 2006

3.3.3.2.4 Mass Burn/Grate Incinerator

Grate incinerators are widely used for the incineration of mixed municipal wastes. They account for 60 of the 89 WTE plants in the U.S., and nearly 90 percent of the installations in Europe. The process starts with a crane lifting the MSW from the waste storage area onto the loading end of the grate, called the throat. As the material moves down the grate it is combusted and the generated ash falls below the grate and is collected for disposal.

Combustion air is supplied through the grate from below. This air flow also has the purpose of cooling the grate. Cooling is important for the mechanical strength of the grate, and many moving grates also are internally water cooled.

Secondary combustion air is supplied into the boiler at high speed through nozzles over the grate. It facilitates complete combustion of the flue gases by introducing turbulence for better mixing and by ensuring a surplus of oxygen. In multiple/stepped hearth incinerators, the secondary combustion air is introduced in a separate chamber downstream the primary combustion chamber.

Incineration plants must be designed to ensure that the flue gases reach at least 850°C (1,560°F) for 2 seconds in order to ensure proper breakdown of organic toxins. Backup burners are installed in the system and activated if the temperature drops below that point. The flue gases are then cooled in the superheaters, where the heat is transferred to steam, heating the steam to typically 400°C (752°F) at a pressure of 40 bars (580 psi) for the electricity generation in the turbine. At this point, the flue gas has a temperature of around 200°C (392°F), and is passed to the flue gas cleaning system.

Grate incinerators (Figure 16) usually have the following components: (1) waste feeder; (2) incineration grate; (3) bottom ash discharger; (4) incineration air duct system; (5) incineration chamber; and (6) auxiliary burners.

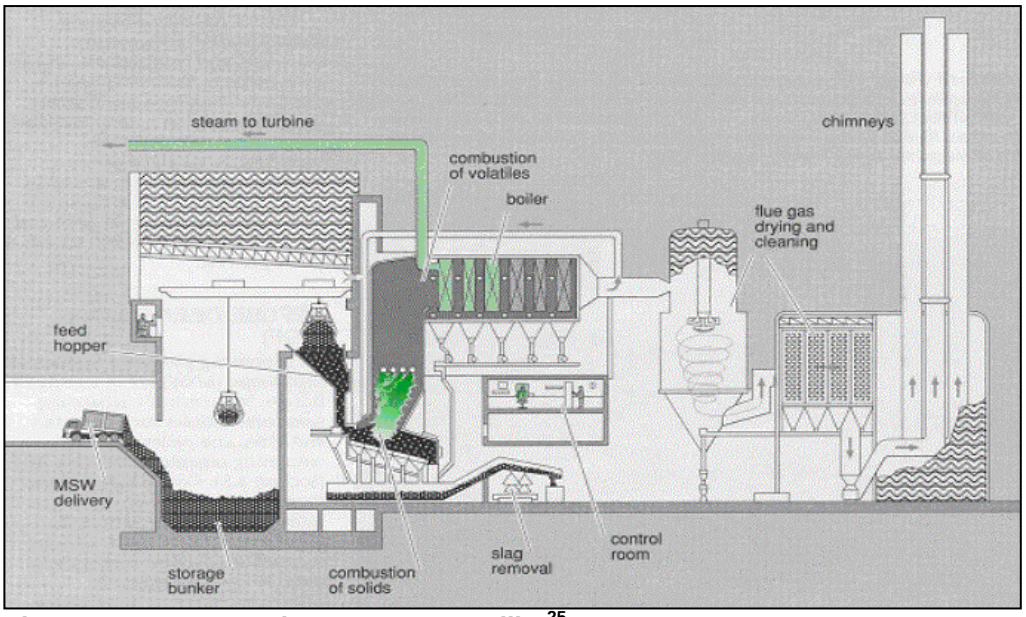

Figure 16. A Grate Incinerator WTE Facility[25]

3.3.3.2.5. Rotary Kilns

The rotary kiln operates in a manner similar to the grate incinerator, but utilizes a large rotating cylinder that is slightly inclined rather than a system of grates. Waste is conveyed through the kiln by gravity as it rotates. The amount of time the waste is in the vessel is determined by a combination of kiln rotation speed and horizontal angle. Solid waste, liquid waste, gaseous waste, and sludge can be incinerated in rotary kilns. Solid materials are usually fed through a non-rotating hopper; liquid waste may be injected into the kiln through burner nozzles; pumpable waste and sludge may be injected into the kiln via a water cooled tube. At the end of the kiln, there is typically a post combustion chamber added to ensure that all toxic compounds have been destroyed in the process. Figure 17 shows a schematic of a rotary kiln.

[25] http://www.rise.org.au

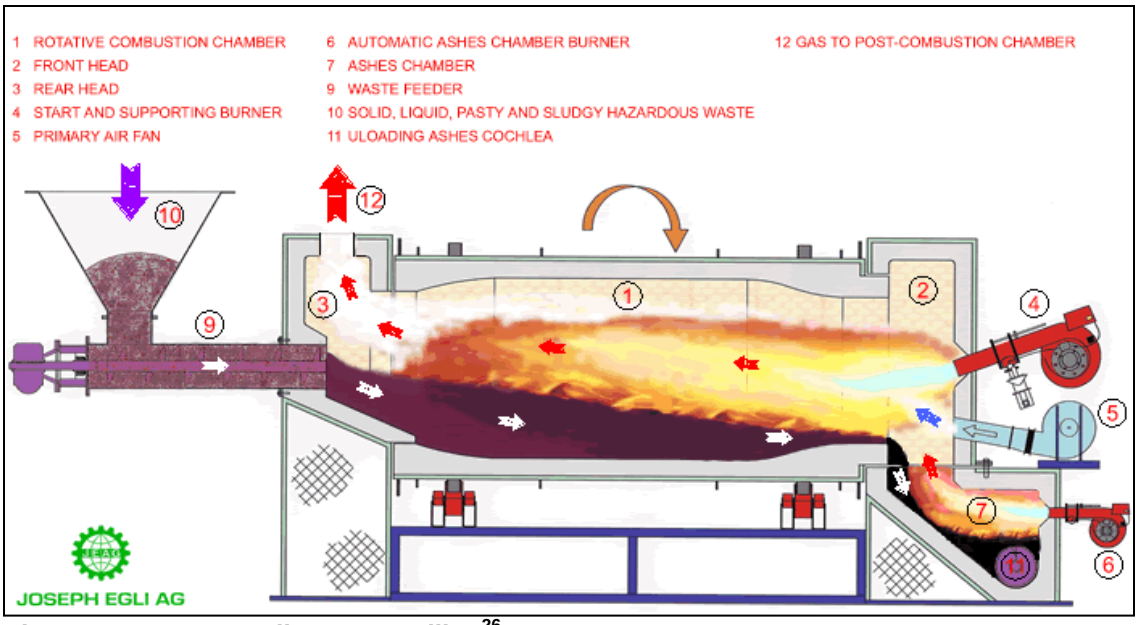

Figure 17. A Rotary Kiln WTE Facility.[26]

3.3.3.2.6. Fluidized Beds

The fluidized bed incinerator is a lined combustion chamber in the form of a vertical cylinder. The lower portion of the cylinder has sand or ash on a grate. The material to be incinerated is fed continuously onto the sand. Preheated air is introduced to the chamber just above the lower portion of the cylinder. This creates a high temperature area (850°C to 950°C where drying, volatilization, ignition and combustion can occur. The MSW being fed into the bed is typically pretreated via a crushing and shredding processes. Ferrous and non-ferrous material removal also occurs during pre-loading of the chamber. Figure 18 shows a schematic of a fluidized bed.

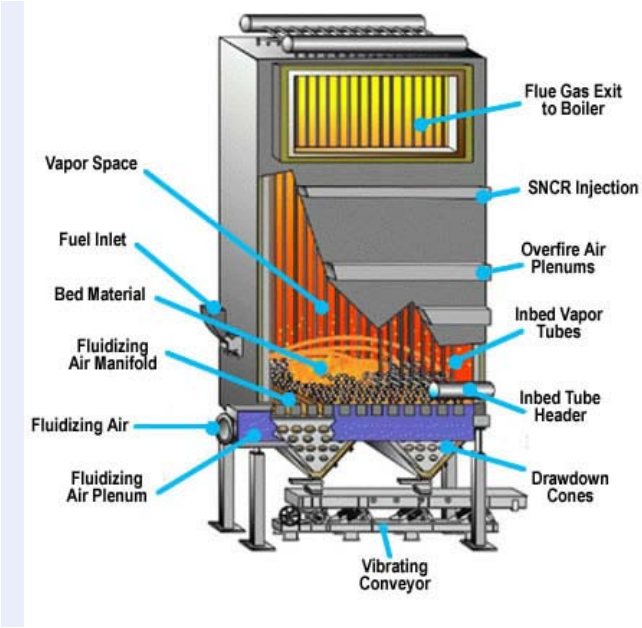

Figure 18. A Fluidized Bed Mechanism.[27]

[26] http://www.jeag.com
[27] http://www.enpowercr.com

3.3.3.2.7. Pyrolysis and Gasification[28]

The following information comes directly from the European Commission report, as they have concisely summarized the connection between these technologies.

Both pyrolysis and gasification differ from incineration in that they may be used for recovering the chemical value from the waste (rather than its energetic value). The chemical products derived may in some cases then be used as feedstock for other processes. Gasification is a partial combustion of organic substances to produce gases that can be used as feedstock (through some reforming processes) or as a fuel. Pyrolysis is the degassing of wastes in the absence of oxygen, during which pyrolysis gas and a solid coke are formed. The heat values of pyrolysis gas typically lies between 5 and 15 MJ/m³ based on municipal waste and between 15 and 30 MJ/m³ based on refuse derived fuel (RDF). In a broader sense, "pyrolysis" is a generic term including a number of different technology combinations that constitute, in general, the following technological steps:

- Smoldering process: Formation of gas from volatile waste particles at temperatures between 400 and 600°C
- Pyrolysis: Thermal decomposition of the organic molecules of the waste between 500 and 800°C resulting in formation of a gas and solid fraction
- Gasification: Conversion of the carbon share remaining in the pyrolysis coke at 800 to 1000°C with the help of a gasification substance (*e.g.*, air or steam) in a process gas (CO, H_2)
- Incineration: Depending on the technology combination, the gas and pyrolysis coke are combusted in an incineration chamber.

However, when applied to wastes, common practice combines pyrolysis, gasification, and combustion-based processes, often on the same site as part of an integrated process. When this is the case the installation is generally recovering the energy value rather than the chemical value of the waste, as would a normal incinerator. In some cases, the solid residues arising from such processes contain pollutants that would, in an incineration system, be transferred to the gas phase, and then with efficient flue-gas cleaning, be removed with the flue gas treatment residue. The following systems and concepts have been developed (with different levels of proven success on an industrial scale):

- System 1 Pyrolysis in a rotary kiln – coke and inorganic matter separation – incineration of pyrolysis gas
- System 2 Pyrolysis in a rotary kiln – separation of inert materials - combustion of the solid carbon rich fraction and the pyrolysis gas
- System 3 Pyrolysis in a rotary kiln – condensation of pyrolysis gas components - incineration of gas, oil and coke

[28] Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes" Alexander Klein, Advisor: Professor Nickolas Themelis ,Submitted in partial fulfillment of the requirements for the degree of M.S. in Earth Resources Engineering Department of Earth and Environmental Engineering Foundation School of Engineering and Applied Science, Columbia University, May 2002 www.columbia.edu/cu/earth

- System 4 Pyrolysis on a grate – directly connected incineration
- System 5 Pyrolysis on a grate (with subsequent melting furnace for low metal content molten bottom ash production) – circulating fluidized bed (burnout of particles and gas).

Figure 19 depicts the pyrolysis process.

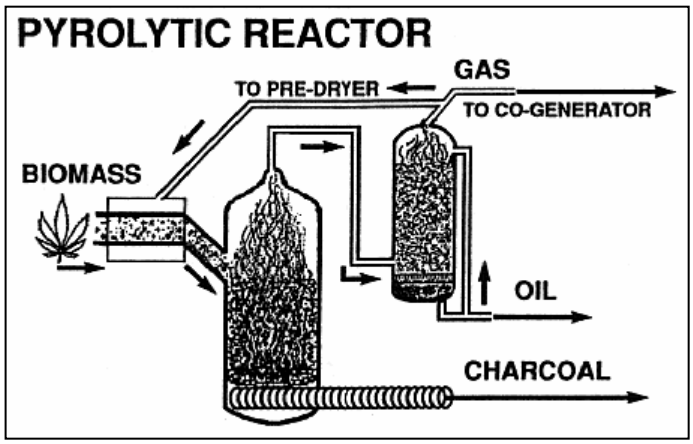

Figure 19. The Pyrolysis Process.[29]

Gasification systems for wastes, an example of which is given in Figure 20:

- System 1 Fixed bed gasifier – pretreatment drying required for lumpy material
- System 2 Slag bath gasifier – as fixed bed, but with molten bottom ash discharge
- System 3 Entrained flow gasifier – for liquid, pasty and fine granular material that may be injected to the reactor by nozzles
- System 4 Fluidized bed gasifier – circulating fluid bed gasifier for pretreated municipal waste, dehydrated sewage sludge and some hazardous wastes
- System 5 Bubbling bed gasifier – similar to bubbling fluidized bed combustors, but operated at a lower temperature and as a gasifier.

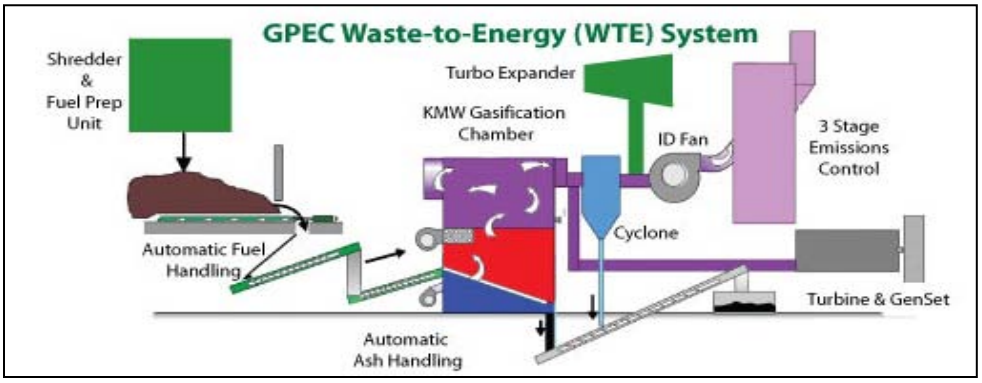

Figure 20. The Gasification Process.

[29] http://www.ratical.org/renewables/pyrolytic.gif

Pyrolysis - gasification systems for wastes:

- System 1 Conversion process – pyrolysis in a rotary kiln – withdrawal and treatment of solid phase – condensation of gas phase – subsequent entrained flow gasifier for pyrolysis gas, oil, and coke
- System 2 Combined gasification-pyrolysis and melting – partial pyrolysis in a push furnace with directly connected gasification in packed bed reactor with oxygen addition

Many companies are currently working on developing the pyrolysis and gasification technologies that are useful for converting waste packaging into energy. Some of these companies are listed below:

Pyrolysis:

1. Energos: www.energ.co.uk
2. BEST Pyrolysis: www.bestenergies.com
3. Pyromex: www.pyromex.com/
4. Polymer Energy: www.polymerenergy.com/

Gasification:

1. Recovered Energy: www.recoveredenergy.com/
2. Plasco: www.plascoenergygroup.com/
3. GE Energy: http://www.ge-energy.com/

3.3.3.2.8. Refuse Derived Fuel

In the refuse derived fuel process, MSW is sorted and non-combustibles (glass and metals) are removed from the waste stream. The waste is ground, dried, and mixed with binders before being processed in a hot extruder to make pellet shapes. The pellets are sold to be used as a heat source. Figure 21 outlines the process.

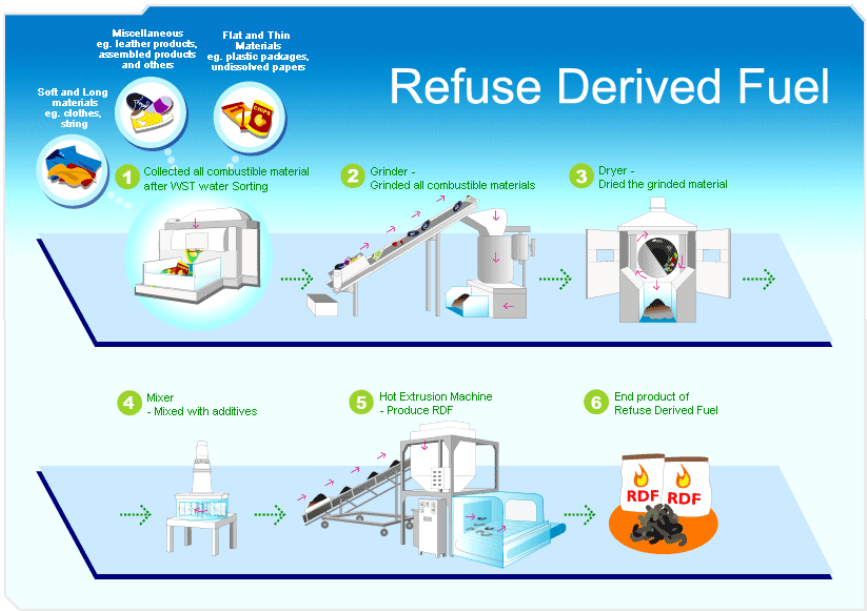

Figure 21. Refuse Derived Fuel Process.

3.3.3.2.9. Emissions Controls[30]

As noted above, the incineration plants of past decades developed a bad reputation because they lacked emissions controls and did not capture the energy of combustion and put it to use. The MACT standards enacted in 2000 mandate that tight emission controls be implemented to scrub the combusted material. Currently, WTE, as a power generation source, emits less greenhouse gases than coal, natural gas, or oil fossil fuel energy plants. Table 12[31] compares the power generation methods.

Table 12. A Comparison of Air Emissions from Several Electricity Generation Sources

FUEL	Carbon Dioxide	Sulfur Dioxide	Nitrogen Oxides
	Pounds per Megawatt-Hour		
MSW	837	0.8	5.4
Coal	2249	13	6
Oil	1672	12	4
Natural Gas	1135	0.1	1.7

WTE technology prevents the release of 40 million metric tons of greenhouse gases in the form of carbon dioxide equivalents that otherwise would be released into the atmosphere on an annual basis, according to an analysis developed by the EPA and the Integrated Waste Services Association (IWSA) using EPA's Decision Support Tool program. Annual reporting by IWSA to the DOE's Voluntary Reporting of Greenhouse Gases Program confirms that waste-to-energy also prevents the release each year of nearly 24,000 tons of nitrogen oxides and 2.6 million tons of volatile organic compounds from entering the atmosphere.

"Dioxin" describes a family of 210 different organic compounds, all of which contain carbon, chlorine, hydrogen, and oxygen. Concern over dioxins led the EPA to undertake the task of researching and writing a major scientific report entitled, "Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds." This report is commonly referred to as the EPA dioxin reassessment.

The potential for harmful effects of some dioxins was not recognized globally until the late 1980s. Major efforts since then to reduce dioxin emissions to the environment have been directed at controlling most of the known industrial sources of dioxin. With respect to the waste-to-energy industry, EPA ensures strict dioxin controls through implementation of Federal MACT regulations noted above. Modern waste-to-energy plants combust municipal solid waste at temperatures of 2000°F (which destroys most dioxins) and utilize sophisticated pollution control equipment to further reduce emissions to meet EPA's stringent requirements. Test results from WTE facilities nationwide demonstrate that emissions of dioxins are well below the EPA's MACT regulations, found at levels barely detectable by the most sophisticated instrumentation.

[30] IWSA Fact Sheet, "Waste to Energy is an Insignificant Source of Dioxin" www.WTE.org

[31] "Comparison of Air Emissions from Waste-to-Energy Facilities to Fossil Fuel Power Plants" Jeremy O'Brien, Solid Waste Authority of North America, www.swana.org

In a study developed by the EPA[32] using the Municipal Solid Waste Decision Support Tool (MSW-DST) nine scenarios were evaluated to compare the life-cycle environmental tradeoffs and costs for a range of technologies for a medium-size, U.S. community. The tool includes comparisons of greenhouse gas emissions, energy balances, and cost. The nine scenarios are outlined in Table 13.

Table 13. End-of-life Scenarios Compared Using MSW-DST

Scenario	Description
1	10 percent recycling with remainder being landfilled with no landfill gas collection and control
2	Same as scenario 1 except 20% recycling rate
3	Same as scenario 2 except 30% recycling rate
4	Same as scenario 3 except with landfill has gas collection and control using flare
5	Same as scenario 4 except landfill gas is used to produce electricity using internal combustion engine
6	Same as scenario 4 except landfill gas is piped to nearby industrial facility and combusted in boiler (displacing fuel oil)
7	Same as scenario 3 except use of waste-to-energy facility (generating electricity and recovery of metals)
8	Same as scenario 3 except waste is collected and transported to transfer station, and then long hauled 500 miles to landfill using semi-tractor truck
9	Same as scenario 8 except waste is long hauled to landfill by rail

Figure 22 outlines the carbon equivalent emissions according to the nine scenarios of the report. The data shows that Scenario #7, the end-of-life option that includes waste-to-energy, is the only scenario to have a negative emission value. The reasons for this are twofold: (1) the excellent emission controls that have been implemented in WTE facilities and (2) electricity generated via the combustion of trash offsets electricity that would have been created using fossil fuel sources.

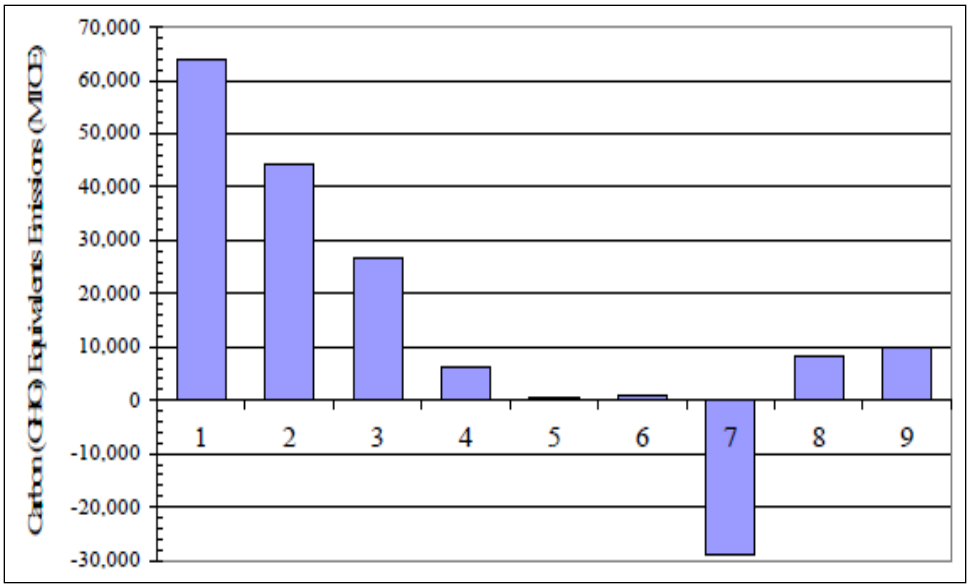

Figure 22. Net Greenhouse Gas Emissions by Scenario (MMTs of carbon equivalents).

[32] "Moving from Solid Waste Disposal to Materials Management in the United States" *For presentation at the tenth International Waste Management and Landfill Symposium in Cagliari, Italy on October 3-7, 2005. Susan A. Thorneloe*, Keith A. Weitz**, and Jenna Jambeck**

3.3.3.2.10 WTE Ash Creation

Ash is created from the combustion process in a WTE facility. This ash has historically been sent to a landfill for management. Currently though, nearly 3 million tons of ash (1/3 of all ash generated) is being reused annually as landfill roadbed material, daily and final landfill cover, road aggregate, and asphalt.

In accordance with the Federal law, WTE ash is tested to ensure it is non-hazardous. The EPA developed a test called the Toxicity Characteristic Leaching Procedure (TCLP) that subjects ash to acidic liquid, causing metals to leach from the material. If metals leach in amounts greater than a fraction of a percent, the ash is considered hazardous. Years of testing ash from every waste-to-energy facility in the country has proven ash safe for disposal and reuse. Waste-to-energy ash consistently passes the TCLP.

3.3.3.2.11 Current WTE Spatial Considerations

The building of new waste to energy plants is driven by several factors, including available (or lack of) landfill space, landfill tipping fees, electricity prices, shipping costs for municipal solid waste, WTE plant tipping fees, and regulations.

3.3.3.2.12 WTE Compatibility with Recycling

In addition to the historical negative connotations about the environmental impacts of the WTE facilities, there have also been misconceptions about its compatibility with the recycling infrastructure. As a result, some communities have opted against the WTE facility because it would reduce the amount of recycling. However, the data on WTE and recycling compatibility[33] shows that communities with WTE plants recycle more than those that do not, as shown in Figure 23.

Overall resource recovery is improved when WTE and recycling are used to manage municipal solid waste in a community.[34] Since WTE facilities can recover ferrous metals once the MSW has been combusted, they do not need to be included in the recycling waste stream. WTE and recycling work together as a part of the end-of-life hierarchy to reduce overall landfill usage. When there is an efficient recycling program used in conjunction with WTE plants, the WTE facility can work more with the commercial and spot waste markets, which typically result in higher deposal fees and make the facility more profitable.

A 2008 study[35] that analyzed 82 WTE facilities across 22 states obtained the following data about recycling rates in communities with and without WTE plants.

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[33] "A Compatibility Study: Recycling and Waste-to-Energy Work in Concert" Eileen Brettler Berenyi, PhD, September 2008 www.WTE.org/docs/2008_Berenyi_compatibility_study.pdf

[34] "Recycling and Waste to Energy, the Ongoing Success Story" Kiser, Jonathan, *MSW Management*, May/June 2003

[35] "A Compatibility Study: Recycling and Waste-to-Energy Work in Concert" Eileen Brettler Berenyi, PhD, September 2008 www.WTE.org/docs/2008_Berenyi_compatibility_study.pdf

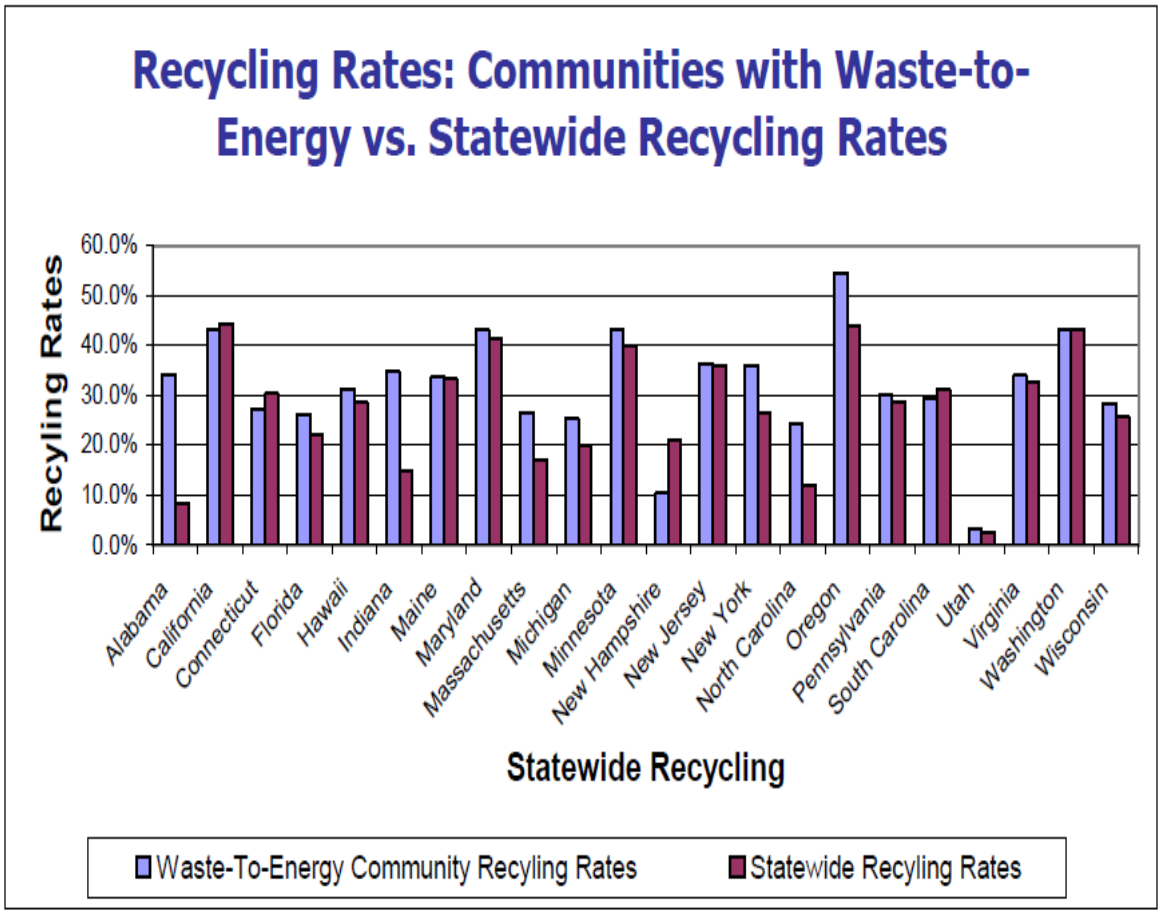

Figure 23. A Comparison of How WTE Availability Affects Recycling Rates.

As the data shows, the presence of a waste to energy facility does not negatively affect recycling rates.

3.3.3.2.13 Tipping Fees in North America

The National Solid Wastes Management Association (NSWMA) has annually surveyed the landfill tipping fees in the United States for 7 regions of the country since 1982.[36] These fees are outlined in Table 14 and Figure 24.

The regional landfill tipping fee breakout can be directly overlaid with the location of WTE plants (Figure 24) to see the influence on building new plants. The majority of the WTE plants in the U.S. are clustered in the Northeast, where landfill tipping fees are the most expensive and landfill space is least available. Conversely, in the central region of the U.S. there are no WTE plants and landfill space is abundant.

[36] "NSWMA's 2005 Tip Fee Survey" Edward W. Repa, Ph.D. *NSWMA Research Bulletin 05-3* March 2005 http://www.nswma.org/

Table 14. Historical Breakdown of Landfill Tipping Fees in the U.S.

Landfill Tip Fees ($/Ton) 1985 - 2004											
Region	**1985**	**1986**	**1987**	**1988**	**1990**	**1992**	**1995**	**1998**	**2000**	**2002**	**2004**
Northeast	12.66	17.11	52.41	61.11	64.76	65.83	73.17	66.68	69.84	69.07	70.53
Mid-Atlantic	16.99	22.08	26.32	33.84	40.75	47.94	45.68	44.11	45.84	45.26	46.29
South	3.24	5.76	13.13	16.46	16.92	22.48	28.5	30.89	30.53	30.43	30.97
Midwest	7.23	11.75	16.42	17.7	23.15	27.1	31.15	30.64	32.85	34.14	34.96
South Central	7.24	7.61	10.17	11.28	12.05	12.53	20.3	21.02	21.9	23.28	24.06
West Central	5.36	6.21	7.23	8.5	11.06	12.62	23.29	22.51	22.29	23.4	24.13
West	10.96	11.1	13.92	19.45	25.63	27.92	37.69	36.08	34.54	38.9	37.74
National	8.2	10.92	16.11	19.12	23.01	26.32	32.19	31.81	32.19	33.7	34.29

Regions:

Northeast: CT, ME, MA, NH, NY, RI, VT	Mid-Atlantic: DE, MD, NJ, PA, VA, WV,	Midwest: IL, IN, IA, MI, MN, MO, OH, WI
South: AL, FL, GA, KY, MS, NC, SC, TN	South Central: AZ, AR, LA, NM, OK, TX	
West Central: CO, KS, MT, NE, ND, SD, UT, WY	West: AK, CA, HI, ID, NV, OR, WA	

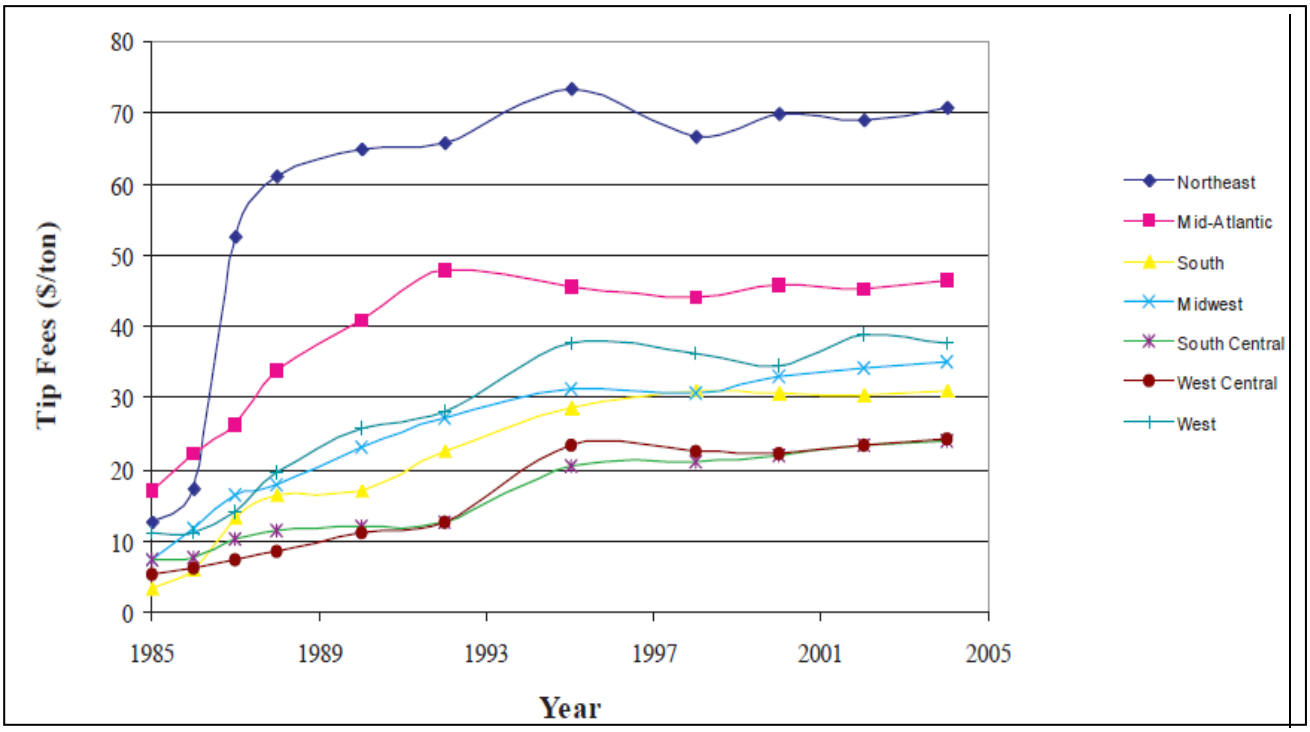

Figure 24. Historical Breakdown of Landfill Tipping Fees in the U.S.

3.3.3.2.14 The Economics of WTE

WTE facility revenues come from fees paid for garbage disposal and the price paid for electricity generated by WTE plants. New facilities or new generating units built at existing facilities require significant capital investment. The capital, and the operation and maintenance (O&M) costs at a facility equal about $100 for each ton of garbage processed at a facility. On an energy revenue basis, about 20 cents per kWh would be required for capital and O&M. For example, a facility that processes 2000 tons of trash each day into 60 MW of electricity would require about $200,000 in revenues daily, coming from either disposal fees or electricity revenues, or both.

WTE power must be sold as "base load" electricity and cannot be operated to supply "peak load" power simply because there is a constant need for trash disposal by combustion that keeps power generation steady and reliable. Similar to other alternative energy sources, WTE plants are qualified facilities (QFs), eligible under the Public Utility Regulatory Policies Act (or PURPA) for mandatory power purchase at avoided cost. Most existing facilities have been financed based, in part, on long-term PURPA contracts that run commensurate with the facility debt. The market price and disposal fee on average are not sufficient to cover the cost of a new waste to energy unit.

The cost of financing WTE plants includes siting, construction, operation over a 20-40 year lifetime, and decommissioning. Because of "Not-in-My-Backyard – NIMBY" factors, siting is a major fraction of the cost. In 1999, typical landfill tipping fees were $25 to $75 per metric ton, WTE fees were $40 to $100 per ton, recycling fees were $40 to $90 per ton. This relative comparison is still true today, although the recycling numbers changed during the fall of 2008 due to the widely fluctuating recycling market.

For example, there was a WTE facility built in Lancaster, PA in the late 1990s that processed 1100 ton per day of MSW. The initial capital cost was $110 million. Annual operating costs for the plant were $9.5 million, offset by electricity generation of $12 million; reclaimed ferrous metal from the ash sold for approximately $200K per yr.

Compared to high technology WTE operations, landfills are a relatively inexpensive, low technology operation involving mostly an earth (and waste) moving exercise. Landfills do not require up front capital, and have a lower operating cost.

The financial outcome of recycling and WTE is subject to cyclic and unpredictable marketing of energy and recyclables. But, financial costs do not take into account (1) the permanence of landfills (2) impairment of ground water by leaking leachate and (3) degradation of atmosphere by emissions.

Following are the five significant monetary aspects that a community must evaluate in comparing landfills to incinerators when considering the WTE option[37]:

1. CAPITAL COST TO START THE FACILITY: based on amount of daily capacity. Amounts can range from $100,000 per daily ton to $200,000 per daily ton. With the

[37] The Economics of Waste by Richard C Porter, Resources for the Future, Washington DC, ISBN 1-891853-43-0, paperback, 301 p.

various tonnage sizes of 300 to 3000 ton capacity per day, upfront costs = $30 to $600 million to start. This large debt can put a lot of financial stress on the owner over the 20-year life of the operation.

2. SCALE: large incinerators are cheaper per ton than smaller (modular) incinerators Capital costs are similar, ash disposal and electricity generation revenues are similar, but operating and maintenance costs are cheaper than small scale operations by $10 per ton.
3. LAND: The cost of land is a deciding factor. Land costs are a small total of the overall cost. Tipping fees in the Northeast can be $100/ton in densely populated urban areas and less than $10 in the rural Southwest.
4. FLOW: Incinerators are not flexible to varying amounts of waste streams. They have one design capacity, and run less efficiently (and more costly) if the optimal design conditions are not met. If waste flows higher than the design capacity are received at the facility, they must be land filled, because few have capacity for overflow.
5. ENERGY: Net operating costs of WTE are much lower than landfills because of the electricity production offset.

The benefits of WTE over land filling include: (1) reduced amount of waste put in landfills; (2) operating costs offset by electricity sales; and (3) reduced amount of land use. The shortcomings are: (1) enormous initial capital investment; and (2) inability to accept varying flows of garbage. Tipping fees for each of the two methods can help quantitatively show the difference in overall cost: fees for WTE are typically twice the national average for landfills.

3.3.3.3 New WTE Technologies/Developments

3.3.3.3.1 Cement Kilns

Cement kilns are used in the manufacture of cement, where calcium carbonate chemically reacts with silica-bearing minerals to create calcium silicates. In 2007, there were approximately 95 million tons of cement produced in the United States.[38] The critical operation in cement manufacturing is the kiln, which requires heat to fuel the reaction. Typically, cement kilns use wide variety of fuel sources including used tires that are added to the kiln due to their high heat value. The extremely hot temperatures, greater than 1000°C[39], result in complete combustion of the tires. Cement kilns are included in this sustainability report because of their use of tire waste as a fuel for energy creation.

3.3.3.3.2 Waste to Ethanol[40]

Agresti Biofuels (formerly Indiana Ethanol Power LLC) announced that it will begin contract negotiations with Pike County, Kentucky in fall 2008 for a commercial municipal solid waste to cellulosic ethanol production facility. The facility and process are completely clean and waste materials like plastic, rubber, and metal will be separated from the MSW for recycling.

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[38] http://minerals.usgs.gov/minerals/pubs/commodity/cement/mcs-2008-cemen.pdf
[39] "The Rotary Cement Kiln" K E Peray, CHS Press, 1998
[40] "Agresti Biofuels to build waste-to-ethanol plant" OCTOBER 2008, http://www.americanrecycler.com /1008/agresti.shtml

Pike County, searching for a more cost effective and environmentally-friendly alternative to its current landfill (now nearing capacity), voted to begin contract negotiations with Agresti Biofuels for construction of the Central Appalachian Ethanol Plant. The county's current landfill receives 400 tons of MSW per day; when fully operational, the new plant is projected to process as much as 1,500 tons of MSW per day.

A major decision to move forward came following announcements that the new renewable fuel standards in the U.S. mandate the production of 36 billion gallons of ethanol by 2022. The Central Appalachian Ethanol Plant is expected to produce 20 million gallons of fuel-grade ethanol and other saleable products derived from MSW by utilizing the patented GeneSyst process invented by James Titmas.

3.3.3.3.3 Plastofuel Nuggets[41]

James Garthe, a professional engineer at the Pennsylvania State University Agricultural and Biological Engineering Department, invented Plastofuel in the early 1990s with the idea that energy recovery through the clean incineration of waste agricultural plastics might be a better alternative.

In the agricultural community, plastics are used widely for chemical containers, greenhouse covers, hay bale wrap, bunker silo covers, high and low tunnel covers, nursery trays and pots, and many other applications. But due to the contamination of the plastics, they are used only once and then discarded because the cost to clean them cannot be justified. The result is an estimated 1 billion pounds of waste agricultural plastics generated annually by the U.S. agricultural community alone. Several companies incorporate these waste plastics into products such as composite lumber. However, only 5 percent of all waste agricultural plastics generated in the U.S. are recycled in any form. The majority of the plastic used for plastic lumber comes from plastic shopping bags that have not been contaminated. Since they currently cannot be recycled, most used agricultural plastics are disposed of by open burning, on-site piling, on-site burying, or landfilling.

Plastofuel is created by forcing unsorted, dirty agricultural plastic through a heated extrusion die. Minimal energy is used to form the nugget, as just the exterior is melted thus encasing the unmelted contents. The nuggets can then be transported and metered into a specially designed incinerator to reclaim the very high energy content of plastic. Plastic is a petroleum-derived product, therefore the energy content of plastics (approx. 19,000 BTU/lb) is very near that of fuel oil (approx 21,000 BTU/lb).

In 2005, the Pennsylvania State University was awarded a 2-year, $87,000 grant from the Pennsylvania Department of Agriculture to scale up production of Plastofuel from the existing prototype machine. The initial prototype machine produced about 10 lbs of Plastofuel per hour, while the scaled up prototype could produce up to 61l lbs of Plastofuel per hour. An energy ratio based on the energy consumption of the machine and the energy content of the fuel pellets produced was calculated at 47:1. In other words, the energy in the plastic nuggets produced was equal to 47 times the amount of energy used to form the nuggets. Energy recovery values of various materials are listed in Figure 27.

[41] http://www.personal.psu.edu/mjl145/phd_research.htm

Table 15. Energy Recovery Values from Various Combustion Sources

Material	Heating Value, MJ/kg (Btu/lb)
Fuel Oil	48.6 (20,900)
Polyethylene	46.3 (19,900)
Polypropylene	44.1 (19,000)
Polystyrene	41.4 (17,800)
Tires	30.1 (13,000)
Sub bituminous Coal	27.3 (11,729)
Wood (pine)	22.3 (9,600)
Wood (oak)	19.3 (8,296)
Municipal Solid Waste (dry)	16.2 (6,968)

Professor Garthe was interviewed for this study. He noted that the major limiting factor in taking the technology to market is the delayed development of the combustion technology used in conjunction with the pellets.

3.3.3.3.4 Air Force Mobile Waste-to-Energy[42]

United States Air Force researchers are developing a transportable waste-to-energy system to produce electricity at forward military operations.

A prototype, mounted on a 48-foot flatbed semi-trailer, is being tested at Tyndall Air Force Base in Florida by the Air Force Research Laboratory Materials and Manufacturing Directorate, which conducts programs that enhance readiness, deployment, fire protection, peacetime training, and crash and rescue operations. The transportable WTE system could reduce the amount of fossil fuel used at each forward military operation and could also be used at domestic bases. Transportable WTE system investigations began in 2004. The system consists of a furnace and an energy recovery unit. The movable furnace system was complete as of fall 2008. The system is designed for 50 tons per day of feed. Figure 25 displays the prototype unit.

Figure 25. Prototype Transportable WTE System.

[42] "Air Force develops mobile waste-to-energy system: Combustible waste lowers fuel usage and costs" http://www.americanrecycler.com/1008/air.shtml

3.3.3.3.5 Small Scale WTE Collaboration[43]

Several central Ohio collaborators including Univenture, The Columbus Zoo and Aquarium, The Ohio State University, Honda of America Manufacturing, The Ohio Grocers Association, Rockwell Automation, The Center for Innovative Food Technology, Makel Engineering, George J. Igel and Company, and Resource100 LTD submitted a Research Commercialization Proposal (RCP) for a "Scalable and Integrated Waste to Energy System" to the Ohio Department of Development's Third Frontier Commission.

This unique project would use an integrated and synergistic system of technologies to provide waste removal, clean water, energy and food on a small footprint of less than five acres. Univenture's rapid algae farm will be the hub of the system, which makes the integration possible.

The diverse group of organizations together has a common goal of developing sustainable infrastructures that can lead to development of a sustainable community by ensuring that the development of a zoo, community, or nation makes smart infrastructure improvements that do not deplete natural resources. Therefore, the transition and adoption of policies and actions that rely on renewable resources figure heavily into the development of sustainable infrastructures including the zoo project that Univenture and the collaborators want to replicate around the globe.

The collaborators on the proposed RCP project will:

- Receive Honda cafeteria and zoo restaurant food waste, mix it with zoo animal waste, and anaerobically digest the mixture, assuring it does not go into a landfill or incinerator.
- Produce digester gas that will be converted into electricity in the Makel Engineering engine.
- Produce compost that can be used in landscaping and food production.
- Produce a nutrient-rich liquid from the digester, which will be modeled by The Ohio State University / OARDC and controlled by technology from Rockwell Automation to provide "food" for Univenture's algae farm.
- Harvest and dewater the algae, producing oil which will then be atomized and fed into the Makel engine to make electricity or ultimately be used to produce biodiesel fuel.
- Take the remaining biomass from the algae and either anaerobically digest it to produce more gas and electricity or use it as an animal feed based on recommendations of the animal nutritionists at the zoo and at Ohio State.

A similar concept has been envisioned for high waste density areas such as interstate interchanges. The concept would be to locate a small scale waste-to-energy system at a large energy consumer at the interchange, such as a grocery store, that would collect the area trash, convert it to energy, and use that energy as a backup source for emergency generators or

[43] Information supplied from Mike Long, Resource 100LT D, 6478 Winchester Blvd. PMB 231 Canal Winchester, OH 43110 Phone: 614-266-4977 Fax: 614-448-4584 Email: mike@resource100.com

refrigeration units. Figure 26 shows a typical interstate interchange where this could be implemented.

Systems similar to these could be established to recover packaging in critical areas where large amounts are generated. Or, the system could be established or co-established by packaging manufacturers to include both used packaging and other forms of MSW.

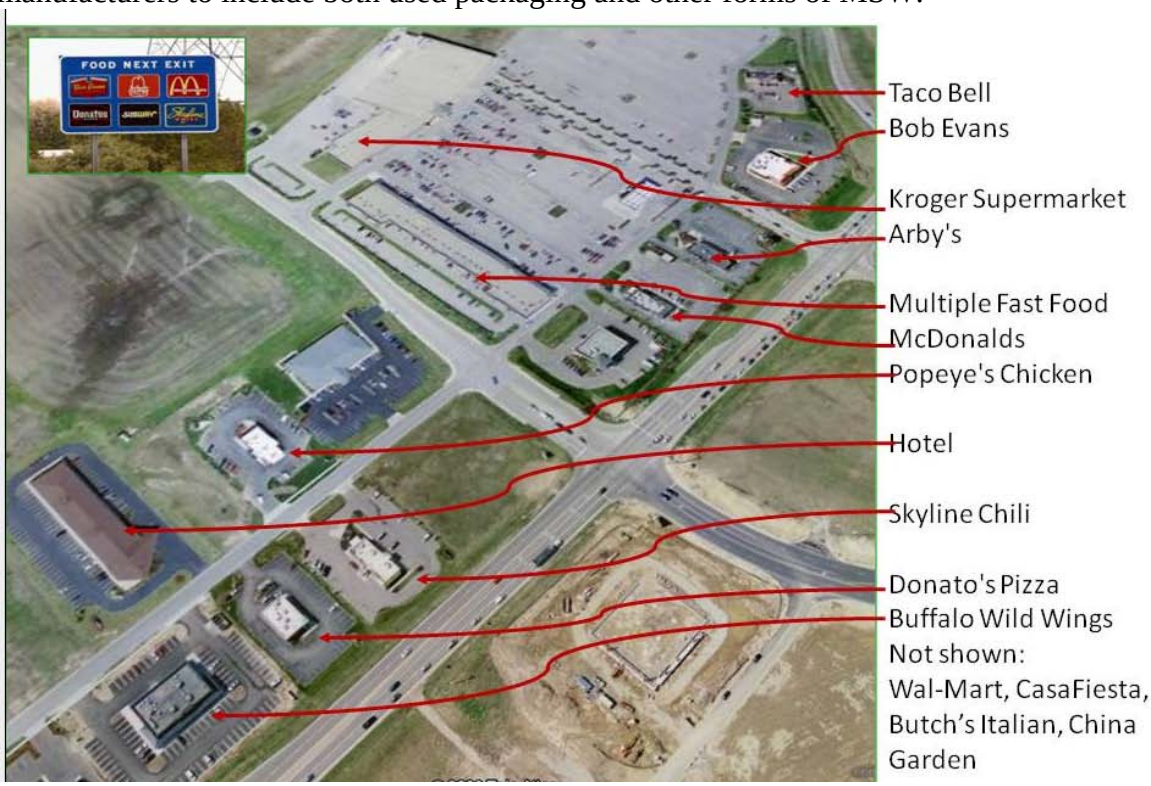

Figure 26. Interstate Interchange Where Small-scale WTE Could be Implemented.

3.3.4 WTE Insights from Industry

In order to better understand the current state of converting flexible packages to energy via combustion, industry representatives were interviewed. The interview responses are included in Appendix B. Fourteen WTE industry representatives were contacted to obtain their insights on the state of the industry. In general, they said:

- Materials can arrive unsorted or pre-sorted from the collection point. The typical scenario is that the waste is brought directly from where it is collected.
- WTE facilities can be profitable, and exist without the assistance of Government subsidies. This assumes that location of the facility is in a region where landfill tipping fees are high
- WTE facilities are not being built because there is still a misunderstanding about the technology in our society, and because of the large capital cost and still relatively cheap landfill costs in most areas.

3.3.5 International WTE Insights

As was shown in Table 10, WTE is more common in European and Asian countries than in the United States. These countries often have more aggressive legislation in place, less landfill space, and different infrastructures that can utilize not only electricity from WTE but also the steam to be used in central heating districts. Figure 27[44] shows a breakdown of the global WTE capacity.

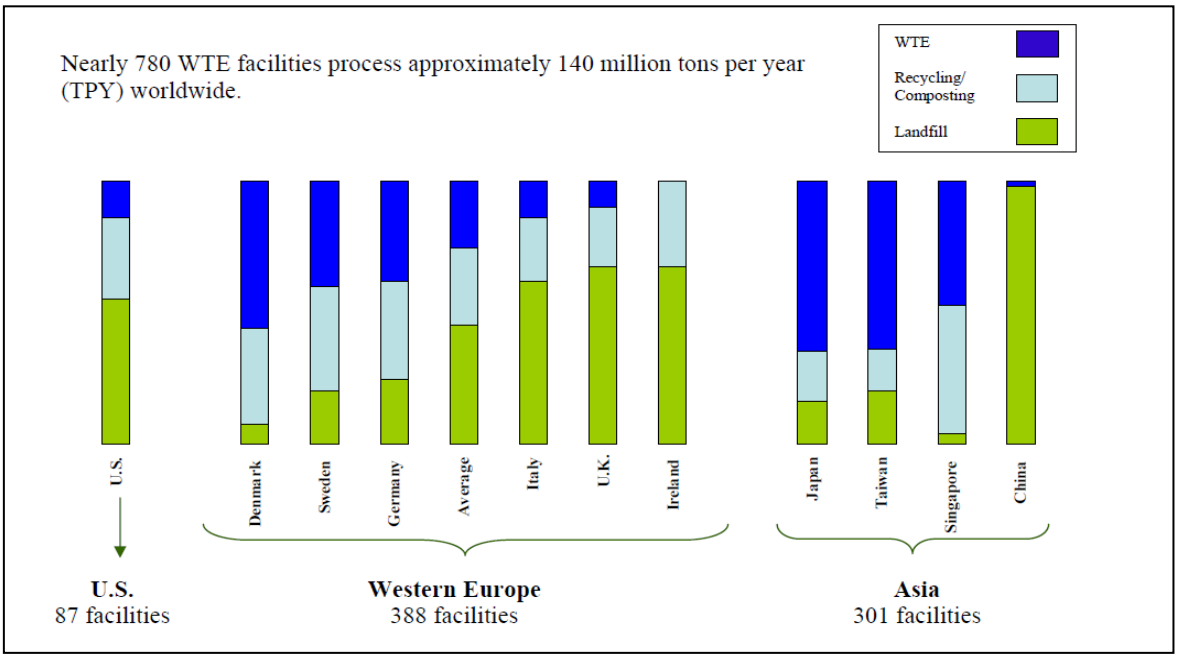

Figure 27. Global WTE Capacity

(Note: the reported number of WTE facilities in the U.S. varies from 87 to 89, depending on the source. The difference can be accounted for based on when the data was taken and the types of facilities included in the number.)

3.3.6. WTE in Europe

The prominence of incineration differs widely from one European Union (EU) member country to another. WTE is most widespread in Sweden, Switzerland, the Netherlands, and Germany. In these countries, local governments play a significant role in the organization of the waste sector. EU legislation on waste management includes:

- Waste Framework Directive: provides a definition of waste and sets out a general ranking of the waste management methods.
- Waste Incineration Directive: stipulates that waste incineration facilities shall have an environmental permit and also lays down rules pertaining to operating conditions and emission to air and water.
- Landfill Directive: states that only waste that has been subject to treatment may be landfilled.

[44] "The 2007 IWSA Directory of Waste-to-Energy Plants" http://www.WTE.org/directory.shtml

In February of 2004, the European parliament issued directive 2004/12/EC[45] mandating on how packaging and packaging waste were to be handled. In order to comply with the objectives of this directive, member states shall take the necessary measures to attain the following targets covering the whole of their territory: the history of the directive was written as follows:

- No later than 31 December 2008 between 55 percent as a minimum and 80 percent as a maximum by weight of packaging waste will be recycled
- No later than 31 December 2008 the following minimum recycling targets for materials contained in packaging waste will be attained:
  - 60 percent by weight for glass
  - 60 percent by weight for paper and board
  - 50 percent by weight for metals
  - 22.5 percent by weight for plastics, counting exclusively material that is recycled back into plastics
  - 15 percent by weight for wood.

The majority of the heat produced via incineration of MSW in Europe is ultimately for a heat source, and not an energy source. Throughout Europe, districts of homes are heated via a central steam source. Figure 28 outlines the ratio of electricity to heat recovery throughout various European countries.

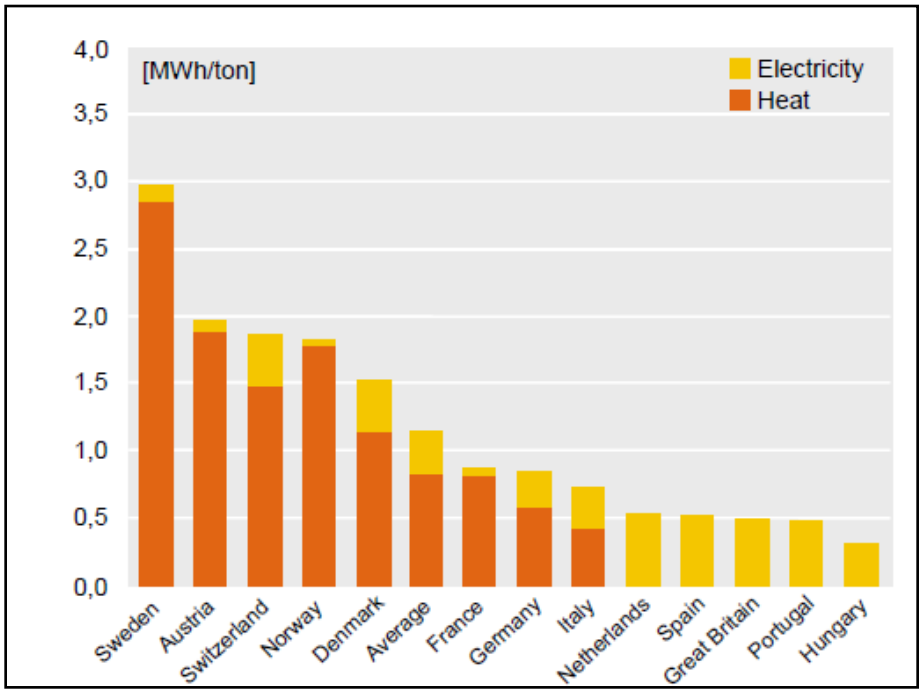

Figure 28. Absolute Energy Recovery from MSW Incineration.

[45] Directive 2004/12/EC of the European Parliament and of The Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste.

Denmark has always been world leader in WTE. According to the Danish Environmental Protection Act, the municipalities are responsible for the management of all waste. They have the responsibility and decision-making authority for the collection and treatment of household waste and control the flow of commercial and industrial waste to assigned treatment and disposal facilities.

At the end of 2005, Denmark had 29 WTE facilities treating 3.5 million tons of waste, which corresponds to 26 percent of the total waste generated in Denmark. Most of these facilities are owned by municipalities or inter-municipal companies and are operated by non-profit companies. Environmentally friendly electricity and district heating are produced from this waste, corresponding to the energy consumption of 400,000 households. The existing legislation on environmental protection, heat, and electricity supply ensures favorable conditions for waste incineration.

Denmark incinerates the greatest amount of waste per capita under very strict environmental regulations. The gate fee at WTE facilities in Denmark is one of the lowest in Europe. The low gate fee is attributed to the efficiently operated facilities and the extensive energy recovery.

3.3.7 WTE in Asia[46, 47, 48]

As land surrounding large cities has become increasingly scarce in several Asian countries, the combustion of MSW in WTE incineration facilities has become the preferred disposal option. The benefits of incineration are explained above, but the technology can become a societal danger if proper emissions controls are not implemented.

MSW incineration began in China in the late 1980s and developed rapidly in the 1990s. As of 2003, there were only 19 WTE combustors in China. This is a very low number in comparison to its massive country. The small island of Taiwan exceeded that figure with 21 facilities serving 22 million people.

China produces about 280 million tons of municipal solid waste a year, most of which is currently disposed of in landfill sites. The Chinese Ministry of Construction has set out a national waste disposal plan under which the amount of waste used to generate energy would be raised from 2 percent of the total waste in 2005 to 30 percent by 2030. Companies from around the world are competing to participate in this huge market. For example, U.S. Covanta agreed to buy a 40 percent stake in the Chongqing Sanfeng Environmental Industry Company that has designed and built two 1,200 ton per day WTE facilities. Diverting waste away from landfills reduces greenhouse gas emissions because the decomposing garbage in landfill sites produces methane, a greenhouse gas . Where landfill sites already exist, this landfill gas can be captured and used for

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[46] "Waste & the Environment 2007: Modern techniques fire a burning argument" Fiona Harvey, Environment Correspondent, *Financial Times*, Published: April 18 2007

[47] "Part I. Thermal Breakdown Characteristics of Municipal Solid Waste Components in Varying Oxygen Environments and Part Ii. Municipal Solid Waste Management In China" Alexander P. Whitworth Advisor: Prof. Marco J. Castaldi Co-advisor: Prof. Nickolas J. Themelis Earth Engineering Center at the Henry Krumb School of Mines Submitted in partial fulfillment of the requirements for the M.S degree in Earth Resources Engineering

[48] "Waste Management in China: Issues and Recommendations" Urban Development Working Papers, East Asia Infrastructure Department, May 2005, World Bank Working Paper No. 9

electricity generation by burning it as a fuel in gas turbine or boilers. Figure 29 shows some of the WTE facilities in China.

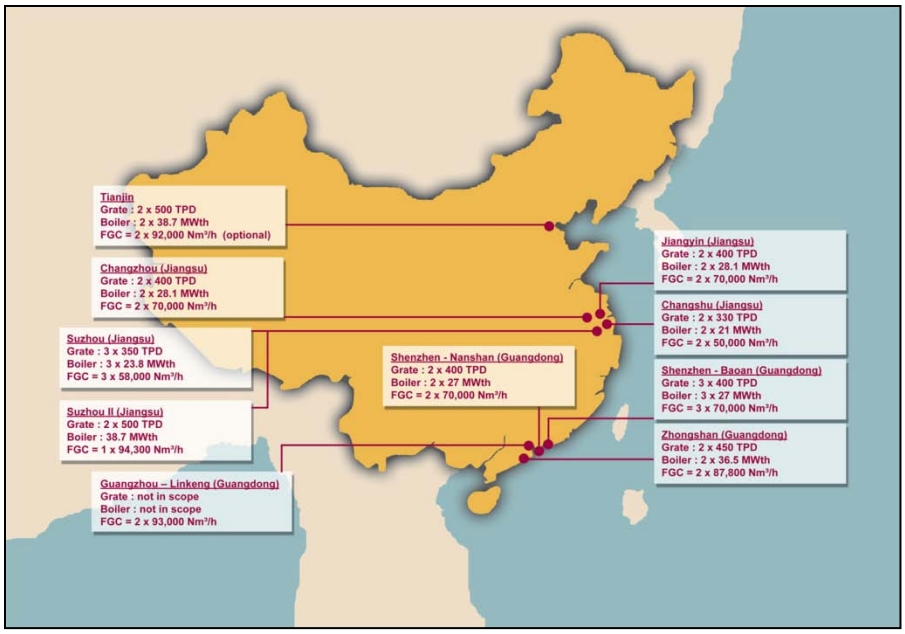

Figure 29. WTE in China.

In 2004, the urban areas of China generated about 190 million tons of MSW and by 2030 this amount is projected to be at least 480 million tons. No country has ever experienced as large, or as rapid, an increase in waste generation. Management of this waste has enormous domestic and international implications.

China has made significant improvements in waste management over the last 10 years. Most larger cities are aggressively moving towards sanitary landfilling as their main disposal option. Improved landfill operations and increased availability is likely China's most pressing waste management need. Even though the pace of improvements in China's solid waste management is significant, it has been unable to keep up with the growing demand for waste service coverage, environmental requirements for safe disposal systems, and rationalization of cost-effectiveness in service delivery. China's waste management practices now have global impacts. For example, secondary materials prices in the U.S. are now influenced by China's demand for these materials.

Due to a number of factors such as the low cost of land, commodities and labor the capital cost of WTE in China are significantly lower than overseas. International average costs for landfilling and incineration are $30 and $150 respectively, which clearly reflects the high capital cost of WTE facilities — generally over $100,000 per daily ton. However, the capital cost of WTE construction in China has been as low as $31,000 per daily ton and might decrease further.

Due to the high food and organic waste content of Chinese MSW, its heating value is much lower than that of North American or European garbage. Although it has increased in recent years, in 2002, the average calorific value of Chinese MSW was about 3300MJ/kg, and ranged from as low as 2000MJ/kg up to 7000MJ/kg. This means that most Chinese MSW cannot sustain combustion without an auxiliary fuel.

Table 16. WTE in Japan

Maishima Waste-to-Energy Facility, Sports Island, Osaka, Japan 	Insights about the facility: • Located on a constructed island at the mouth of the Yodo River in Osaka Bay. • Population of metropolitan area is 17. 5 million • Building Architect: Friedensreich Hundertwasser • Operating since 2001 • Plant capacity is 328,000 tons per year of municipal solid waste • Produces 32 MW of electricity. Surplus electricity sold to the local power company • Heat is used on site for floor heating, hot water and heating combustion air • Air emissions controlled using state-of-the-art equipment
Naka Waste-to-Energy Facility, Hiroshima, Japan 	Population of metropolitan area is 2.9 million • Building Architect: Yoshio Taniguchi • Also a museum and waterfront park • Operating since 2004 • Plant capacity is 220,000 tons per year of municipal solid waste • Produces 15 MW of electricity. Surplus electricity is sold to the local power company • Heat is used on site and hot water is supplied to a neighboring indoor pool • Air emissions controlled using state-of-the-art equipment

In Japan, which has a high population density and little extra space for large WTE plants, the WTE facilities must be gracefully included into the surroundings.[49] Two examples of this are in Osaka and Hiroshima, Japan. These facilities are outlined in Table 16.

3.3.8 Market and Consumer Insights

Packaging publications, customer surveys, and conference proceedings in the packaging industry provide insight that can be combined with the research on recycling and WTE to assist in determining FPA next steps.

Dr. John Heckman, presenting at the 2008 Sustainable Packaging Forum,[50] outlined that consumers are concerned with sustainability and environmental concerns. However, consumers feel that the responsibility falls more on corporations and "others," rather than individuals. Some of the insights from his presentation were: (1) 90 percent of customers interviewed believe companies have social and environmental responsibilities beyond making profits; (2) 55 percent are "concerned whether companies behave responsibly on issues like consumer health, the environment and worker rights"; and (3) 60 percent say they take social and environmental factors into account when choosing what brand to buy. This is outlined in Figure 30.

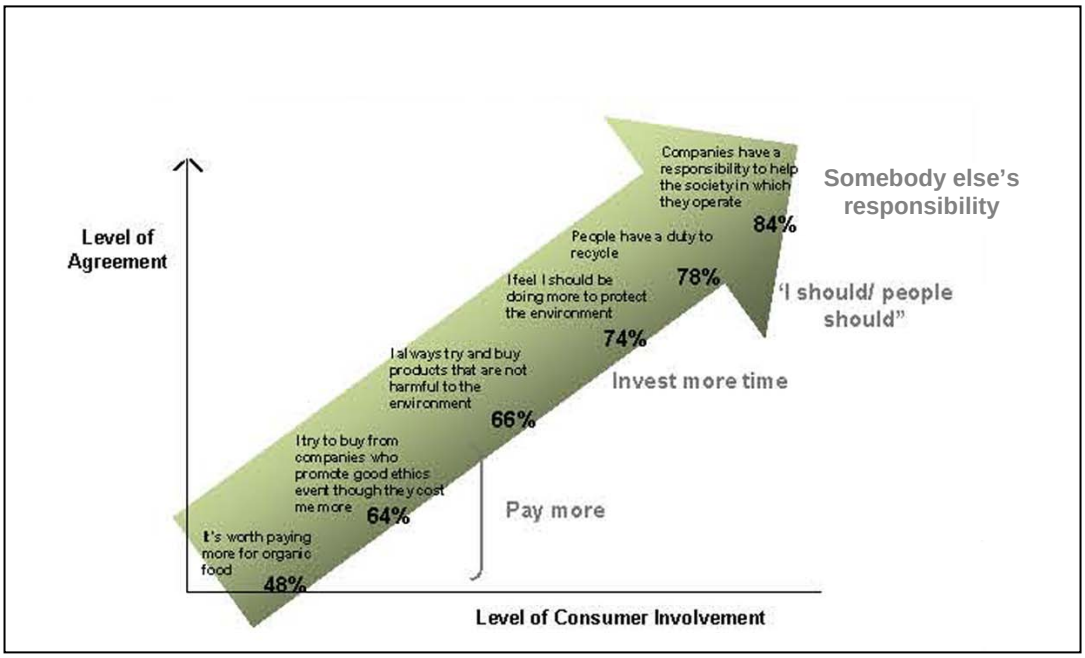

Figure 30. Consumer Insights on Importance of Sustainability Issues and Purchasing Habits.

From a market and consumer point of view, concern about recycling (and green efforts, in general) is, unfortunately, on a case by case basis. A multitude of variables such as education, economic status, environmental awareness, age, and gender all play a role in defining this level of concern. Also, playing a major factor is the way that these initiatives are marketed – pertaining to both the product being advertised and the name recognition of the company manufacturing the product.

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[49] http://www.metrovancouver.org/services/solidwaste/zerowaste/PDF%20documents/Waste-to-EnergyFacilities.pdf

[50] "Responsible & Appropriate Uses of LCA" Dr. John Heckman, *Sustainable Packaging Coalition*, September 2008

A November 2007[51] study conducted by BBMG, a New York based branding and marketing company, found that 56 percent of those surveyed considered price and 66 percent considered quality of the utmost importance when making purchasing decisions. Increasing numbers are concerned with social responsibility. Those social concerns breakdown as 41 percent for energy efficiency, origin of manufacture was 44 percent, while convenience was important to only 34 percent of those surveyed.

The companies making the effort to be eco-conscious are seeing the benefits. According to BBMG's survey, 90 percent of consumers are more likely to purchase energy efficient products and 88 percent are more likely to purchase goods promoting consumer health and safety. If the producing company commits to environmentally friendly practices, 87 percent of consumers stated they would be more likely to purchase goods from that manufacturer.

A May 2008 article in *Adweek* outlines several recent surveys that seek to understand consumer preferences on green and sustainability.[52] "Greenwashing" is a term used to describe consumer perception that they are being misled by a corporation's product stewardship claims. Most notable, is the "greenwashing index" (http://www.greenwashingindex.com), which ranks the spin believed to be put into ads on a 1 ("good ad") to 5 ("total greenwashing") scale.

The area that has the most potential for recycling is packaging. Packaging offers myriad benefits to products including keeping items sanitary, fresh, unharmed, and improves ease of shipment. But packaging can also be excessive and cumbersome. Recycling and waste reduction are regarded as the most pressing environmental issues to consumers; however, these are not of the utmost concern when they are making purchasing decisions. With regard to packaging, roughly 50 percent of consumers said they would omit packaging if it was good for the environment, but only 27 percent would omit packaging intended to keep products clean. So consumers are demanding more portability and want a package that can be readily thrown away with no regard to where it goes from there. John Kalkowski, editor of *Packaging Digest Magazine*, notes that most consumers admit to having a responsibility to the environment, but in the U.S., they feel that their obligation is not as important as is the obligation of the manufacturer.

Along with consumers, the biggest resistance to eco-friendly packaging comes from the packaging itself, because much of packaging was not designed with recycling in mind. To alleviate this problem, an entire retooling of the product life cycle is needed. Aiding in this retooling concept are groups such as the Sustainable Packaging Coalition[53], which was founded in 2003 and now has more than 210 corporate members, including Starbucks, Target, and Estee Lauder, to name a few – all of which have already started to re-design their packaging.

The Sustainable Packing Coalition defines sustainable packaging as packaging that is beneficial, safe, and healthy for individuals and communities throughout its life cycle; meets market criteria for performance and cost; is sourced, manufactured, transported, and recycled using renewable

[51] http://www.fmi.org/docs/sustainability/BBMG_Conscious_Consumer_White_Paper.pdf
[52] ADWEEK May 2008, "Deflating a Myth: Consumers aren't as devoted to the planet as you wish they were." May 12, 2008
[53] http://www.sustainablepackaging.org

energy; maximizes the use of renewable or recycled source materials; is manufactured using clean production technologies and best practices; is made from materials healthy in all probable end-of-life scenarios; is physically designed to optimize materials and energy; and is effectively recovered and utilized in biological and/or industrial cradle to cradle cycles. This group is focused on creating a true "cradle-to-cradle" cycle, where environmental health is promoted through supply chain collaboration[54].

[54] http://www.sustainablepackaging.org

Appendix A

Flexible and Alternative Packaging Systems Case Studies

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Case Study 1: Dry Goods Package

Raisin Package Description

For raisin packages, Battelle assessed three alternative systems:

1. A paperboard canister which comes with a plastic lid and is sealed with a flexible film
   - The paperboard canister consisted of the canister, the polypropylene lid, an outer safety seal (PVC), and an inner safety seal (polyethylene, PE). The paperboard canister was printed, but the inks and adhesives were ignored for this assessment because of their low mass. For the assessment, we modeled one canister that contained 24 ounces of raisins.
2. A paperboard box with inner flexible liner
   - The paperboard box had a capacity of 9 ounces so we modeled the use of 2.67 boxes. It was composed of the outer, printed paperboard with an inner polyethylene liner. Again we ignored the inks and adhesives, because of their low mass.
3. A multi-layer, polyethylene-based, zip closure pouch
   - The polyethylene terephthalate (PET) and low density polyethylene (LDPE) flexible pouch consisted of 11 layers including binders or adhesive layers, and inks. For this study, the inks were ignored because of their low mass, and the adhesives were modeled as polyethylene. For the assessment we needed one pouch containing 24 ounces of product (raisins).

All of these containers are currently found on grocery shelves, with larger volumes favoring the paperboard canister and the flexible pouch, while smaller volumes favor the paperboard box. Similar flexible packages are found used for other dried fruits, nuts, cereals, pet foods, and some snack foods, recognizing the composition and package-to-product ratio might change with these alternative applications. Details of the package materials masses are provided in Table A-1.

Table A-1. Raisin Package Details

Package (Capacity per Package)	Components and Mass (grams), per Package
Paperboard Raisin Canister (24 ounces)	Total: 38.4 Paperboard: 28.6 PE (Film Seal): 0.64 PP (Lid): 8.37 PVC (Safety Seal): 0.81
Paperboard Raisin Box (9 ounces)	Total: 21.1 Paperboard: 18.8 LDPE (Liner): 2.35
Stand-up Flexible Raisin Pouch (24 ounces)	Total: 11.3 LDPE: 7.52 PET: 3.51 Ink: 0.30

Raisin Package Results

Figure A-1 shows the results of the energy consumption assessment of the package alternatives for the entire life cycle (cradle-to-grave). The flexible pouch consumes about 54 percent of the energy of the next most energy efficient package, the paperboard box with liner. The flexible pouch consumes more energy during manufacture of the plastic materials and other package materials, than does either of the alternatives. This is a result of the high-energy intensity of plastic manufacture, and the highly engineered nature of plastics relative to paperboard. Energy required to process pulp into paperboard during the production of the canister and box (Package Manufacture phase) was calculated and compared with that for the flexible pouch, where the plastics are more readily manipulated once formed.

Since we ignored any differences in placing the product into the package, the difference with the Packaging phase are due to the weight differences associated with the transport of the package alternatives from producer to grocer warehouse, and not due to significant differences in filling any of the package alternatives.

Differences in energy consumption during the Consumer Use phase of the life cycle are also derived from differences in package mass during transport. Once again, we ignored any, perceived minimal, differences in energy consumption during warehousing, at the grocer, and at the consumer's home. The energy consumption during this life cycle stage is the transport from warehouse to grocer and the transport from grocer to home.

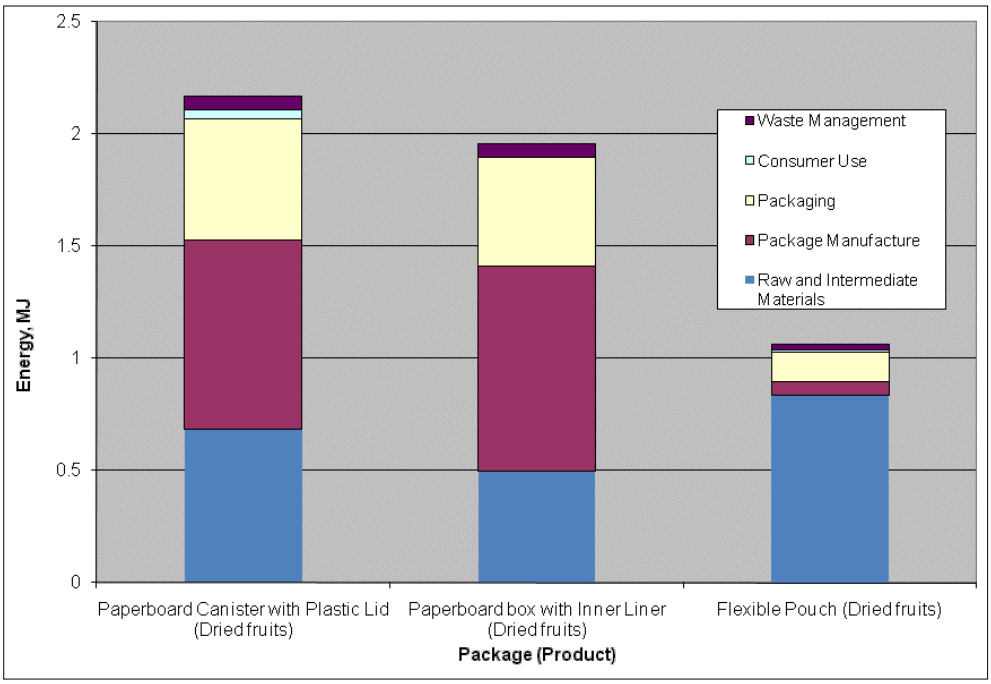

Figure A-1. Raisin Package Total Energy Consumption

In Figure A-2, only life cycle stages from manufacture of the package through waste management are included; manufacture of the packaging materials was not. The more efficient energy utilization of the flexible package is more obvious as the flexible pouch consumes about

16 percent of the energy of the paperboard box, the next most energy efficient package option. Differences in package manufacture and energy consumed during transport are magnified because the energy intensive materials manufacture stage has been eliminated.

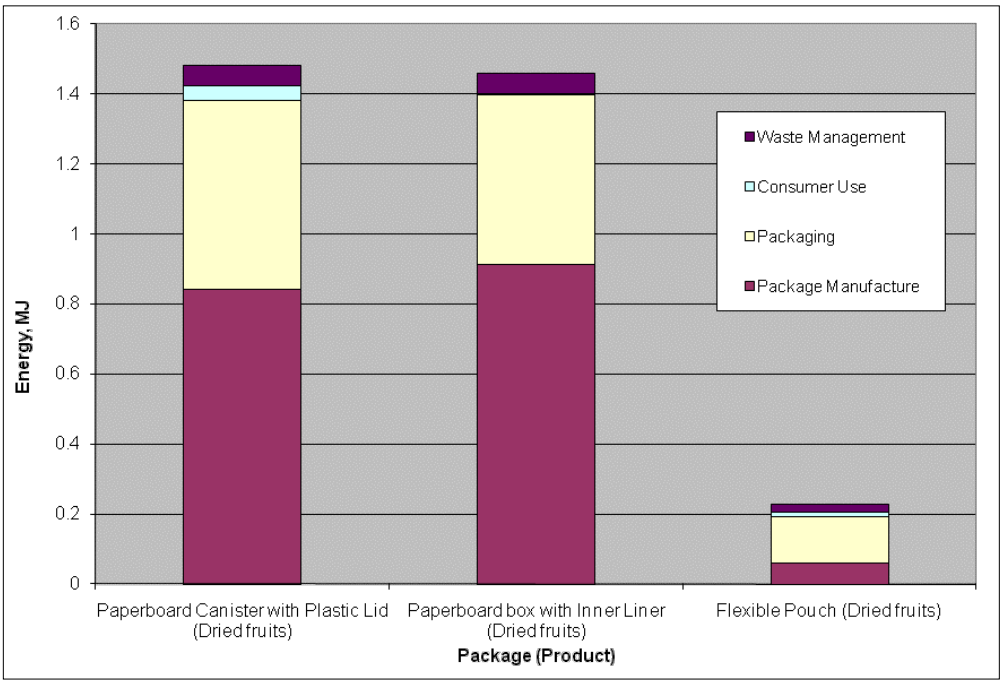

Figure A-2. Raisin Package Pellets-to-Grave Energy Consumption

Figure A-3 shows the carbon footprint for the raisin package alternatives. As expected, it parallels the total life cycle energy consumption (Figure A-1), with the flexible pouch having the lowest carbon footprint. The calculated carbon footprint was computed with the GaBi model using the TRACI impact method for Global Warming Emissions to Air. Using this approach does include non-carbonaceous emissions, but these non-carbonaceous items amount to less than 0.5 percent of the total global warming emissions on a CO_2-equivalent basis.

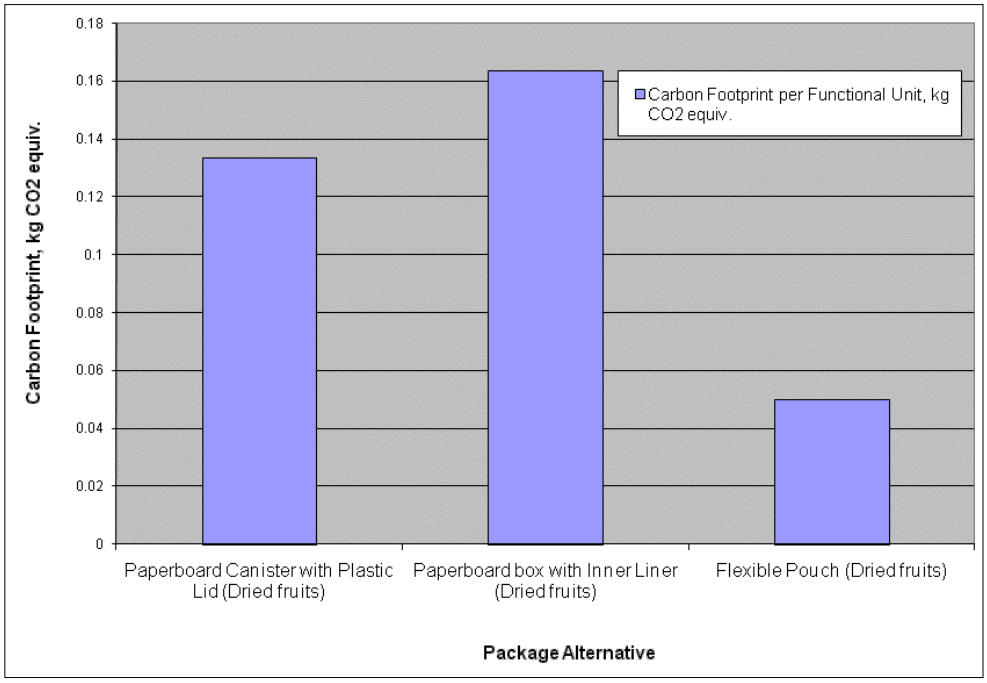

Figure A-3. Raisin Package Carbon Footprint

Figure A-4 shows the potential recoverable energy as a fraction of the Total Energy Consumption, which is the absolute energy used by the system, and includes energy consumed by the system and lost to society forever, as well as the inherent energy of the materials, i.e. energy consumed in the package. The inherent energy or the consumed energy is not lost, but its further use is deferred until the package is no longer of use as a package. There are then three energy quantities, the Total Energy or Total System Energy Consumed; the Inherent Energy, which is the energy value of the packaging materials upon combustion, and the Net Energy Consumed, or the energy lost to society. The Inherent Energy, because it may be recovered at package end-of-life, is also referred to here as the Potentially Recoverable Energy. The Total System Energy is shown in Figure A-1 as the summation of the contributions by life

Calculating Potential Energy Recovery

To calculate potential energy recovery for any of the package systems, we assumed the package would be collected and combusted in a waste to energy facility. We assumed 100 percent collection from the consumer, and 100 percent of the collected packages converted to energy through combustion. This differs for all packages from current practice, where a significant, but not 100 percent fraction of packages is collected from the consumer, and a smaller fraction combusted for energy recovery. The fraction of packages going to beneficial uses from waste collection, either through recycling, reuse, or energy recovery, ranges from less than 10 percent for plastic wastes to greater than 50 percent for paper products. Only about one-seventh percent of the total mass of waste collected is combusted for energy recovery. Thus, the actual energy recovery under current conditions for any package type is much less than the calculated potential shown here.

cycle stage. It is shown again in Figure A-4 as the summation of the Potentially Recoverable and Net Energy Consumed.

While all three systems offer similar potential energy recoveries (energy recoverable upon combustion of the package), the fraction of energy recoverable from the flexible pouch and paperboard canister are close to 50 percent of the total; for the paperboard box it is about 20 percent. The flexible pouch and paperboard canister perform better from this perspective because of the inherent energy of the materials. *(Note: Even though there is more paper in the paperboard packages, the plastics contain about twice as much potentially recoverable (inherent) energy per unit mass of package material.)*

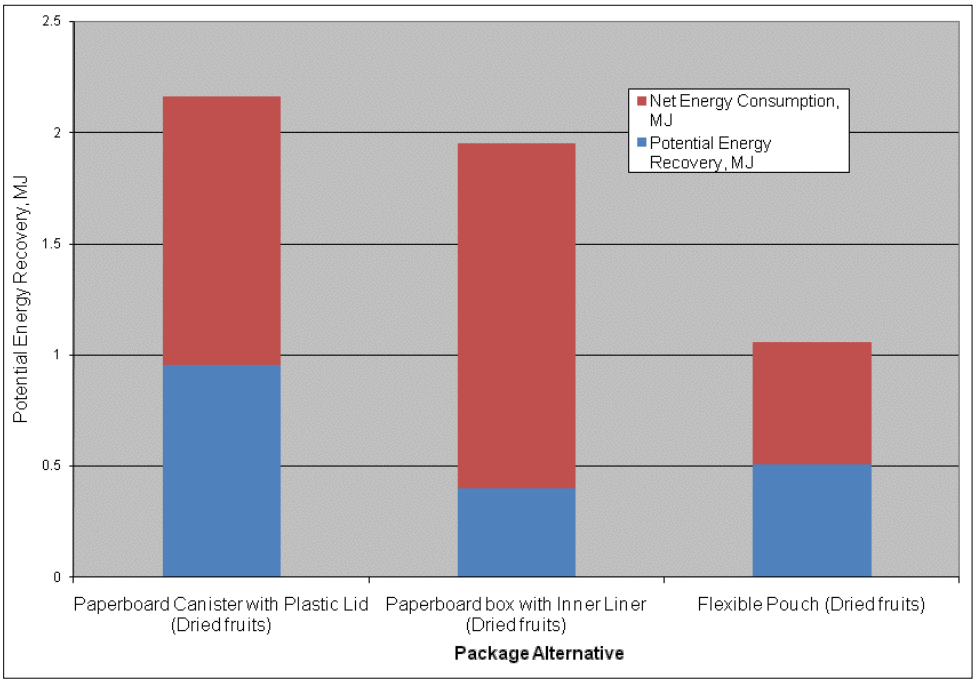

Figure A-4. Raisin Package Energy Consumption and Potential Energy Recovery in MJ

Figure A-5 shows the fractional or percentage energy recovery for the raisin packages. Here the potentially recoverable energy has been divided by the total system energy consumption. The figures are percentages, and serve to reiterate the point of demonstrating the advantage of the flexible pouch in which less of the total energy is lost; its use is just deferred.

Figures A-6, A-7, and A-8 depict the life cycle flows for the models Battelle developed for a flexible pouch, a paperboard box, and a paperboard canister, respectively

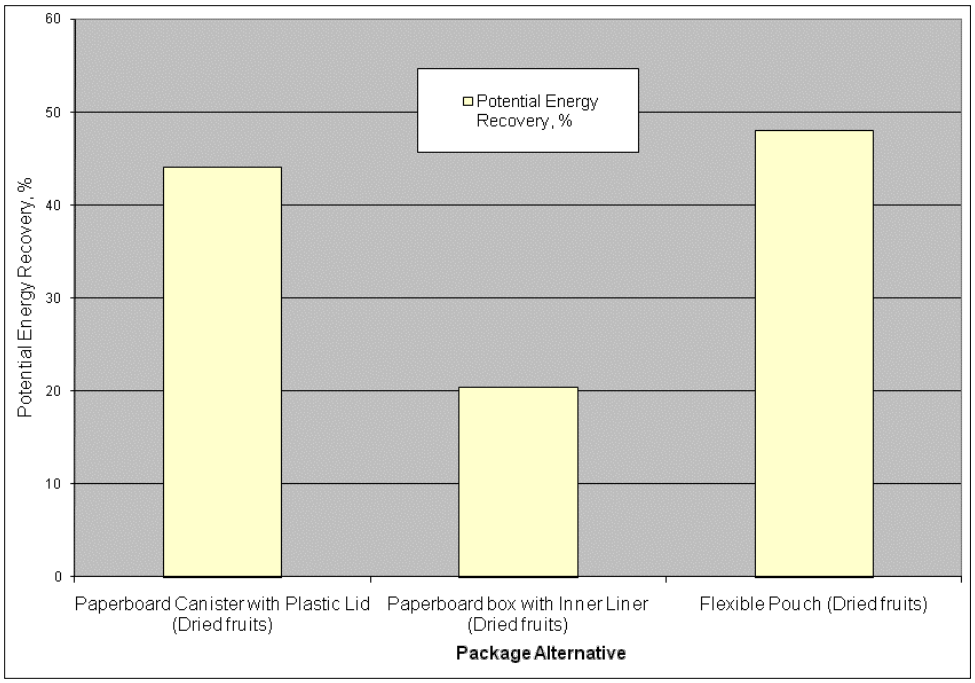

Figure A-5. Raisin Package Percentage Potential Energy Recovery

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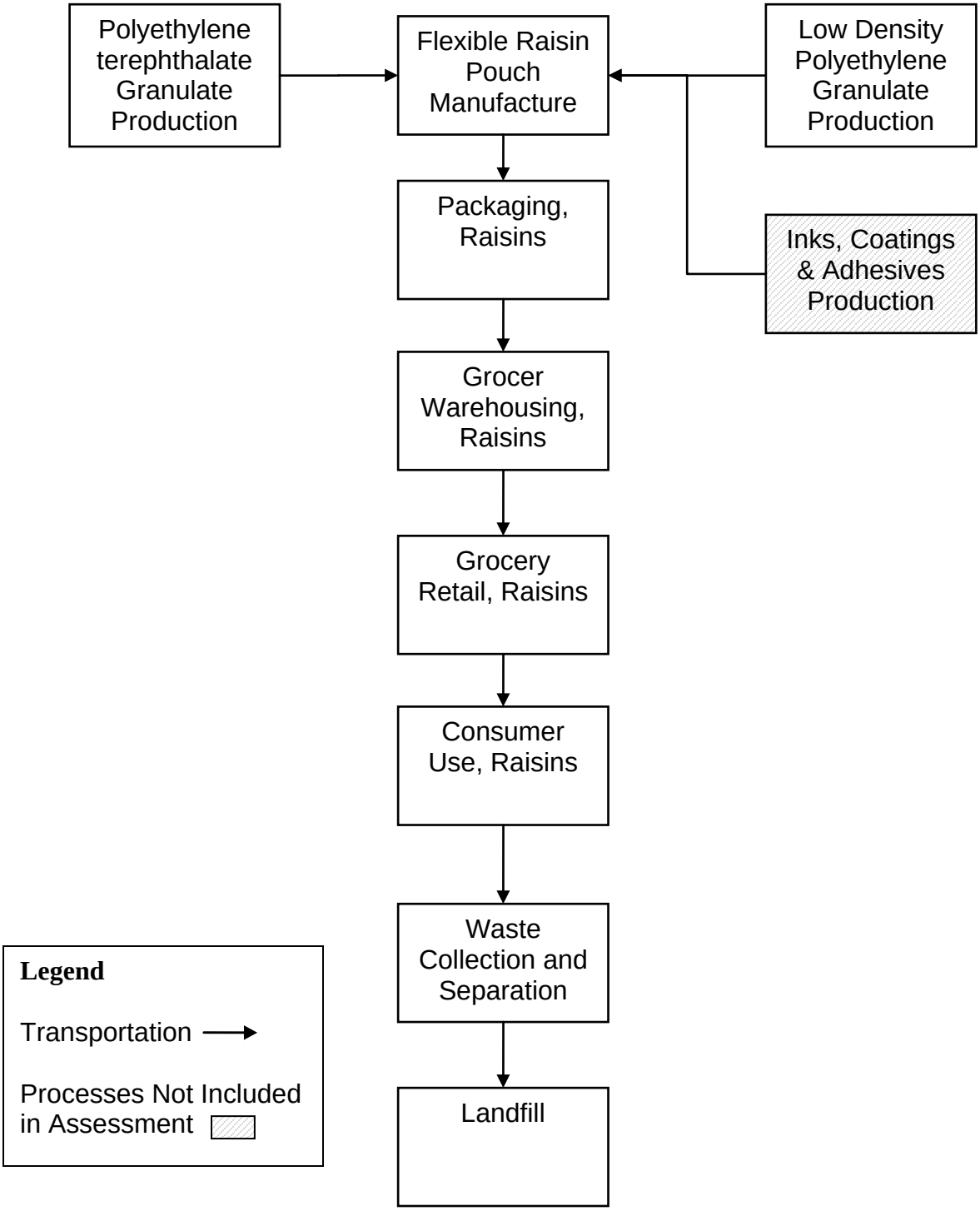

Figure A-6. Flexible Raisin Pouch Life Cycle Flows

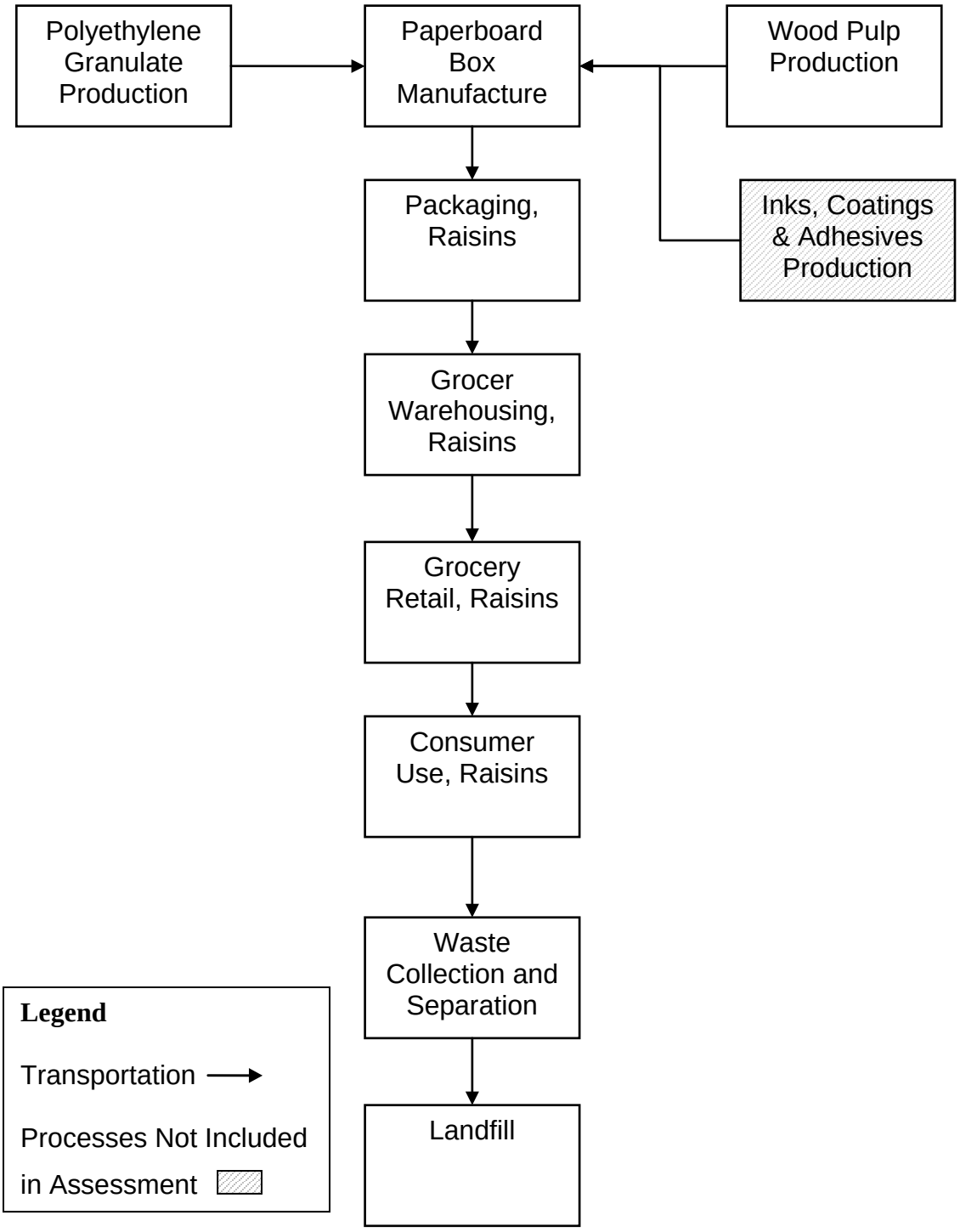

Figure A-7. Paperboard Box Life Cycle Flows

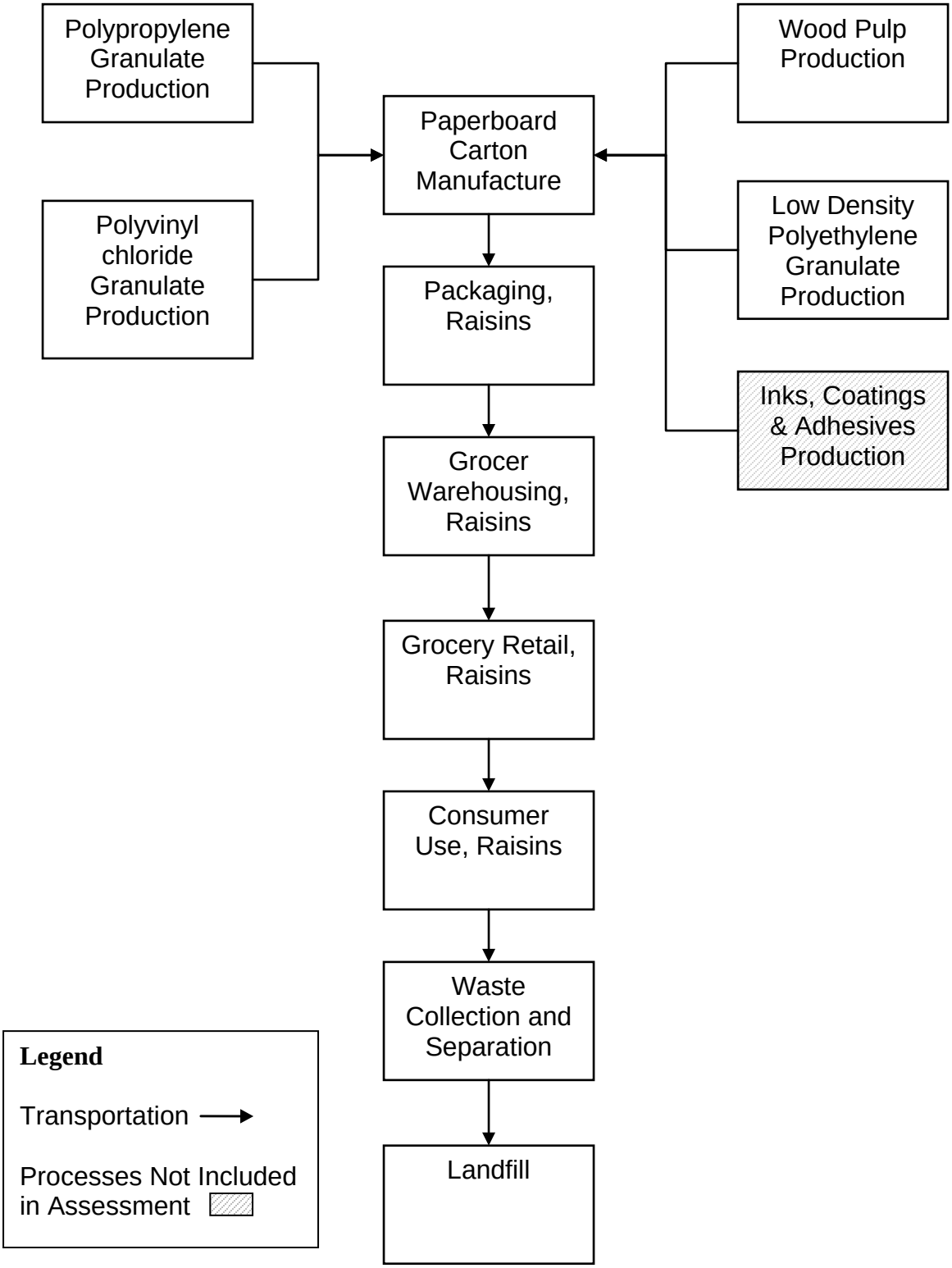

Figure A-8. Paperboard Canister Life Cycle Flows

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Case Study 2: Beverage Packages

Beverage Package Descriptions

Battelle assessed four beverage packages for delivery of one liter of non-carbonated beverage. These included:

1. A single serving 187 mL glass bottle, five and one-third were required
   - The glass bottle was modeled with closure: cap, lid, or stopper. The label or any direct printing was ignored, as these were relatively small quantities by mass compared to the glass in the bottle.
2. A single serving 187 mL PET bottle, five and one-third are required
   - The PET bottle was modeled with the cap. Any label was ignored, which also removed the inks and coatings from consideration.
3. A single serving 12-ounce aluminum can, 2.8 cans were required
   - The aluminum can was comprised of two sections, the can body and the lid, each of aluminum. Inks and coatings were ignored.
4. A single serving 6.75-ounce flexible pouch, five were required
   - The flexible pouch comprised multiple layers including layers of polyethylene, adhesives, inks, and metallized polyethylene. The bulk of the mass was polyethylene. Inks, adhesives, and the metallization were ignored.

All of these are currently found on grocery shelves, but not all types are used for all non-carbonated beverages. Details of the package materials masses are provided in Table A-2.

Battelle constructed streamlined life cycle inventories (LCIs) for the aluminum can and flexible beverage pouch. The data for the glass and PET bottles was derived from the beverage LCI (Franklin Assoc., 2006, Tables ES-1, 3-2a and 3-7a). The system boundaries and assumptions of this LCI were validated against the goals and objectives of the present research to verify a high degree of, but perhaps not exact, similarity between the systems modeled by Franklin Assoc. and Battelle. The work by Franklin, being a full LCI, contained a higher level of detail. It also attempted to understand the influence of secondary and tertiary packaging on the alternatives systems, detail which Battelle did not include when we derived results from the Franklin Assoc. work because it was outside the system boundaries defined earlier in Section 2.1.5.

Table A-2. Beverage Package Details.

Package (Capacity per Package)	Components and Mass (grams), per Package
Glass Bottle with closure (187 mL)[1]	Glass: 152
PET Bottle with closure (187 mL)[1]	PET: 24.1
Aluminum Can (12 ounces)	Aluminum: 14.2
Flexible Drink Pouch (6.75 ounces)	LDPE: 2.43

[1] Franklin Associates., 2006. Table ES-1

Beverage Package Results

The results for the beverage package are similar to but not identical to those for raisin packages. Differences are explained in more detail below.

Figure A-9 shows the total system energy consumption for beverage packages. The glass and PET bottles consume significantly more energy per liter of beverage. For glass, this is a result of the energy intensity of manufacturing glass, even accounting for a significant fraction being recycled (a 15 percent recycling rate has been included in the LCI data module in GaBi). (*Note, the recycling rate varies significantly by glass package type, being highest, over 30%, for beer and soft drink bottle, but under 15% for food jars, with wine bottles also about 15% (US EPA Municipal Solid Waste Factbook, 2007).*) For PET, we see the effect of a relatively much larger mass of package, compared to flexible pouches and aluminum cans, coupled with a high energy intensity of manufacture of the PET. This assessment assumes a negligible recycling rate of PET bottles back into bottles, and if the rate were to increase, the system energy intensity would decrease. The aluminum can as a packaging alternative is not as energy efficient as the flexible package. This is driven by the high energy intensity of manufacturing virgin aluminum, even allowing for recycling of aluminum (a 36 percent recycling rate is assumed in the data). The flexible pouch is the most energy efficient package system, being about 60 percent more efficient than the next most efficient alterative, the aluminum can. As we saw with the raisin package, energy consumption during manufacture of package materials is the largest fraction of alternative materials' energy consumption.

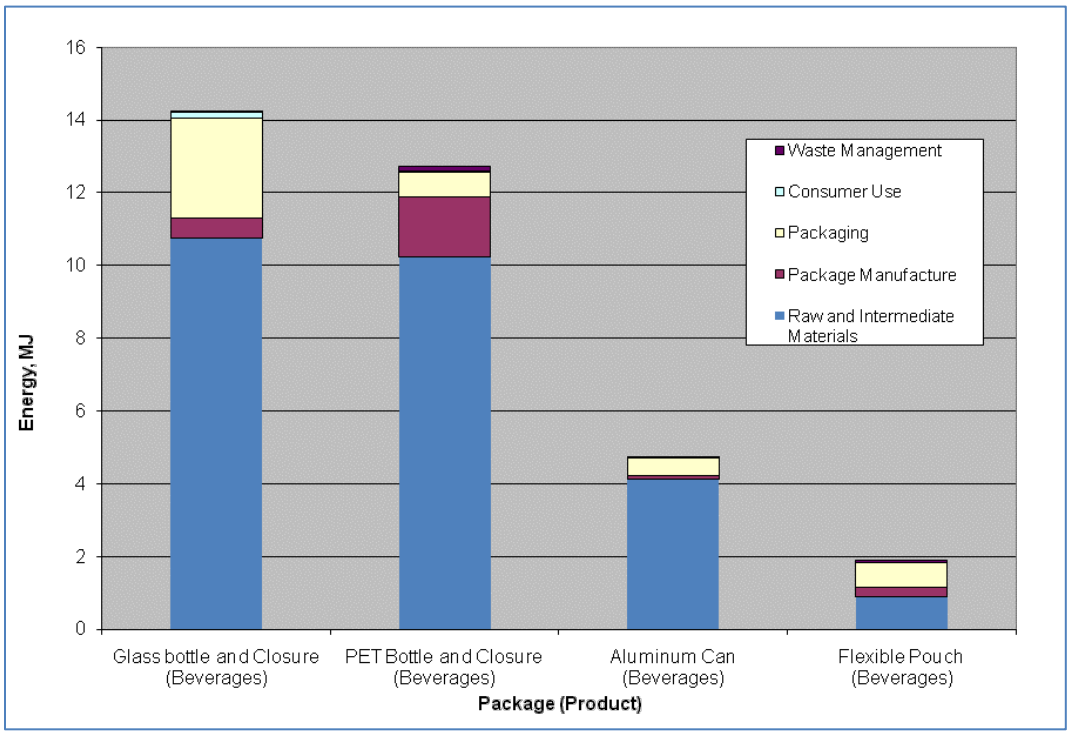

Figure A-9. Beverage Package Total Energy Consumption.

Figure A-10 shows energy consumption for each of the beverage packages without accounting for package material manufacture, or package manufacture through waste management. The

picture here is much different than the previous figure. Here the aluminum can is the preferred alternative, illustrating the high energy intensity per unit mass for the manufacture of virgin of aluminum and reinforcing the argument in favor of recycling aluminum.

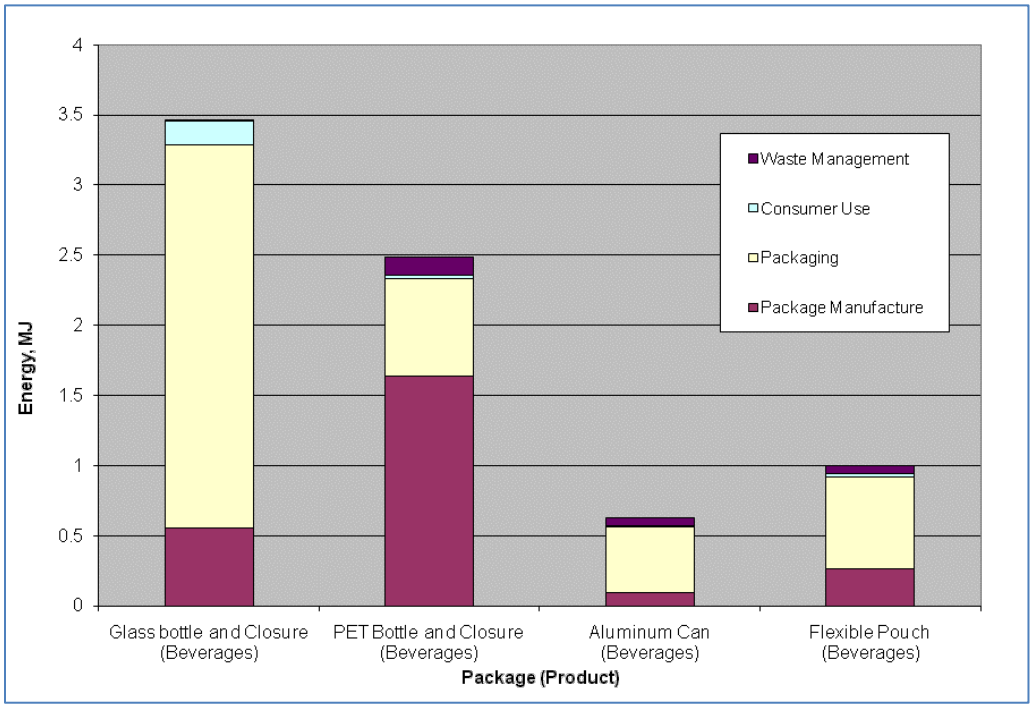

Figure A-10. Beverage Package Pellets-to-Grave Energy Consumption

As with raisin packages, the carbon footprint results parallel the total system energy consumption results (Figure A-11). The flexible pouch offers a considerably lower carbon footprint than any of the other alternatives.

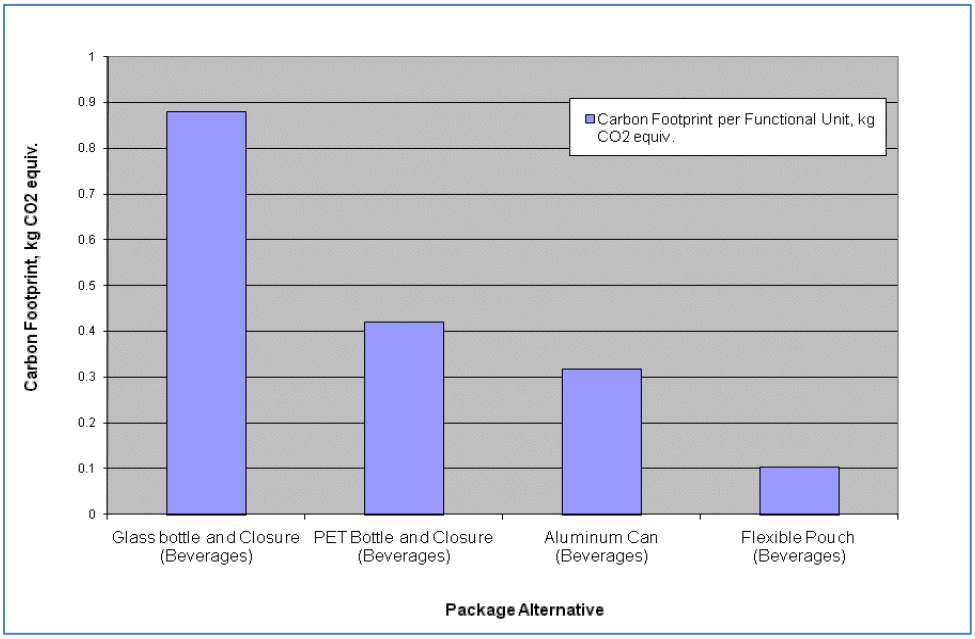

Figure A-11. Beverage Package Carbon Footprint

Figure A-12 shows the potential energy recovery relative to the total system energy consumption for beverage pouches. For the glass bottle and aluminum can, there is little or no recoverable energy upon combustion of the packages at end-of-life, because there is little or no combustible matter in the package (primarily labels and coatings). The PET bottle offers a larger quantity of recoverable energy as a result of the larger package mass. The fraction of recoverable energy for the PET bottle is also greater than for the flexible pouch, as seen in Figure A-13.

Life cycle flows for flexible pouch and aluminum can models developed by Battelle are shown in Figures A-14 and 15.

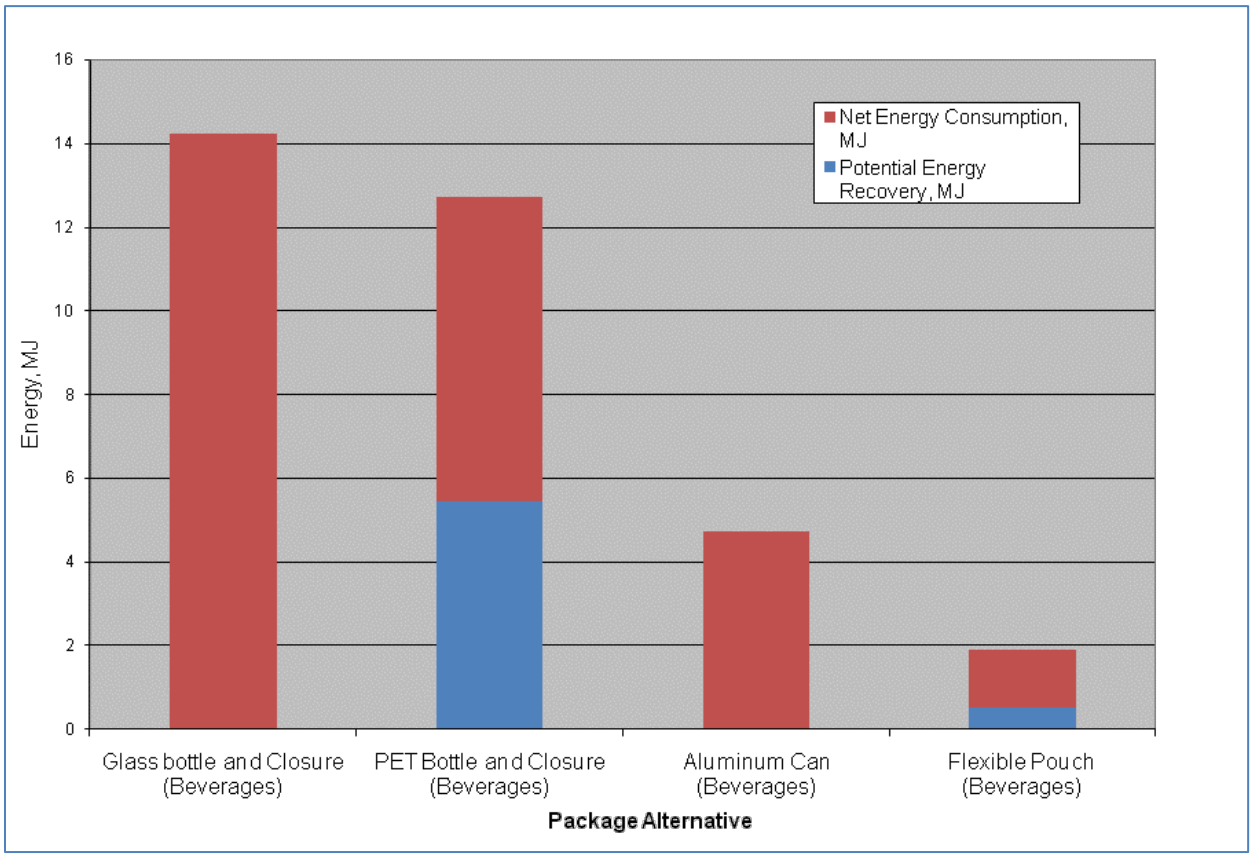

Figure A-12. Beverage Package Energy Consumption and Potential Energy Recovery.

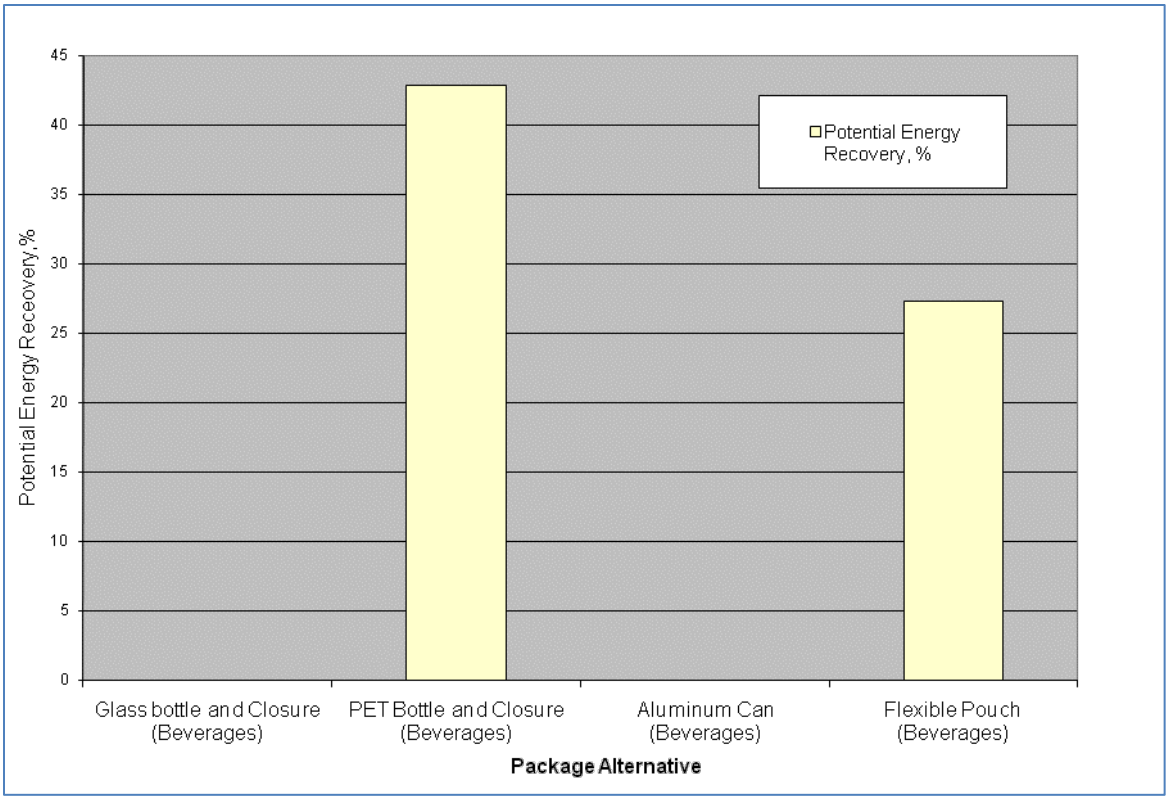

Figure A-13. Beverage Package Percentage Potential Energy Recovery.

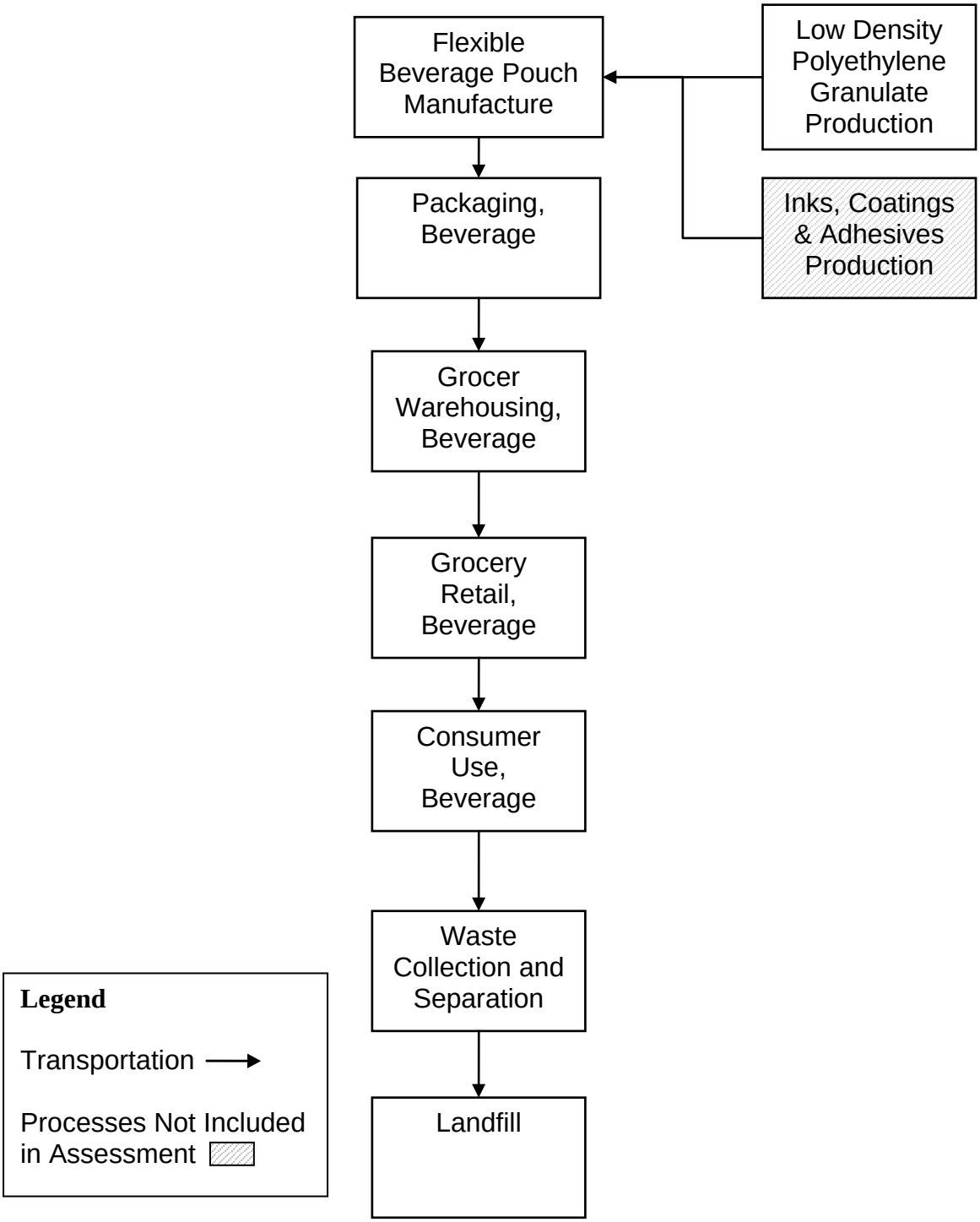

Figure A-14. Flexible Beverage Pouch Life Cycle Flows

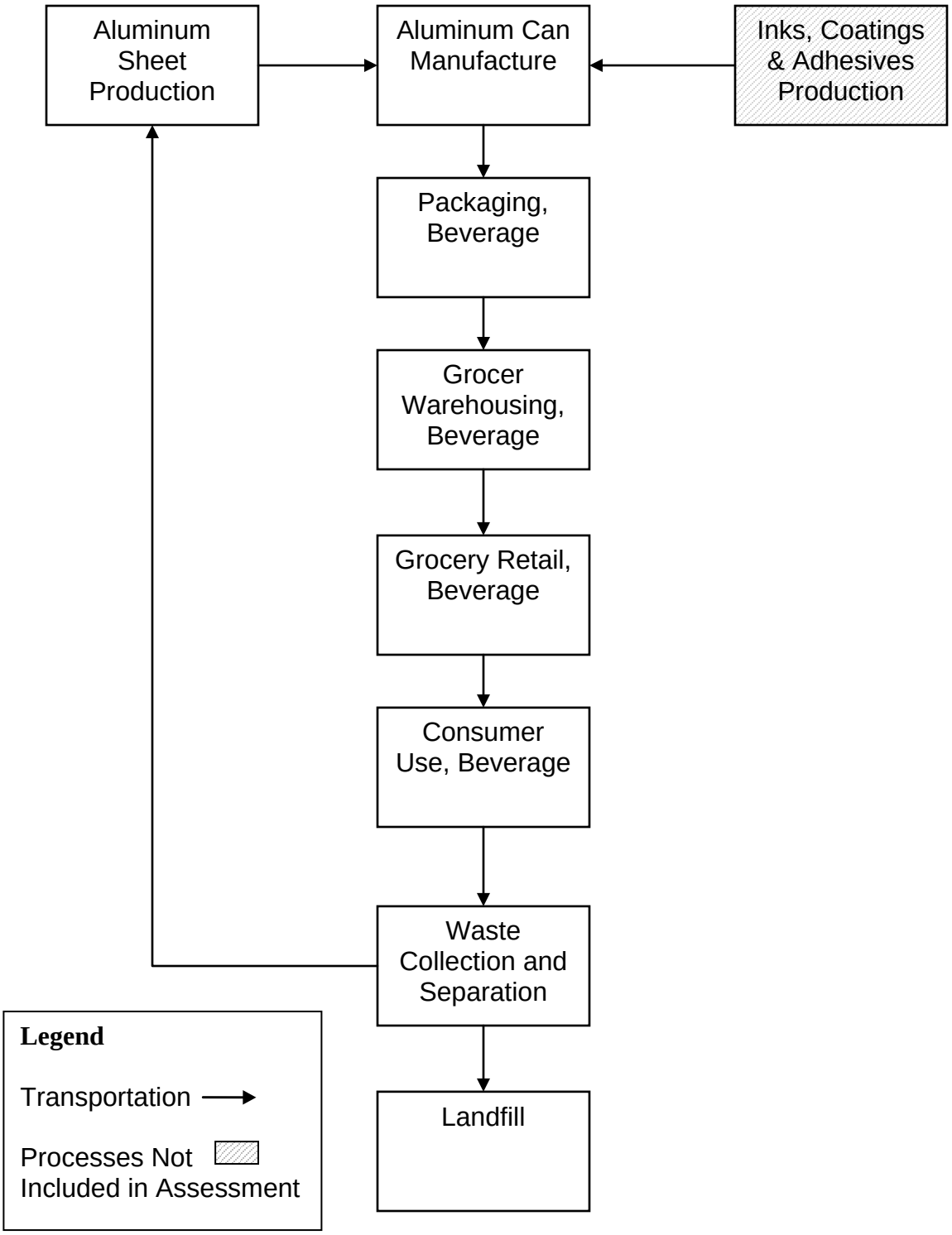

Figure A-15. Aluminum Can Life Cycle Flows

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Case Study 3: Parcel Mailer

Parcel Mailer Descriptions

Battelle evaluated two mailers, or large envelopes, for shipping letters:

1. An unbleached kraft paper mailer
2. A polyethylene-based flexible plastic mailer.

Each of these was modeled as unpadded mailers, the kind intended for shipping a few sheets of paper as first class mail or as an overnight delivery. For the assessment, we needed one of each mailer. The original LCI assessed the mailer, but not any inks or coatings, nor did it assess the contents. Details of the package materials masses are provided in Table A-3. Also note that the original study did not evaluate the more common paperboard mailer, which is why Battelle choose to use the results for the unbleached kraft paper mailer.

Table A-3. Mailer Package Details.

Package (Capacity per Package)	Components and Mass (grams), per Package
Kraft Paper Mailer	Paper: 63.5
Flexible Mailer	LDPE: 30.4

Mailer Results

The results for manufacture of package materials and manufacture of the packages are presented as one aggregated value for each alternative. This is how the background study results were presented (Franklin, 2004). As with the previous examples, manufacture of the package and package materials were the most significant energy-consuming operations, accounting for a 30 percent recycled materials content for the kraft paper mailer. However, as seen in the Figure A-16, the flexible alternative for a mailer may not be significantly more energy efficient than the kraft paper alternative. This finding differs in that respect than most of the other flexible package alternatives examined in this report. The flexible mailer consumed approximately 70 percent of the energy across the life cycle as did the kraft paper mailer.

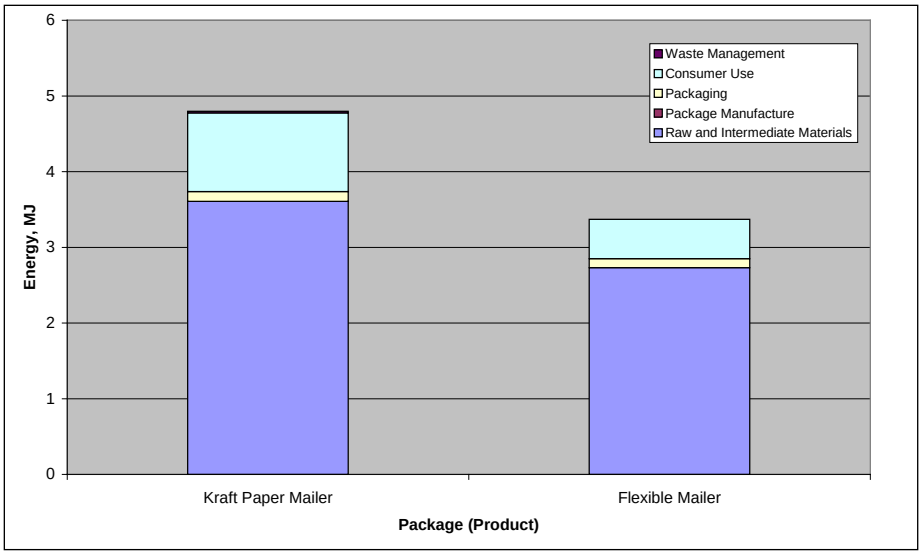

Figure A-16. Mailer Total Energy Consumption.

When we remove the package and package material manufacture life cycle stages, as was done in the previous examples, we see the flexible mailer is more energy efficient, with the difference between the systems increasing to about 50 percent (from 30 percent) (Figure A-17). The significant activity here is the transportation of the mailer during use (enclosure of the parcel being mailed).

Figure A-18 shows the carbon footprint results. As with previous examples, the flexible pouch offers the lowest carbon footprint by a significant margin, being nearly one-half the kraft paper alternative. These results are heavily influenced by the transportation distance and mode assumed for the scenario. Lower transportation distances, or more carbon efficient means, would reduce the difference between these two alternatives.

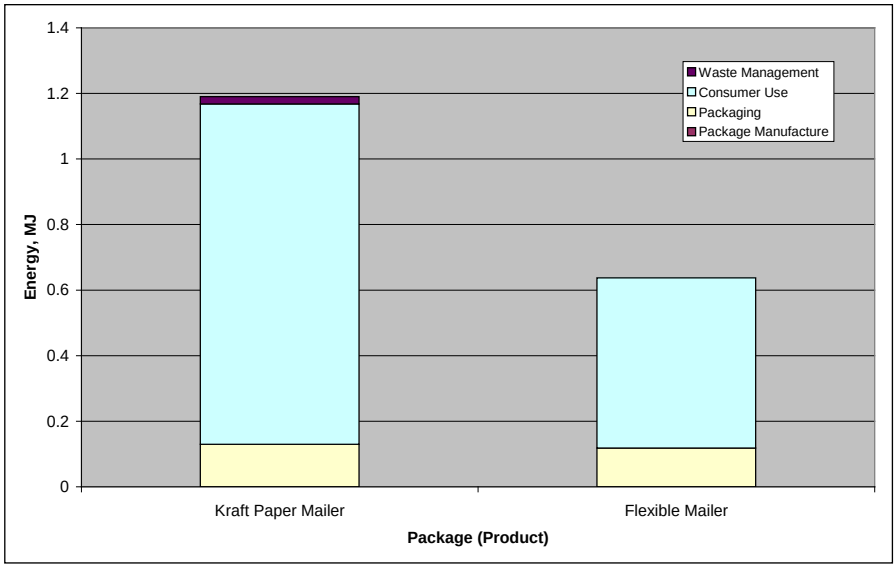

Figure A-17. Mailer Pellets-to-Grave Energy Consumption

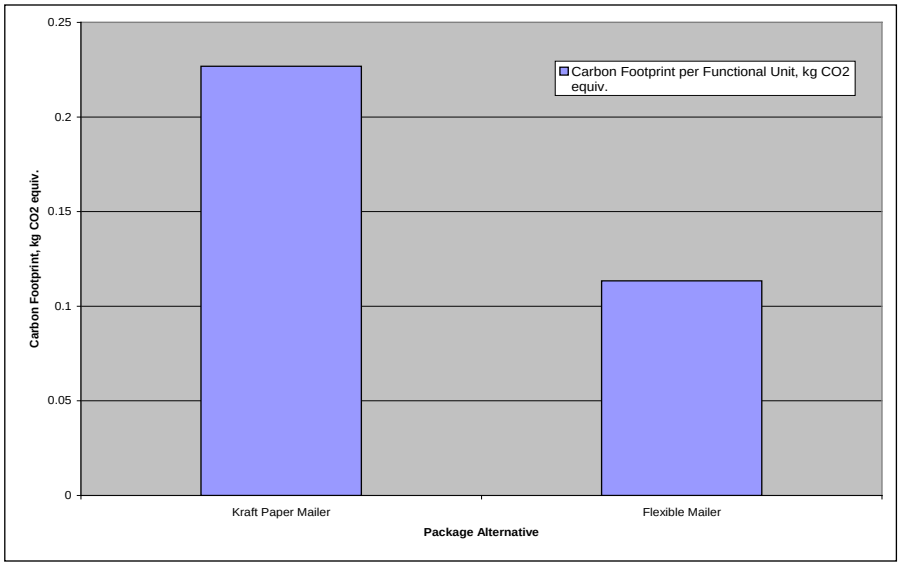

Figure A-18. Mailer Carbon Footprint

As we saw previously, the total system energy for the flexible mailer is lower. Of the total system energy, the flexible mailer offers a larger potentially recoverable energy fraction, being about 20 percent greater (1.3 MJ recoverable versus 1.1 MJ for the kraft paper mailer.) See Figure A-19.

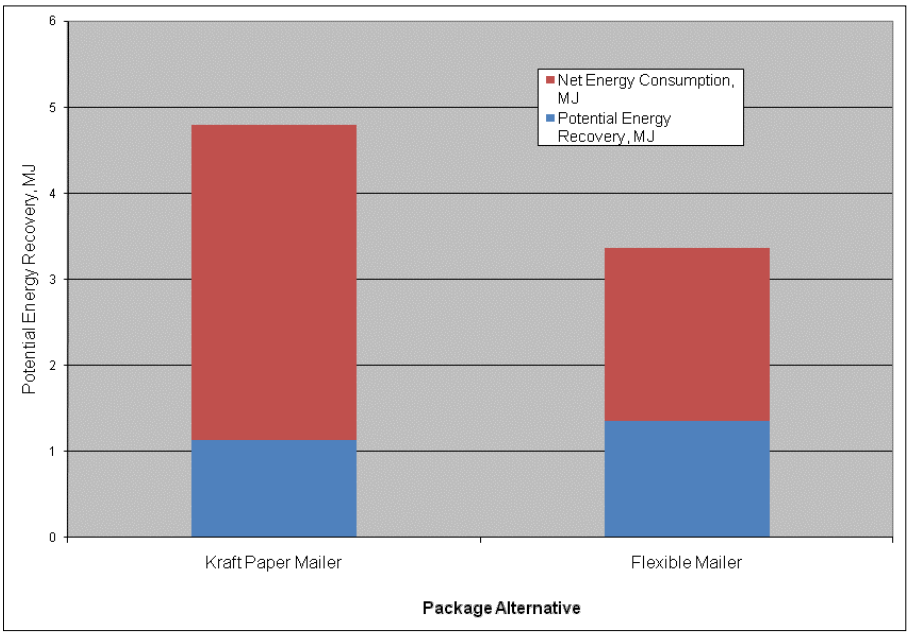

Figure A-19. Mailer Energy Consumption and Potential Energy Recovery

As might be expected from the lower total energy consumption and higher recoverable amount of energy, the fraction recoverable for the flexible mailer is much greater than for the kraft mailer (Figure A-20).

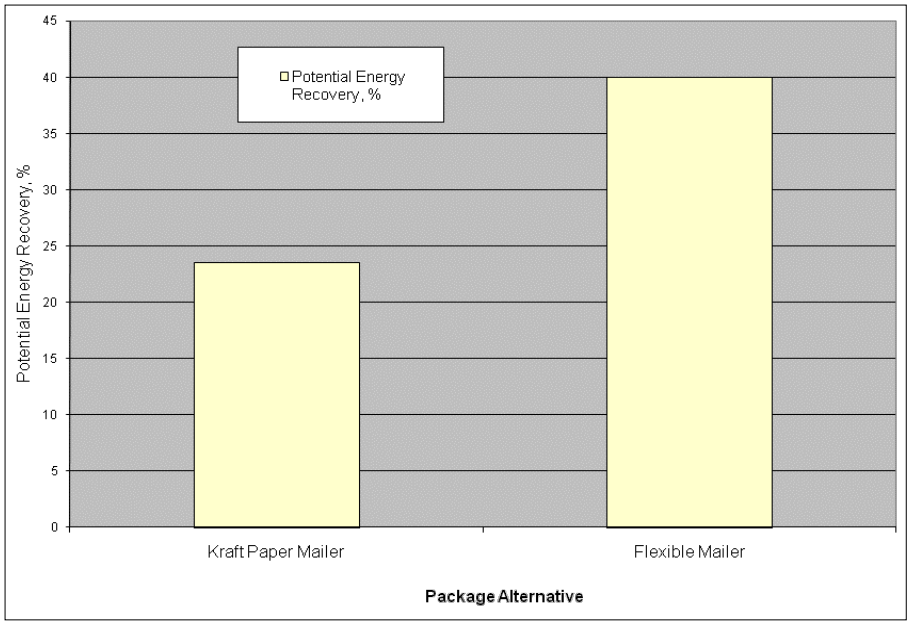

Figure A-20. Mailer Percentage Potential Energy Recovery

Case Study 4: Whole Meat Cuts Package

Whole Muscle Meat Cuts Package Description

For whole muscle cuts of meat, Battelle assessed only a polyethylene shrink wrap package:

1. Polyethylene shrink wrap as might be found by a consumer in the cooler case
   - The polyethylene shrink wrap is a multi-layer material with printing and a label. For this assessment, the label and printing were ignored, and all of the layers were assumed to be polyethylene.

Details of the package materials masses are provided in Table A-4.

Table A-4. Whole Muscle Meat Cuts Package Details.

Package (Capacity per Package)	Components and Mass (grams), per Package
Flexible Shrink Wrap (per pound meat)	LDPE: 2.41

Whole Muscle Meat Cuts Results

Figure A-21 shows the total life cycle energy for the meat packaging alternative. As seen with other systems, most of the energy consumed for the system is expended in the upstream or package materials manufacture stages.

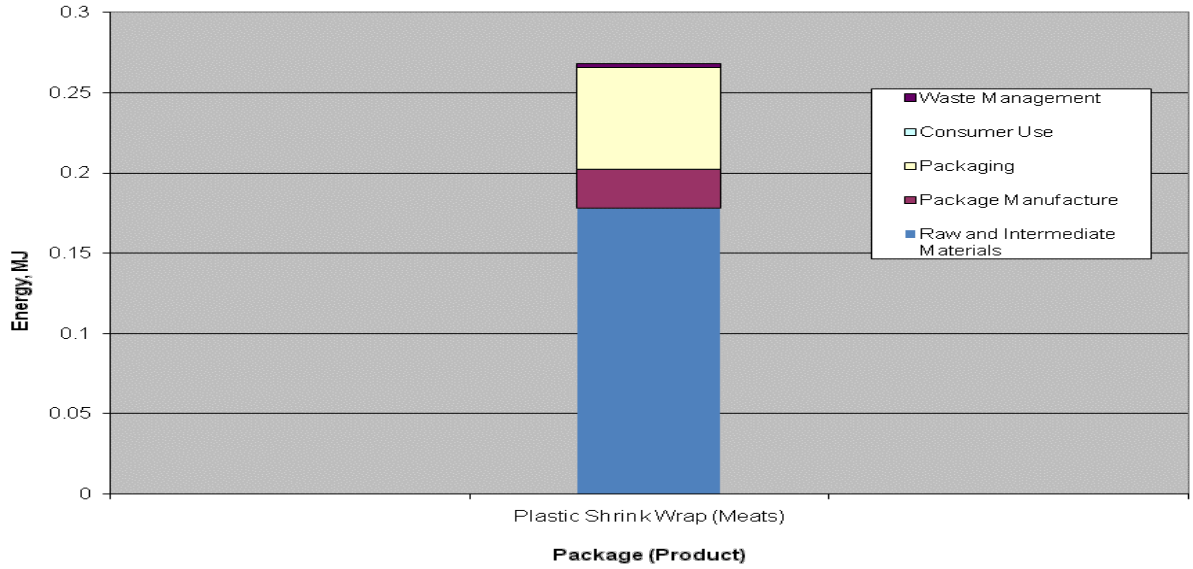

Figure A-21. Whole Muscle Meat Cuts Package Total Energy Consumption

Figure A-22 shows the results found by removing the manufacture of the package materials from the results.

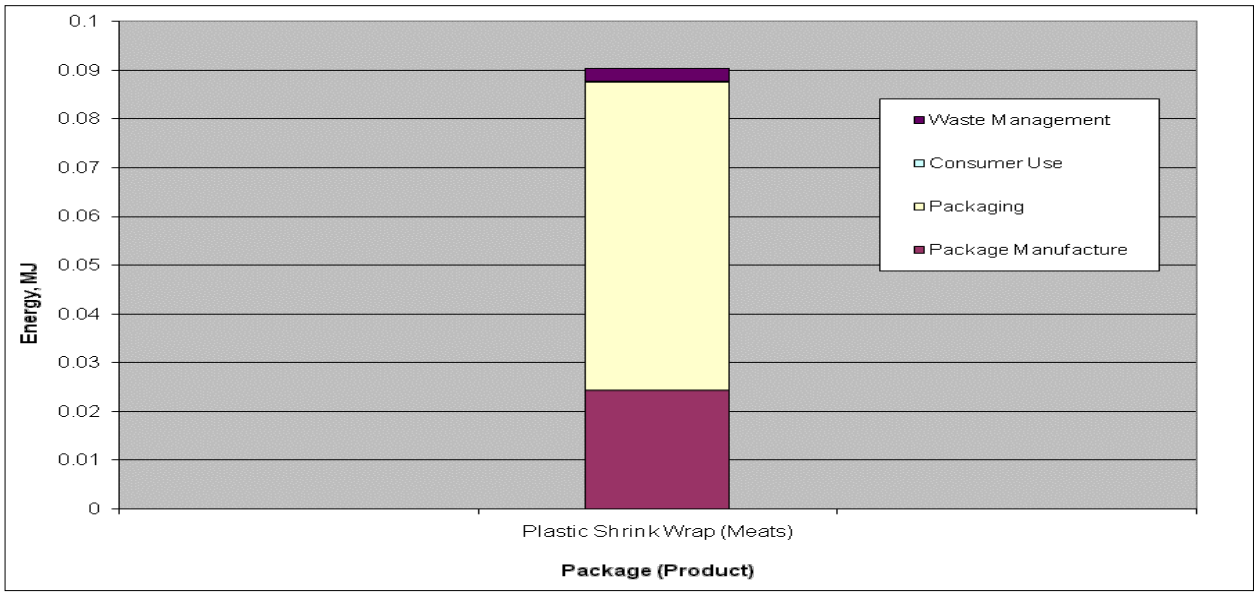

Figure A-22. Whole Muscle Meat Package Pellets-to-Grave Energy Consumption

The carbon footprint results are presented in Figure A-23.

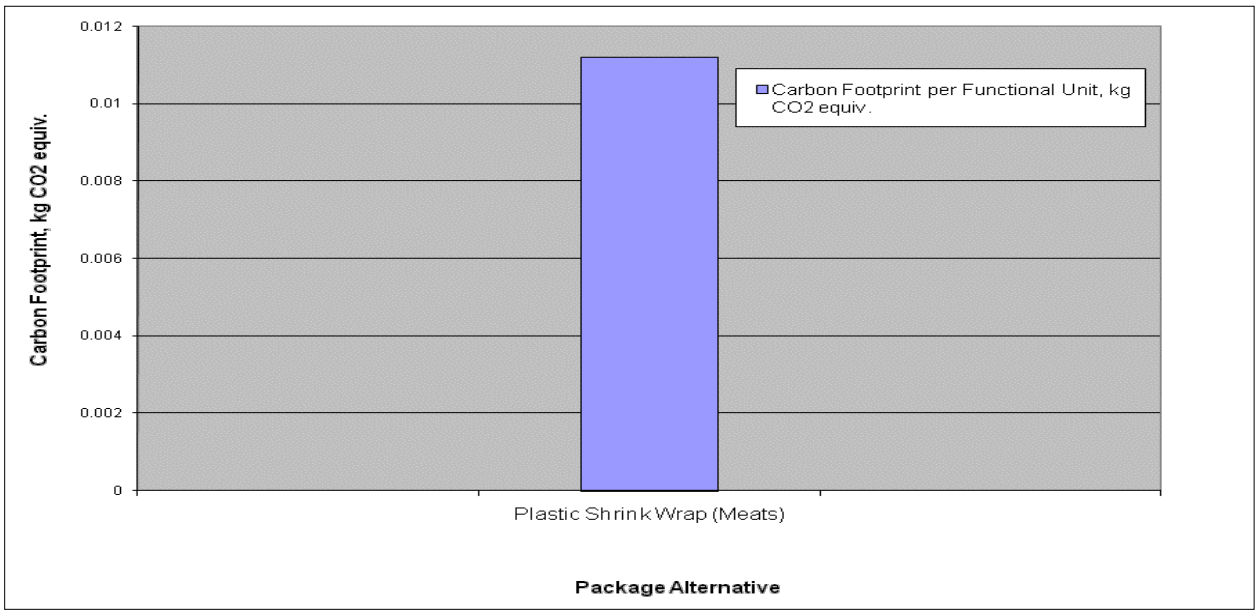

Figure A-23. Whole Muscle Meat Cuts Package Carbon Footprint

Figure A-24 shows both the total energy consumption, as the height of the bar, and the portion that could be recovered at the end-of-life of the package if waste-to-energy were an option (the lower portion).

Figure A-25 shows the percentage of recoverable energy and illustrates the flexible package can recover about 38 percent of the total system energy.

The life cycle flows for flexible whole muscle meat cuts shrink wrap model developed by Battelle is shown in Figure A-26.

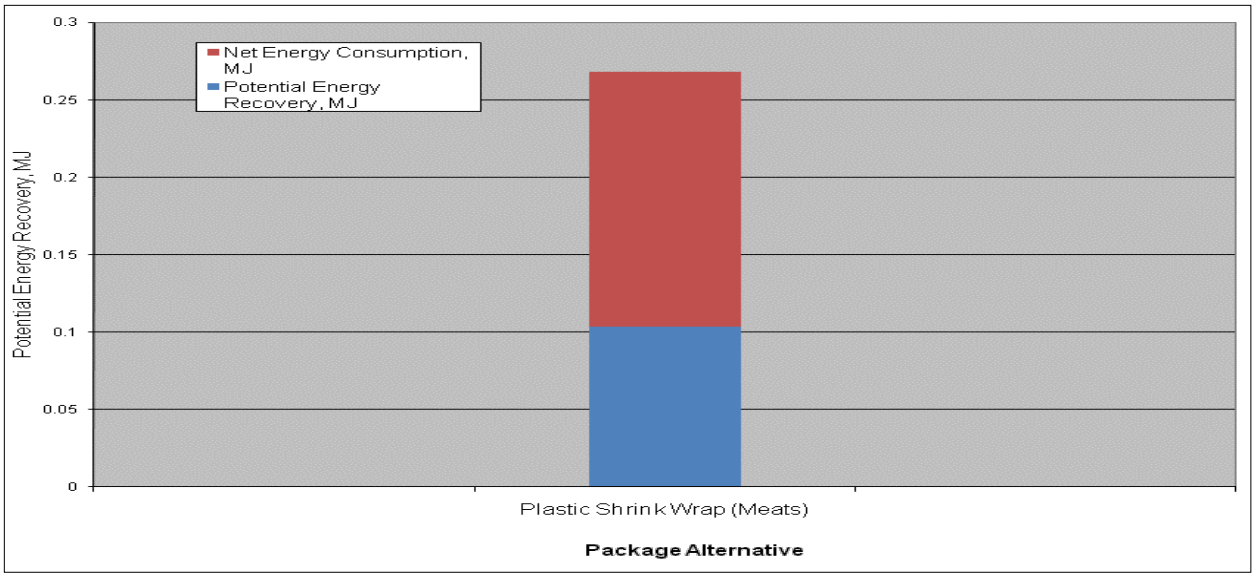

Figure A-24. Whole Muscle Meat Cuts Package Energy Consumption and Potential Energy Recovery

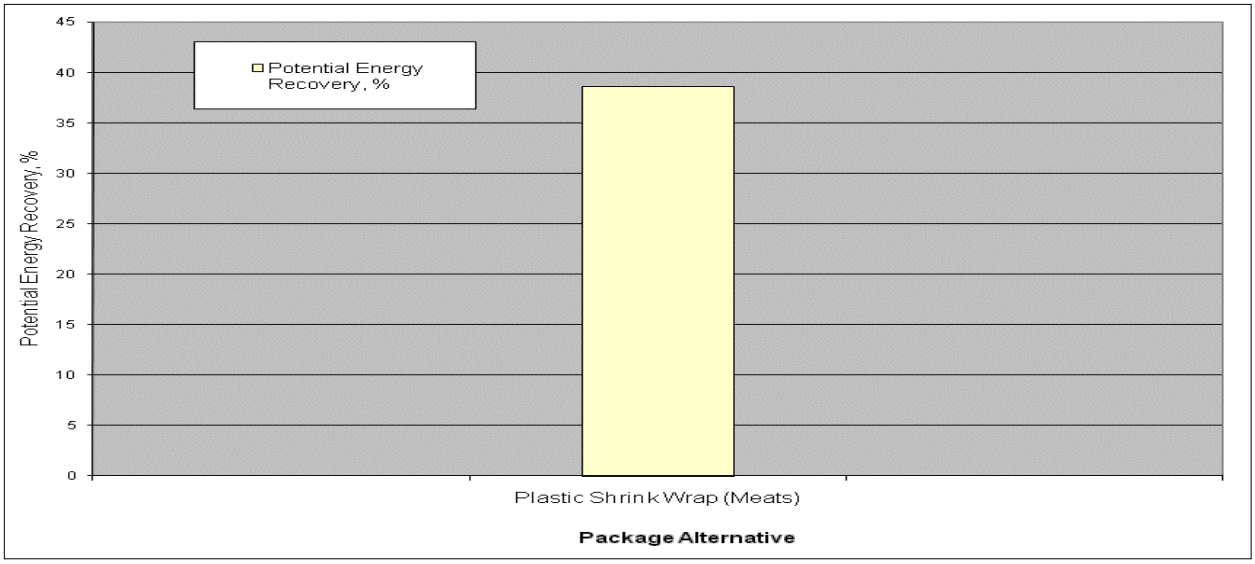

Figure A-25. Whole Muscle Meat Cuts Package Percentage Potential Energy Recovery

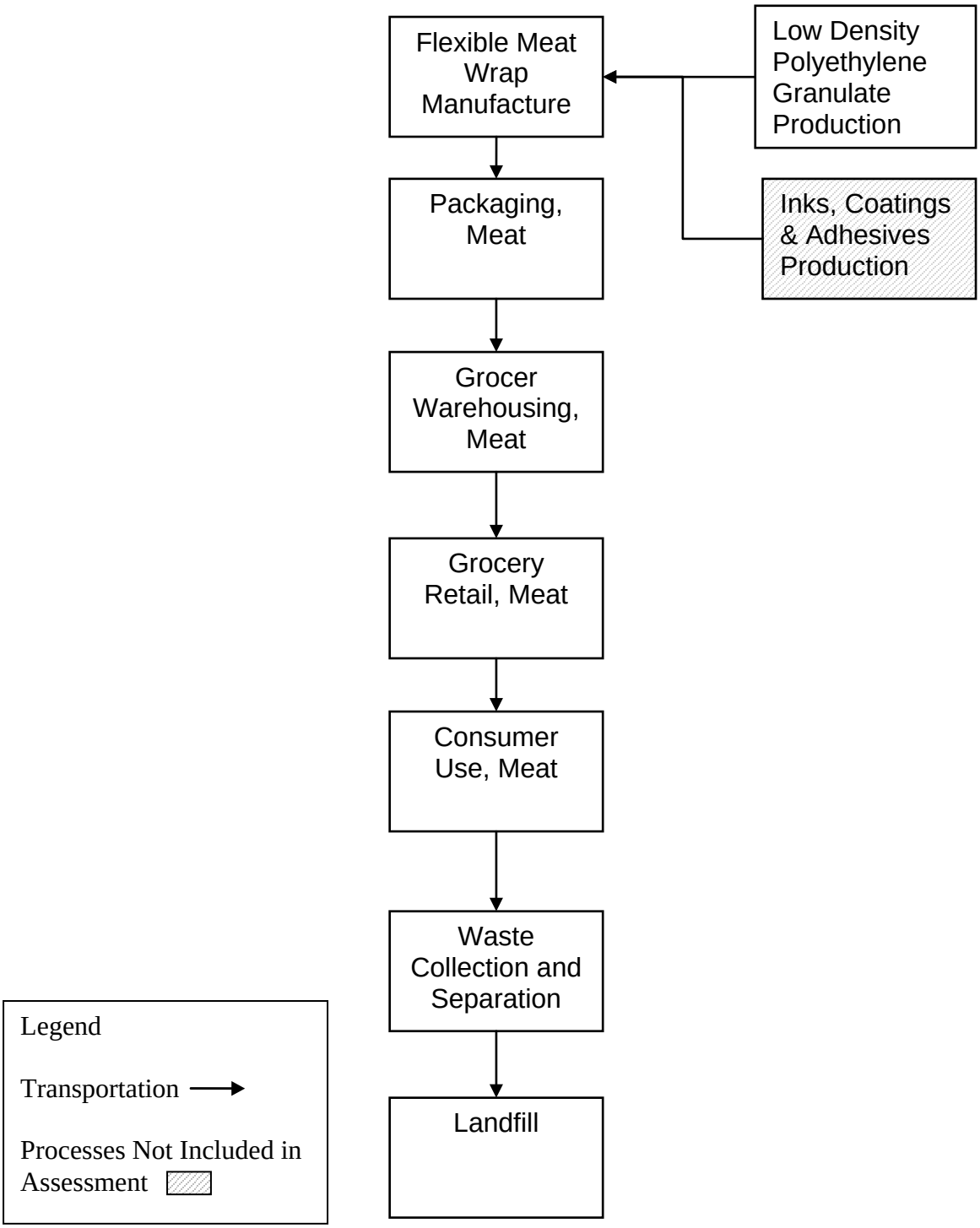

Figure A-26. Flexible Whole Muscle Meat Cuts Package Life Cycle Flows

Case Study 5: Salty Snacks Package

Salty Snack Package Description

We evaluated only one package material for salty snacks, and this by unit area (square meter), a multi-layer polyethylene and polypropylene package. The package materials were composed of inner and outer layers of polypropylene, one of those being metallized, and a middle layer of polyethylene. Inks and coatings were ignored. Details of the package materials masses are provided in Table A-5.

Table A-5. Salty Snack Package Details.

Package (Capacity per Package)	Components and Mass (grams), per Square Meter
Snack Bag (per square meter)	Total: 49.1 PP: 32.4 LDPE: 16.7

Salty Snacks Results

The same five figures total system energy consumption, energy consumption without accounting for package materials manufacture, carbon footprint, potentially recoverable energy, and potentially recoverable energy fraction, are presented for a salty snack bag material (Figures A-27 through 31). There were no comparisons made with alternative package materials.

As with the previous examples, manufacture of the package materials accounts for the most significant fraction of the total system energy. Transportation of the package material is the significant contributor of energy consumption during package manufacture and packaging. Approximately 35 percent of the total system energy could be recovered at the end of the useful life of the package through combustion of the package in an energy recovery facility.

The life cycle flows for flexible chip package model developed by Battelle is shown in Figure A-32.

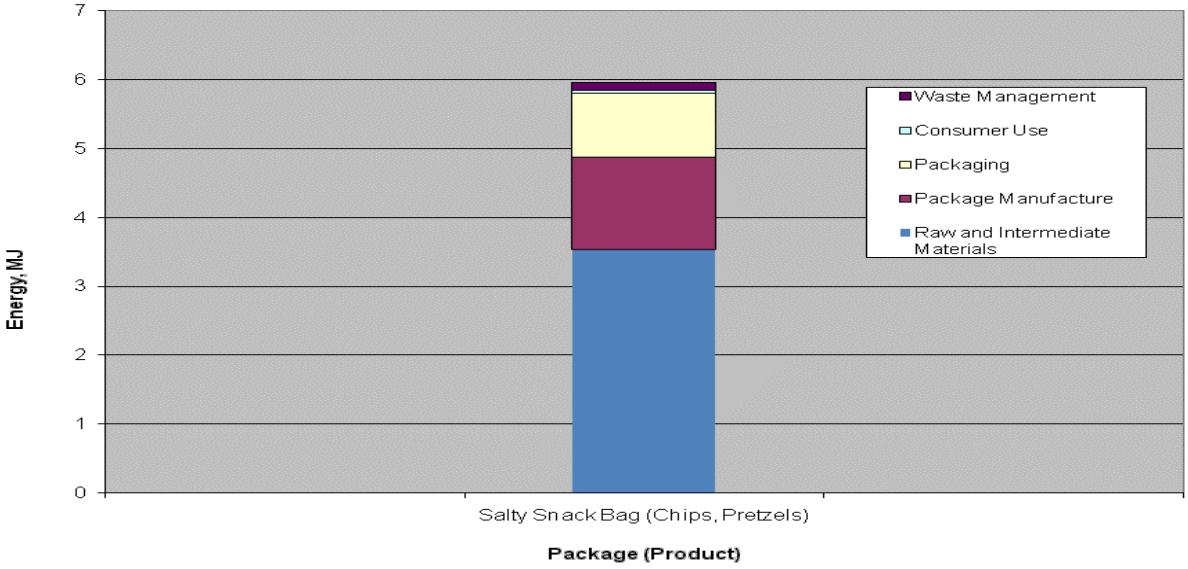

Figure A-27. Salty Snack Package Total Energy Consumption

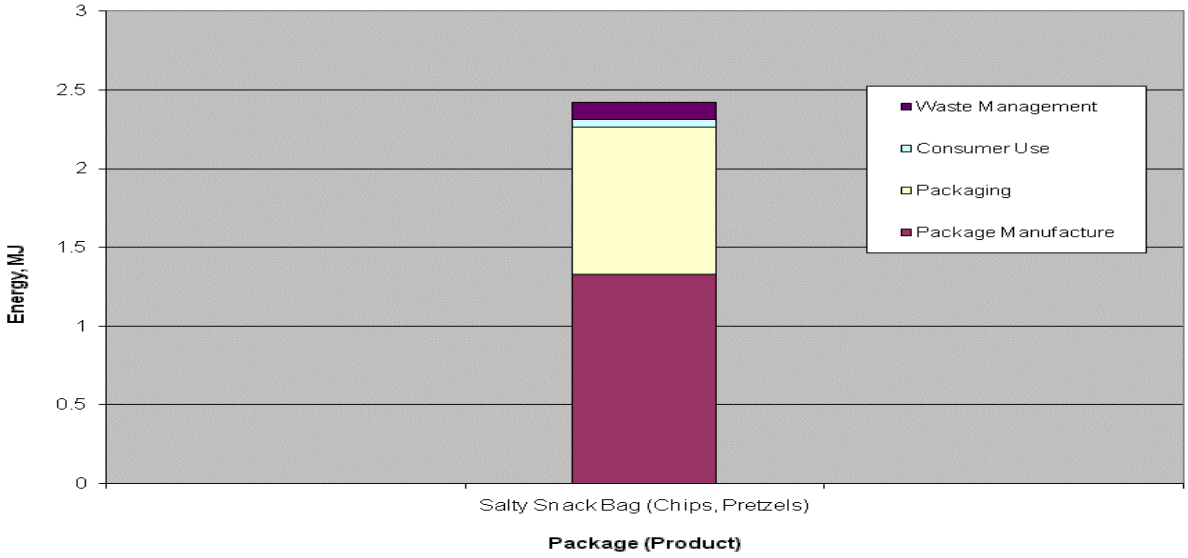

Figure A-28. Salty Snack Package Pellets-to-Grave Energy Consumption

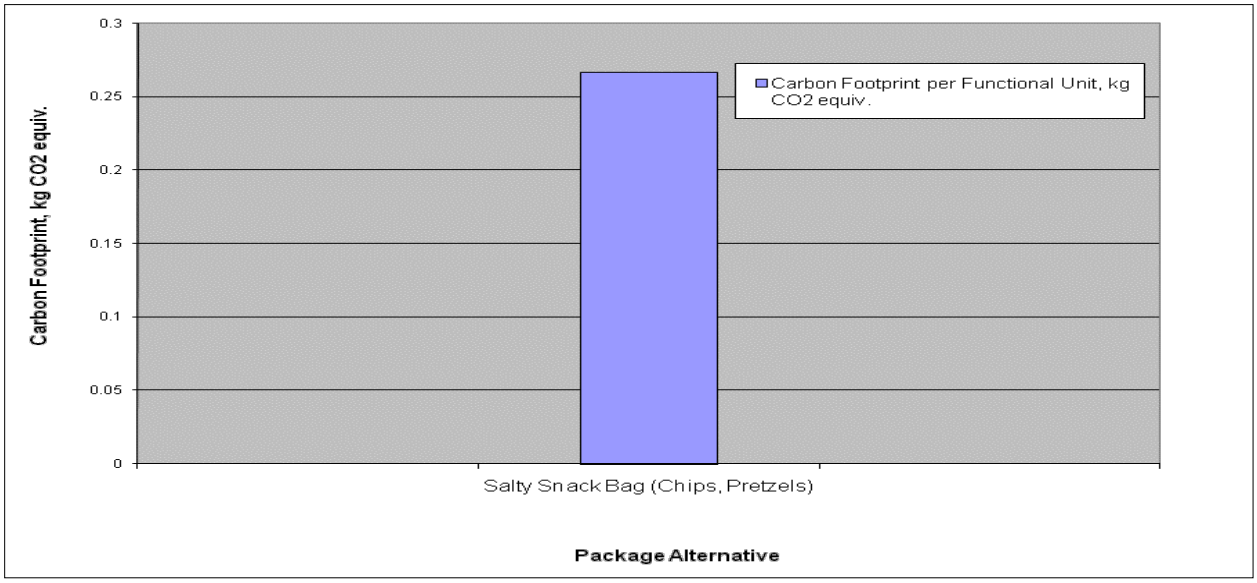

Figure A-29. Salty Snack Package Carbon Footprint

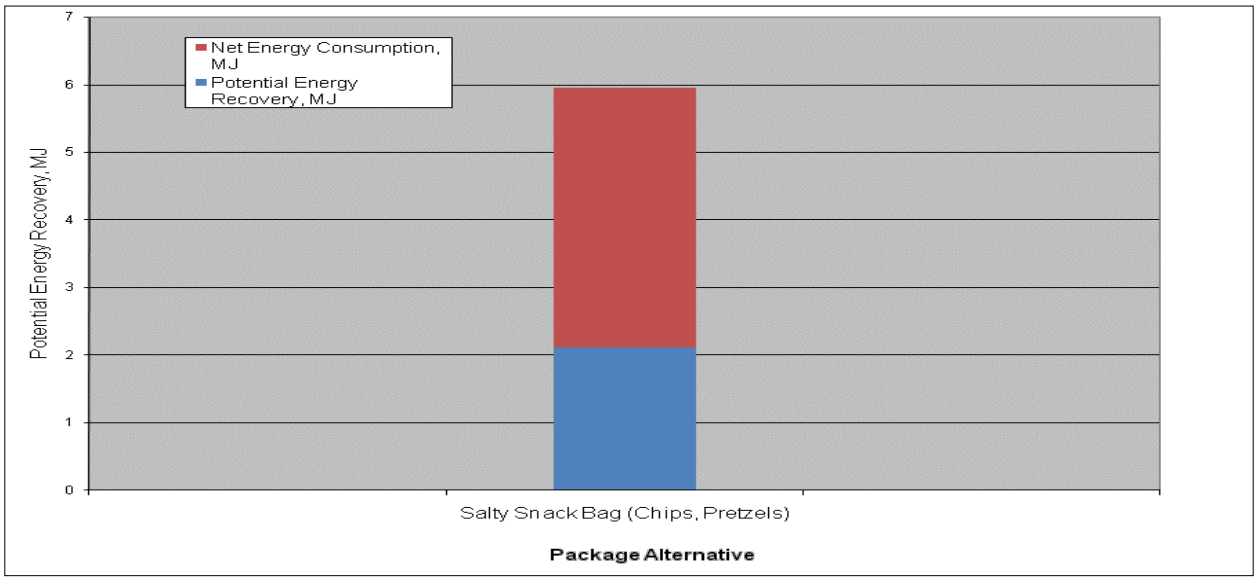

Figure A-30. Salty Snack Package Energy Consumption and Potential Energy Recovery

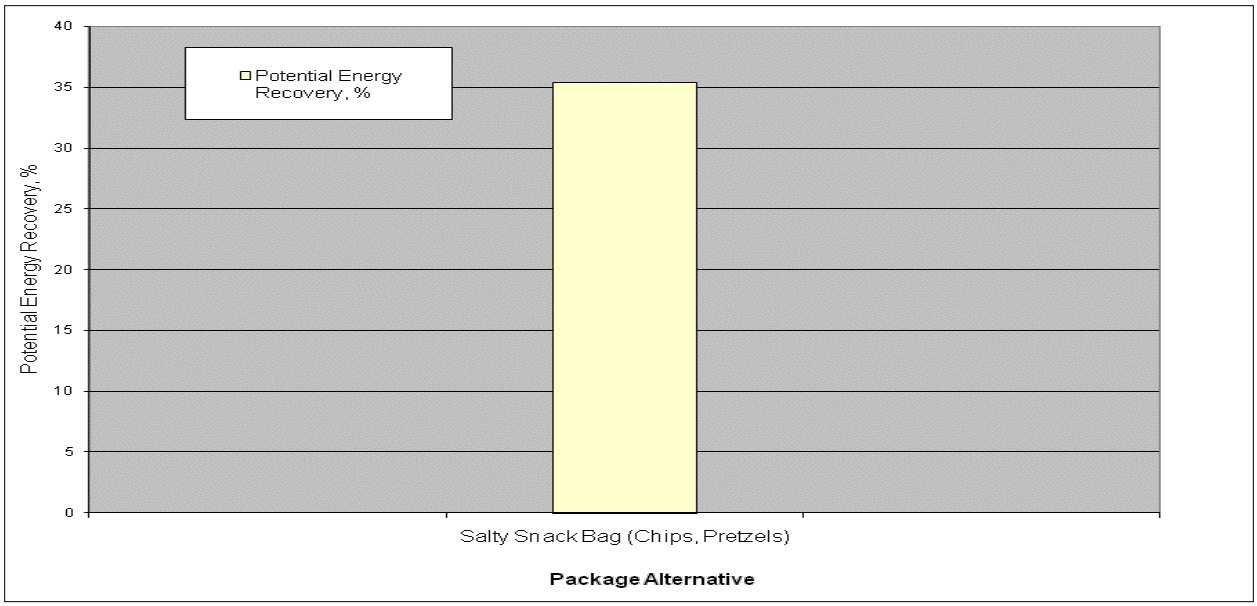

Figure A-31. Salty Snack Package Percentage Potential Energy Recovery

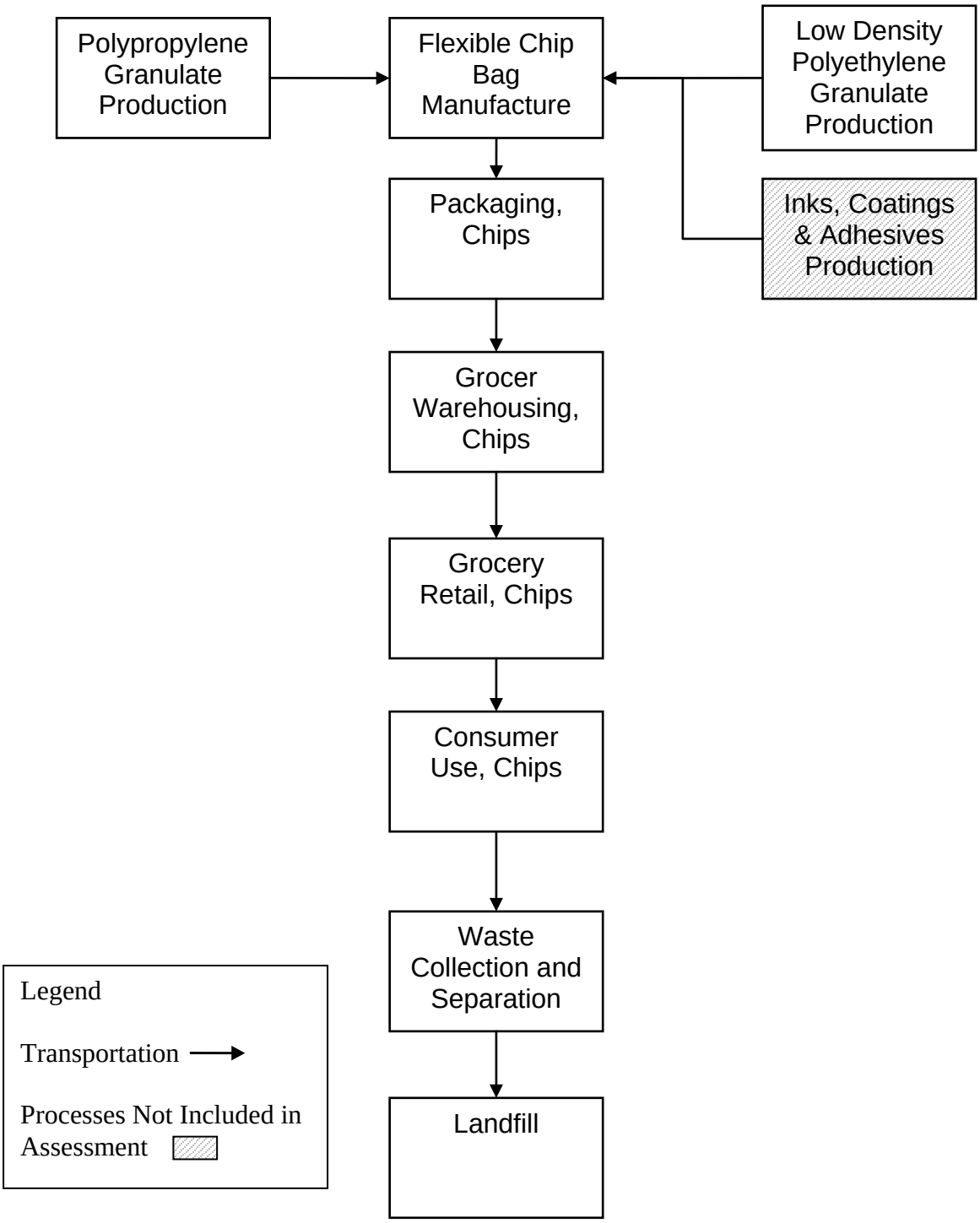

Figure A-32. Flexible Salty Snack Bag Life Cycle Flows

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Appendix B

Interviews with Companies Offering End-of-life Options for Flexible Packaging

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.Company Name	Interview Responses
WASTEC Wilmington, NC 28401	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: WASTEC is a mass burn facility. As such, there is no pre-sorting of the waste stream. We do have convenience drop-off sites around the county for recyclables. We manually remove prohibited items such as electronics, lead acid batteries, tires, refrigerators *etc*. Q2: Do flexible plastic packages, such as those that contain raisins, almonds, or Capri-sun juice pouches, enter your facility for processing? A2: Yes they are a part of the municipal waste stream Q3: What is your perception about the current state of waste to energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A3: The industry as a whole appears to be on the brink a revival, due primarily to the high price of energy, global warming, demand for renewal energy, resistance to siting of new landfills. Barriers will be the NIMBY (not in my backyard) syndrome; failure of states to recognize WTE as a renewable energy source, environmental activist groups.
Perham Resource Recovery Facility Perham, MN 56573	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: Most of the waste that comes to our facility is delivered via transfer trailers and that waste is pre-sorted before it comes to the facility, however we do get some direct haul brought to the facility, this is only from the city limits of Perham, MN. It is usually around 20 tons per day. The material that is sorted does go for recycling and we collect any un-burned metal materials for recycling as well Q2: Do flexible plastic packages, such as those that contain raisins, almonds, or Capri-sun juice pouches, enter your facility for processing? A2: We do see a fair amount of plastic packages that come through the facility, those are generated from a local business in town here that manufacture different types of snacks (potato chips *etc*) and also a pet food manufacturer, they are more of the plastic coated paper variety. Q3: What is your perception about the current state of waste-to-energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A3: I don't deal with the views on the waste from a national

.Company Name	Interview Responses
	perspective but here in Minnesota the Pollution Control Agency has recognized waste incineration as a renewable energy source, obviously recycling, reusing, and reducing are the goals of every state. Here in Ottertail county we are very close to a 50 percent recycling rate of all municipal waste collected. The facility here is in the process of expanding the facility as the waste in Western Minnesota ends up going to a non gas capturing landfill out in North Dakota and since this is part of the problem we want to part of that solution. Q4: Do you know the volume of packaging that your plant processes? A4: I don't know the exact number on the percentage of plastic packaging here at the facility but we burn approx. 35,000 tons of waste a year and I would guess that approx. 4 percent of that waste is plastic packaging.
Huntsville Solid Waste to Energy Facility, Operated by Covanta Huntsville, Inc. Huntsville, Al	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: Directly from collection point. Q2: If there is a pre-sorting, what types of materials can enter your plant for combustion? A2: There is no presorting, we are a mass burn facility Q3: What is your perception about the current state of waste-to-energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A3: Waste-to-energy is not utilized enough in this country and it is likely to grow in the near future with the energy demands placed on the country now.
Haverhill Resource Recovery Facility, Operated by Covanta Energy Haverhill, MA	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: The homeowner conducts any "pre-sorting" that is done. The Commonwealth of Massachusetts has enacted "waste bans", which bans direct that the designated recyclable materials be diverted from transfer stations, energy-from-waste facilities and landfills as indicated. They don't list mercury bearing items specifically on the table below, but at our facilities, we have programs for removing Hg bearing products prior to them getting to our tip floor. Q2: If there is a pre-sorting, what types of materials can enter your plant for combustion? A2: Once a community or private hauler has collected the

.Company Name	Interview Responses
	homeowner source separated materials, typically WTE (Energy from Waste) facilities can take the remaining "household trash", generally with only a size restriction (needs to be less than 4 feet in any measurement – due to hopper size) and it needs to be non-hazardous. At many facilities we can also take broken down furniture, plastic toys, *etc*., but we avoid some building supplies such as sheetrock. Q3: What is your perception about the current state of waste-to-energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A3: With the energy crisis, I think people are more willing to listen to the science of combustion and recognize that it's better to capture a material's BTU value rather than letting combustible, non-recyclable materials be buried in a landfill. They're also recognizing that WTE solves two problems: managing waste and producing energy all on the same small footprint, with excellent air quality control equipment, unlike some of the other fossil fuel energy producers. Covanta has already demonstrated that it's becoming more common via the increased capacity we've added on at different facilities here in the States. We also have international development projects. Barriers would be the continual mis-representation of scientific data by certain "environmental" groups. These groups continue to use data from 25 to 30 years ago to paint WTE as incineration (which is the combustion of materials with no BTU capture, no air quality controls and no energy production) in the hopes that people will recycle all their waste. We believe, however, that WTE is just the next step in recycling and support waste reduction, reuse and recycling at our facilities, followed by energy capture…we like to say reduce, reuse, recycle, re-think…. Q4: Do you know the volume of packaging that your plant processes? A4: If you look at the list of banned items above and/or visit the MADEP website, I'd have to guess that other than the paper, glass, metal, plastic, packaging that's designated by DEP, we would probably get the rest, combust it, and turn it into energy rather than burying it in a landfill. As I'm sure you know, plastic and glass packaging take "forever" to break down in a landfill, so we help our communities to understand the value of at least capturing the energy out of these materials. We have not completed a waste characterization on incoming materials, though, and cannot provide even a guesstimate at this juncture.
Semass Resource Recovery Facility, Operated by Covanta Energy Rochester, MA	Q1: Can a WTE facility operate without Government subsidies? A1: Absolutely. We have privately owned and operated facilities now that do not have Government subsidies. Subsidies are great, but a good company can put together a good, well thought out, well designed, properly sited project that can do very well on its own.

.Company Name	Interview Responses
	Q2: Do you know of any WTE facilities that venture capitalists have invested in to start up? Is it possible? A2: Yes, as I understand it, some of the private facilities built in the late 80s early 90s were built that way. If you need to know which facilities, I would have to dig a little more or refer you to someone else… But based on what I've been told, I'd have to say yes, it still possible and during this energy crunch, I'd say since WTE is a proven technology and has a historical operating and financial record, some venture capitalists would remain interested. Q3: How is the site location for WTE facilities determined? Is it based on population or proximity to a landfill? A3: The site for a facility depends on several things. One, yes, is whether there is adequate local or easily transportable post-recycling waste to make a facility economically viable over the initial term of the project. Proximity to a landfill only matters from the perspective of what to do with the remaining ash after the incoming materials have been reduced in volume by about 90 percent through the combustion process. In some cases, existing landfills are subsequently used as monofills, accepting only ash from the combustors. In other cases, the ash is utilized in a permitted beneficial reuse project. In still other cases, ash is shipped via truck or train to a more distant landfill. Q4: What is preventing more WTE plants from being constructed? A4: In my opinion, two things: cost and mis-information. In the U.S.A, landfilling remains "dirt cheap" when compared to WTE. This is due to the fact that there is a limited capital cost to construct a landfill; limited labor to operate a landfill; and there is virtually no air quality control equipment at a landfill until it's finally closed (and then it's pretty late to capture emissions!). WTE is held to a much higher environmental standard than landfilling, which also equates to cost. I think many people are taking a second look at the value a WTE can bring in terms of the energy production and the commitment by good WTE companies towards supporting recycling. As to misinformation, back in the days of incinerators (no recycling, no air quality control equipment and no energy production), things weren't so good. Then responsible companies and responsible Governments began to demand improvements and the WTE era was born. Responsible WTE companies are constantly upgrading their equipment and facilities, but must fight against what happened at incinerators 30 to 40 years ago! Some opponents refuse to believe in the advances of science and technology. Most recently, there has been great progress in Europe and Asia where WTE is recognized as a valuable tool after reduction, reuse and recycling. That's why we add "re-think" to some of Covanta's media outreach tools…we want people to think about what's the best way to handle post-RRR waste. We believe capturing the energy value makes much more sense than entombing it in a landfill.

.Company Name	Interview Responses
Spokane Regional Solid Waste Facility operated by Wheelabrator Spokane, WA	Q1: Can a WTE facility operate without Government subsidies? A1: WTE can operate without Government subsidies depending on area and $/KW. If good energy rate, can be self-sufficient and people can invest money. Q2: Who gets fuel? Where does the garbage come from? Who is in charge of the garbage? A2: Financial deals depend on the dynamics associated with the electricity. Spokane Facility has a 20 year deal to sell electricity to Puget Power (started in 1989). Puget Power did not need power until 2001 and offered the Spokane Facility two options: • Option 1: Puget Power can pay 2 to 3¢ per kWh for 1st 10 years and 9 to 10¢ per kWh for last 10 years. • Option 2: Puget Power can linearize costs over 20 years. Q3: Do you know of any WTE facilities that venture capitalists have invested in to start up? Is it possible? A3: Wheelabrator owns a lot of WTE plants. Spokane facility: received grants from the state of Washington to build the plant (~$60 million for WTE plant, transfer stations, and composting); also took advantage of municipal financing and revenue bonds. Municipality had to own the plant; Wheelabrator would design, construct, and operate the plant. Q4: How is site location for WTE facilities determined? Is it based on population, or proximity to a landfill? A4: Wheelabrator Process: select a group of sites, narrow the sites through investigation and analysis and make a selection. It is also a public process. Based on community size, population, and economy. The Spokane facility has an agreement with 14 communities and 60 percent of the facility's waste comes from local businesses. Community motivation-look at where WTE plants are sited. • Ex: Florida: landfilling not easy (dig in sand and reach water-not a good thing; limited land area) • Ex: Northeast Coast-no land for landfills • Q5: What is preventing more WTE plants from being built? A5: Money and legal issues are preventing more WTE plants from being constructed. WTE plants require a lot of capital to get start and this can be a major deterrent for potential investors. The legal issues involve interstate commerce and flow control. If it cannot be proven who controls the flow of waste, fuel, tipping fees-investors will not lend money.
Covanta Energy	Q1: Can a WTE facility operate without Government subsidies? A1: In the U.S., the short answer is "yes", but only in regions of the country where solid waste disposal pricing is high enough to justify

.Company Name	Interview Responses
	the costs. These are typically areas where you have high population density and subsequent lack of landfill capacity. For example, Northeast, mid-Atlantic and Florida. Parts of California would also be feasible, except that air quality regulations and the reduced air quality in metro areas (for example Los Angeles) would make securing air permits virtually impossible. Typically, WTE plants operating outside of these regions are supported to some degree by a Government or quasi-Government entity (i.e. such as a local Solid Waste Authority). This support may be direct subsidies or indirect, such as helping to control incoming waste flows, *etc*. In Europe, WTE is supported to a much greater degree by Government & quasi-Government entities. Q2: Do you know of any WTE facilities that venture capitalists have invested in to start up? Is it possible? A2: No new plants have been constructed or started up in the United States since the late 1980's or early 1990's, although I think that a few are being expanded (some Covanta Plants in Florida & Northeast). There may be even 1 or 2 brand new plants in planning. Typically investors can be private entities, or if the Plant is operated by a Government entity or Solid Waste Authority, they are more likely to issue bonds for sale to institutional & private investors. Q3: How is the site location for WTE facilities determined? Is it based on population or proximity to a landfill? A3: The standard approach is to locate a WTE facility within a reasonable proximity of a large metropolitan area for purposes of transportation. The key is the "turn times" required for solid waste collection trucks. Turn times (i.e. time required for a roundtrip to the facility) usually need to be lower for a packer or roll-off collection truck (8-10 tons capacity) but can be higher for a transfer trailer and tractor (~25 tons MSW capacity). Transfer trailers would need Solid Waste Transfer Stations located nearer to the major metropolitan area or source of waste. Location on an easily accessible highway is also highly preferred, in theory. In reality, siting a new WTE plant is VERY DIFFICULT. No one wants the traffic or nuisance conditions (odors, litter, dust, *etc*.). For example, firms like Covanta have been trying to site WTE plants in or near New York City for years and years without success. So, most companies or Solid Waste Authorities will end up happy getting ANY site that they could secure permits for. Typically, it ends up that expanding existing plants (if feasible) is the easier permitting pathway, although that is still a very difficult process. Covanta SEMASS requiring eleven (11) years to secure permits, approvals, financing, design and construction before it's first startup (first permitted by local Town in 1978, started up in 1989). Q4: What is preventing more WTE plants from being constructed? A4: Inexpensive landfill capacity (such as in the middle or southern parts of the U.S.), overall Environmental Opposition (WTE is often accused of having excessive mercury emissions and being "anti-

.Company Name	Interview Responses
	recycling"), and local siting opposition. In Massachusetts, there is a strict moratorium against constructing ANY new WTE capacity in the Commonwealth. Even without a moratorium, the permitting requirements are extreme. An eight to twelve-year lead time would be typically for siting, permitting, designing, financing, and constructing a new plant. The hurdles are not as high as a nuclear power plant, but they're in the same "ballpark".
Spokane Regional Solid Waste System, Spokane, WA	The Spokane Regional waste-to-energy facility is a mass burn facility. We do not utilize any type of presort other than voluntary source separation of recyclables. Any flexible plastic packages that are in the waste stream would be processed at the waste-to-energy facility. If you have additional questions, please give us a call at 509-625-6580.
Recycling & Planning Div. York County Solid Waste Authority, York, PA	A1. Waste is transported directly from the curb to the York County Resource Recovery Center (YCRRC) for waste-to-energy. The only pre-sorting that occurs is done by residents and commercial establishments in removing all the recyclable materials. A2. Processable (burnable) municipal waste (from households and commercial businesses) and small amounts of industrial waste (the industrial wastes need specific approvals) are acceptable at the YCRRC. A3. Current state of WTE - aging facilities, but proven technology. Many existing facilities are exploring expansions (we are planning to add a 600 tpd unit in the 2011/2012 timeframe). I think long-term WTE does have a positive outlook in the U.S. Although there are very few NEW facilities in the planning stages. Hopefully, in the next 5 to 10 years that will change. 'Green' power and renewable energy being the driving force.
Covanta SEMASS, L.P. W. Wareham, MA 02576	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: Materials come directly to the Covanta SEMASS facility by our haulers. Our customers (i.e., municipalities & businesses in MA) conduct their own recycling operations and divert recycled materials from the waste stream before shipment to us. Refer to MADEP website for more recycling info. Q2: If there is a pre-sorting, what types of materials can enter your plant for combustion? A2: Any leftover solid waste that doesn't contain "Waste-Banned" materials. Massachusetts has a large number of items that are strictly "banned from the waste". See MADEP website & use the key words "Waste Bans" under the solid waste requirements. Q3: Do flexible plastic packages, such as those that contain raisins, almonds, or Capri-sun juice pouches, enter your facility for processing?

.Company Name	Interview Responses
	A3: Covanta SEMASS accepts approximately 3,000 tons per day of solid waste, among the highest streamflows in the country. I'm sure this material is in the waste stream. Flexible plastic packages are not a MADEP "Waste Banned" item….only recyclable plastics Nos. 1 – 7. Q4: What is your perception about the current state of waste-to-energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A4: WTE industry has faced a VERY hostile regulatory climate in Massachusetts for nearly 2 decades (1990s & 2000s). There is currently a regulatory moratorium that does not allow permitting of ANY new WTE capacity in Massachusetts. In Massachusetts, WTE is opposed due to two primary beliefs: 1) Excessive mercury emissions, and 2) WTE undercuts recycling efforts. Both of these beliefs are erroneous, but long-held attitudes and biases are very hard to change. $4 per gallon gasoline is only now starting to overcome that. As a result, MA exports more than 1 million tons per year (will grow soon to 3+ million) of solid waste to other states as far away as Virginia & Ohio. We at Covanta object to this poor solid waste policy. If a state generates the waste, it should process/handle the waste. Q5: Do you know the volume of packaging that your plant processes? A5: Unfortunately, we don't know specifics on packaging quantities.
Wasatch Integrated Waste Layton, Utah 84041	Q1: Does the municipal waste in your area come directly from its collection point to you, or is there pre-sorting that occurs? Do the sorted materials go to recycling or the landfill? A1: We are a mass burn facility. There is no presorting prior to incineration. After incineration, ash is delivered to our landfill 2 miles away. At the landfill, a magnet goes over the ash for steel recycling. Q2: What is your perception about the current state of waste-to-energy in our country at this point? Do you foresee it as a technology that will become more common in the near future? If not, what are the barriers? A2: Unfortunately, waste-to-energy facilities are on the decline. Our waste-to-energy facility ships steam to the air force base (adjacent properties) which is used for heating some of their facilities. Our landfill ships methane gas from the capped cells of our landfill to the air force base which convert the methane to electricity via generator. Due to rising oil prices, alternative energies are now being researched more fervently but waste-to-energy has largely been ignored even though it is an excellent, renewable, and available source of energy.

.Company Name	Interview Responses
Arnold O. Chantland Resource Recovery System Ames, Iowa 50010	All municipal solid waste from Story County in Iowa comes directly from its collection point to our Resource Recovery Plant. There may be pre-sorting at the collection point in the form of cardboard recycling. That cardboard goes directly to recycling. We accept all types of materials into the plant; our process determines what goes out as combustible product. My perception of the current state of waste-to-energy in our country is that it is not used widely enough. I do foresee it as a technology that will become more common in the near future as energy costs continue to rise and energy demand continues to rise. Barriers might be emissions control, and certainly the cost of waste-to-energy versus landfilling. I don't know the volume of "packaging" we process. I can tell you that 57,690 tons of municipal solid waste were available for processing in our facility in the past 12 months; 84 tons of that total was metal that was removed for recycling prior to the processing of the material, 5,581 tons were sent directly to a local landfill for disposal because of equipment malfunction in either our facility or at the power plant that uses our product. 52,128 tons were processed in our facility, resulting in 2,019 tons of ferrous metals removed for recycling, 14,440 tons rejected from the process and landfilled, and 35,669 tons used as refuse derived fuel in our City's power plant.
Wheelabrator	The following responses apply to all Wheelabrator waste-to-energy facilities. 1. Trash that is sent to Wheelabrator waste-to-energy facilities has been subjected to whatever sorting that the homeowner or business conducts. Wheelabrator does not further process the trash to remove recyclable materials once it is received at our facility, other than to remove materials that are called "white goods" (*e.g.*, water heaters, washing machines, *etc.*) and wastes that are prohibited from being accepted by permit, law or regulation. 2. There is no pre-sorting at our facilities other than mentioned above; municipal solid waste is accepted at our facilities. 3. If these packaging materials are part of the municipal solid waste stream, they are accepted. 4. The waste-to-energy industry is strong in the U.S. and internationally. The realization that waste-to-energy uses a domestic "fuel" to produce clean, renewable energy and thereby displace millions of barrels of oil, has increased its visibility. Consequently, the use of waste-to-energy is expanding with new facilities being proposed and constructed. 5. Most waste-to-energy plants operate without Government subsidies. Waste-to-energy plant revenue comes from two basic sources: revenue derived from charging customers for the disposal of waste and revenue from the sale of energy (electricity and

.Company Name	Interview Responses
	sometimes steam). Some plants also recover ferrous and other metals from the ash residue and sell it to metal recycling firms. 6. Many waste-to-energy plants are merchant plants, that is the plants were developed, constructed and are owned and operated by private companies that offer disposal to communities in the region. 7. The location is mostly dictated by the region's need for trash disposal capacity. 8. Economics. The viability of a waste-to-energy plant is determined principally by the local cost for trash disposal and the price electricity companies are willing to pay to purchase electricity. Up until recently, trash disposal had been relatively inexpensive at large, regional landfills, and energy prices had been relatively inexpensive. The recent dramatic increase in energy prices has increased the interest in waste-to-energy. One Florida county has just completed an expansion of their existing plant and another county is in the process of constructing an addition. Two Maryland counties and the City of Los Angeles have issued requests for proposals (RFPs) for new waste-to-energy plants and a county in Florida and two regions in Canada are about to issue RFPs. Several other municipalities are seriously considering WTE projects.