



Advancing Sustainable Materials Management: 2016 Recycling Economic Information (REI) Report Methodology

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1. Introduction

1.1. Economic Contributions of Recycling

Recycling is an important part of the U.S. economy that contributes to national economic activity (Ross and Evans 2003; Ayres 1997; Byström and Lönnstedt 1997; Craighill and Powell 1996; Hawley 2009). From an economic perspective, recycling contributes to increased productivity, competitiveness and economic activity, including increased job creation, wages and tax revenue (R.W. Beck/NRC, 2001; Fiksel, 2006; OECD, 2012). Recycling is fundamental to sustainable materials management (SMM), which aims to reduce our reliance on limited natural capital and strengthen the economic position of future generations (EPA, 2009a).

The economic benefits of recycling have rarely been measured. In 2001, EPA laid the groundwork for better understanding the economic benefits of recycling with the National Recycling Economic Information (REI) study, *U.S. Recycling Economic Information Study* (R.W. Beck/NRC, 2001). This study estimated the contributions of recycling to national economic activity and helped raise awareness of the ways in which recycling activities support jobs, wages, revenue, and government tax receipts. The 2001 REI study also provided valuable insights for understanding how changes in waste management policy and investments in recycling markets can contribute to economic outcomes.

The 2001 study acknowledged several challenges and limitations of the REI methodology, including the inability to isolate recycling activities within multi-faceted manufacturing sectors and the issue of double-counting inherent in the methods being used (see Figure 1) (R.W. Beck/NRC, 2001). Since the release of the 2001 report, other researchers have introduced refinements to the methodology to address some of these issues, but challenges remain. The 2016 REI effort represents the next iteration in national REI analysis. It explores alternative approaches for measuring the economic activity associated with recycling, addresses uncertainties from the previous study and creates the foundation for a reinvigorated analysis of the economic impacts of recycling.

The 2016 REI study focuses on the diversion of nine categories of useful material from the waste stream. The material categories include paper, aluminum, glass, plastics, ferrous metals, rubber, food and organics, electronics and construction and demolition (C&D) material that are diverted from the waste stream (e.g., municipal solid waste) and recycled to make new products. The 2016 REI study includes recovery and refurbishing or remanufacturing for reuse of products and materials that have reached the end of their intended useful life, including electronics and certain types of C&D material (e.g., wood flooring). The study also considers the economic activity associated with the salvage and donation of edible food (e.g., canned goods nearing their expiration date).

EPA recognizes that food salvage for donation and the reuse or remanufacturing of electronics are not “recycling” activities. However, for brevity, the 2016 REI Report uses the term “recycling” when describing the overall scope and results of the analysis. In sections describing food donation and electronics recovery, reuse and remanufacturing, more precise language is used.

The 2016 REI study uses four approaches to measure the contribution of recycling to economic activity the U.S. economy:

- The **"direct production of recycling"** approach accounts for the direct economic activity associated with recycling operations. This definition includes, for example, the number of employees associated with recycling operations that produce steel castings from iron and steel scrap.

- The "**direct and indirect production of recycling**" approach accounts for not only direct but also indirect production such as upstream supply chain economic activity that supports recycling processes. Using the steel recycling example, this approach adds the number of employees who work in material recovery facilities that separate steel scrap, employees who work for suppliers of steel recycling facilities (e.g., electric utilities) and employees of other suppliers throughout the upstream supply chain.
- The "**recycled content in final demand**" approach is a novel methodology developed for this study. The approach estimates the direct and supply chain economic activity attributable to recycling based on the recycled content of final products consumed by households. Under this approach, for example, the number of employees directly and indirectly associated with recycling activities in the upstream supply chain of automobile manufacturing is allocated proportionally to the recycled content of an automobile by mass. This approach attempts to measure the size of the economy sustained by the physical presence of recycled materials in final products.
- The "**direct household demand on recycling**" approach accounts for direct and indirect (supply chain) economic activity associated with recycling that is demanded directly by households. Given that most of the recycled materials are used first by industry rather than households (i.e., they are intermediate products), this approach is expected to yield smaller estimates of economic activity (e.g., employment) compared to the other approaches in this study. The direct household demand on recycling approach is considered for the sake of completeness.

To estimate the economic activity associated with recycling using these different approaches, a waste input-output (WIO) model was compiled for the U.S. that distinguishes recycling operations and recyclable and recycled material flows from other sectors of the economy. This model was built on the official U.S. input-output (I-O) tables maintained by the Bureau of Economic Analysis (BEA), which describe the economic transactions between industries in the U.S. and are used, in part, to formulate U.S. monetary and fiscal policy. The U.S. official I-O tables do not distinguish recyclable and recycled material flows. For example, the I-O tables aggregate many of the recyclable material flows addressed in this study in a single "scrap" category (USBEA 2014). In addition, recycling activities are either embedded in the broader activities of a manufacturing sector (e.g., I-O category "331110, Iron and steel mills and ferroalloy manufacturing") or combined and included within the I-O category "562000: Waste management and remediation services."

The WIO model estimates the economic activity attributable to recycling in terms of employment, wages and tax payments. Using the I-O tables as the starting point, the WIO model distinguishes recyclable and recycled material flows and recycling processes and associates information about jobs and wages, as well as local, state and federal tax revenue to specific recycling processes. Combining this information with detailed statistics regarding economic transactions enables the estimation of the economic activity attributable to recycling for a specified year.

In addition to supporting the existing study, a key benefit of developing a WIO model was that it established a sound analytical framework for estimating the broader environmental and economic benefits associated with recycling. The WIO model could provide a framework for analyzing economic impacts (e.g., in terms of shifts in employment from extractive to recycling industries) associated with counterfactual waste management scenarios and recycling policy alternatives. The WIO model could also be extended to analyze environmental impacts associated with different recycling scenarios by linking environmental data to recycling processes (i.e., using the methods established for environmentally extended input-output life cycle analysis).

Of the four approaches used for this study, the direct and indirect production of recycling approach is the most analytically similar to the approach used for the 2001 national REI study. Nonetheless, the two approaches differed in significant ways, including differences in the scope of recyclable materials included in the analysis, characterization of the contributions of recyclable materials collection and processing industries and assumptions¹ and methods used to attribute economic factors to recycling processes in sectors where recycling takes place alongside other manufacturing operations. Additionally, the methodology for the direct and indirect production of recycling approach is most representative of the current dynamics of recycling flows. Not only are facilities directly involved with recycling impacted, but there is also influence on the surrounding infrastructure. The results from the direct and indirect methodology are towards the center of the range of estimates provided across all four approaches. Finally, the direct and indirect production of recycling approach is able to capture the economic impact of recycling while limiting double-counting, which are reasons why the direct and indirect production approach was chosen to summarize the results from the study in the 2016 REI Report.

In general, the approach used for the 2016 study provides more conservative estimates of the economic activity attributable to recycling than the 2001 study. Specific differences between the two studies are described in Section 4 of this methodology report.

1.2. REI Methodology Report Organization

The following sections of the methodology report describe the updated methodology and present the results of the 2016 REI study:

- Section 2 presents an overview of the methodology used to develop the 2016 REI study, describes important concepts used to define the scope of the analysis, presents alternative approaches for estimating the economic activity attributable to recycling and describes how the WIO model is used to estimate the economic activity associated with recycling based on these alternatives;
- Section 3 describes the data used in this study and the approaches taken for data collection;
- Section 4 presents the main results of the 2016 REI study using the methodology and approaches;
- Section 5 discusses the implications of the results and presents recommendations of the study;
- Section 6 provides references; and
- Sections 7 – 16 include Appendices that detail the WIO methodology and data sources, results, history, and context.

¹ In the 2001 REI study, economic activity associated with collection and processing activities were included as “direct” activities. In the current study, they are included as “indirect” activities.

2. Summary of the WIO Model Methodology

EPA developed a waste input-output (WIO) model to provide an improved analytical framework for better understanding the contributions of recycling to the U.S. economy. The WIO model builds on the official U.S. input-output (I-O) tables maintained by the Bureau of Economic Analysis (BEA). These tables describe the economic transactions between industries in the U.S. and are used, for example, to formulate U.S. monetary and fiscal policy.

Using the I-O tables as the starting point, the WIO model adds information about recyclable and recycled material flows in the U.S. and information about employment and local, state and federal tax revenue. Combining this information with the detailed statistics regarding economic transactions enables the estimation of the economic activity attributable to recycling.

This section of the report presents an overview of the methodology used to develop the 2016 REI study, and describes important concepts that define the scope of the analysis. This section also presents alternative approaches for estimating economic activity attributable to recycling and describes how the WIO model is used to recycling's economic contributions based on these approaches. A more detailed description of the methodology is presented in Appendix B – WIO Model Methodology.

2.1. The Recycling, Reuse and Remanufacturing Value Chain

For the purpose of this analysis, recycling is defined as the recovery of useful materials such as paper, glass, plastic, metals, construction and demolition (C&D) and organics from the waste stream (e.g., municipal solid waste) and the transformation of that material to make new products, resulting in a reduction in the amount of virgin raw materials needed to meet consumer demand. This analysis also includes within the definition of recycling the recovery and refurbishing or remanufacturing of products and materials that have reached the end of their intended useful life. This scope could include, for instance, the recovery of timbers from an old house and milling and finishing the timbers to make wood flooring, or the recovery and remanufacturing of computer components. It does not include the reuse of products that are intended to be reused multiple times and have yet to reach the end of their useful life (e.g., tire casings designed for retreading). To help inform federal efforts to reduce food waste, the study also analyzes the economic activity associated with food salvage and donation.

EPA recognizes that food salvage for donation and the reuse or remanufacturing of electronics are not “recycling” activities. However, for brevity, the report uses the term “recycling” when describing the overall scope and results of the analysis. In sections describing food donation and electronics recovery, reuse and remanufacturing, more precise language is used.

To estimate the economic activity attributable to recycling, it is necessary to associate recyclable and recycling flows with the physical processes involved in transforming recyclable materials into useful products, providing reusable materials to the intermediate or final consumer and delivering salvaged food to those in need. These processes can then be associated with specific product and service industries to estimate the direct, indirect and induced economic activity attributable to recycling, reuse and food donation.

There are many different, and equally valid, definitions of recycling that include some or all of the following activities: 1) material collection; 2) separation, cleaning and/or other processing (e.g., baling plastic bottles); 3) transformation of recyclable materials into marketable products; 4) distribution, storage and service delivery (e.g., distribution of food to and from food banks, used products wholesaling and retailing) and 5)

transportation at each stage. For this analysis, recycling is defined to include all of these activities. However, to create an efficient analytical framework that avoids double-counting, recycling activities are further distinguished as *direct* or *indirect*.

Direct recycling activities are those associated with the actual transformation of recyclable materials into marketable products such as the transformation of aluminum scrap into semi-fabricated products (e.g., ingots) in a secondary smelter. For reuse and food donation, the recycling activity is defined as the point for sale (e.g., where reused goods substitute for new goods) or the point of service (e.g., where a food pantry provides donated food to those in need). Indirect activities associated with recycling, reuse and food donation include the activities involved in the value chain of the direct processes, such as the collection, sorting and transportation of aluminum scrap to the smelter or the transportation of donated food from the food bank to the local food pantry.

Finally, the development of a comprehensive WIO model to estimate economic activity attributable to recycling in the U.S. is a significant undertaking involving documentation and modeling of specific material flows. The initial development of the WIO model focused on the most commonly recycled materials and materials that are significant from an environmental, economic and social policy standpoint. Table 1 summarizes the materials and types of processes captured in the 2016 Report WIO model.

Table 1. Materials Included in the Scope of Recycling for this Study

Material Category	Material Subcategories	Material Description	Example Processes
Ferrous metals	<ul style="list-style-type: none"> • Iron • Steel 	Ferrous metals recovered from appliances, automobiles, steel containers, construction and other sources	Use as a feedstock in steel mills and foundries to manufacture raw steel and castings
Aluminum	No subcategories	Aluminum scrap from used beverage cans, other containers, transportation, construction and other sources	Use as a feedstock in smelting operations to manufacture semi-fabricated products (e.g., ingots, slabs)
Plastics	<ul style="list-style-type: none"> • PET • HDPE • LDPE 	Recyclable plastics recovered for recycling	<ul style="list-style-type: none"> • Use in new food and nonfood packaging products • Use in new rug fibers • Use in new pipe products • Use in new composite lumber
Rubber	<ul style="list-style-type: none"> • Rubber crumb • Other recyclable rubber 	Ground rubber produced from scrap tires used to produce rubber crumb and used in other scrap forms	<ul style="list-style-type: none"> • Use in new molded rubber products • Use for playground surfacing and athletic fields
Glass	No subcategories	Glass cullet recovered from glass bottles and jars	<ul style="list-style-type: none"> • Use in new glass containers • Use in new fiberglass

Material Category	Material Subcategories	Material Description	Example Processes
Paper	<ul style="list-style-type: none"> Paper and newsprint Paperboard 	Recyclable paper and paperboard recovered and recycled	Use in new paper products
Construction and demolition (C&D) material	<ul style="list-style-type: none"> Concrete Asphalt pavement Asphalt shingles Gypsum wallboard Wood 	Recyclable materials recovered from construction and demolition waste ²	<ul style="list-style-type: none"> Use in road construction Use in new building products
Electronics	<ul style="list-style-type: none"> Computers Computer displays Hard copy devices Keyboards and mice Televisions Mobile devices 	Recyclable electronics that are recovered for refurbishing, remanufacturing or resale ³	Refurbishing, remanufacturing and resale as substitute for new equipment
Food and Organics Donated Food	<ul style="list-style-type: none"> Gleaned produce Rescued food Salvaged food 	Produce, prepared food and salvaged food recovered from farms, wholesalers, retailers and food service facilities that otherwise would have been wasted	Delivery to people in need through community food service programs
Food and Organics Recyclable Organics	<ul style="list-style-type: none"> Animal by-products Crop residue Dairy by-products Deceased animal stock 	Recyclable by-products from food processing, spoiled food that is no longer edible, grease and other cooking waste and organic material (food waste and yard trimmings) diverted from the solid waste stream	Use in producing minimally processed animal feed, rendering and animal by-product processing, biofuels manufacturing, anaerobic digestion, compost

² C&D metal waste is included in ferrous and nonferrous metals recycling analysis.

³ For the purposes of this analysis, electronics recycling includes the recovery, refurbishing/remanufacturing and resale of electronics devices. It does not include the processing of used electronics into commodity-grade scrap, such as ferrous metals, nonferrous metals, glass and plastic. To avoid double-counting, commodity-grade scrap is included in estimates of recycling of the respective commodity.

Material Category	Material Subcategories	Material Description	Example Processes
	<ul style="list-style-type: none"> • Grease/FOG • Plate waste • Produce, oilseed and grain residues • Spoiled food • Trim and other cooking waste • Yard trimmings 		manufacturing and landscape material application

EPA recognizes that the current 2016 REI WIO model does not include all of the materials where recycling makes important contributions to the U.S. economy. However, the model is a first step in establishing a framework for integrating additional materials, products, material flow and other information as it becomes available to develop a more complete picture of the economic activity attributable to recycling in the U.S. over time.

2.2. Analytic Approaches Included in the REI Study

Manufacturing a product from recyclable materials requires machinery, raw materials (e.g., water, virgin material inputs), energy and other inputs. Manufacturers of recycled products purchase these inputs from other industries (e.g., machinery manufacturers, power companies) that in turn purchase inputs from upstream suppliers. The effect of the demand for recycling inputs on industries throughout the upstream supply chain is referred to as the *multiplier effect* or *ripple effect*. The multiplier effect can be calculated using the Leontief inverse of an input-output table (see Appendix B – WIO Model Methodology).

Multiplier analyses assume the final and intermediate demands for products and services *pull* corresponding upstream inputs, and upstream factor inputs are attributable to downstream activities that require them. In other words, the demand for aluminum scrap for recycling, for example, creates a demand for facilities that recover aluminum scrap and the demand for energy used in those material recovery facilities. If there were no demand for aluminum scrap, this upstream economic activity necessary for aluminum scrap recovery would not exist.

A key issue to consider in multiplier analysis is therefore the definition of *demand*. As discussed in Figure 1, calculating economic activity attributable to recycling by multiplying intermediate (i.e. business-to-business) demand by an input-output multiplier results in the type of double-counting that has challenged previous REI studies. To overcome these challenges, the WIO model bases estimates of economic activity attributable to recycling on the final demand for products and services – that include recycled content or involve recyclables – by the end-users in the economy. Final demand end-users include households, governments and exports.

It is important to realize that the results from multiplier analyses are the results of an analytical model (as opposed to observation). Therefore, they depend on the methodology and assumptions employed in the analytical model. More than one set of assumptions is possible in modeling the economic activity attributable

to recycling in the U.S. economy. To provide a more insightful analysis, the WIO model is used to estimate recycling's contribution to economic activity using four approaches: 1) direct production, 2) direct and indirect production, 3) final demand and 4) recycled content in final demand. Table 2 shows the direct, indirect and induced economic activity covered by each approach.

Section 3 describes the four approaches and the different assumptions and methods used to model economic activity attributable to recycling. The results shared in Section 4 focus on the direct and indirect production approach, which is the preferred method due to its ability to capture the economic impact of recycling while limiting double-counting.

Complex interconnections between economic sectors make it difficult to quantitatively attribute economic activity to a particular sub-component of a sector, such as recycling. Economic input-output models provide a well-established analytical framework for quantifying *direct* and *indirect* economic activity. Sector interconnections throughout the supply chain can be captured through input-output multipliers. However, input-output multipliers are designed to estimate the activity attributable to changes in *final demand*, rather than intermediate demand between economic sectors. When used to analyze changes in intermediate demand, economic activity can be substantially overstated across the supply chain due to a double-counting effect.

For example, suppose that the recycler processes and delivers steel to a smelter that uses the material to produce hot-rolled coil for use in motor vehicle suspensions. By creating a demand for the recycled steel, each and every industry in the downstream supply chain (e.g., smelter, suspension maker and automaker) can claim the direct and indirect economic activity of the recycling facility as part of their contribution to the economy. Aggregating economic activity at intermediate points along the supply chain will therefore result in figures that far exceed the true regional and national totals.

Existing methods to mitigate the double-counting effect generally involve normalization of the results to dilute the effect. However, the origin of the problem is the misuse of these multipliers, which are designed to be used with final demand, not intermediate demand. Normalization techniques do not specifically address this issue. Final demand in an input-output framework is the end-point of a supply chain. When economic activity is attributed to final demand, consumption—and the economic activity created in the supply chain as a result of that consumption, such as the economic activity associated with recycled steel created by the demand for motor vehicles—is counted only once in a *mutually exclusive and collectively exhaustive* manner (see, e.g., Lenzen et al., 2007).

The WIO model builds on BEA's national I-O tables by disaggregating the "scrap" flow to better represent the flows of secondary materials, recycling processes and their interactions with the rest of the economy. This enables approaches (e.g., recycled content in final demand) that transparently track gross physical and economic recycling activity at a higher resolution and assess the net economic activity of recycling, avoiding the double-counting problem.

Figure 1: Double-Counting Can Occur When Intermediate Demand is applied to an Input-Output Multiplier Framework

Table 2. Four Approaches to Measuring the Impact of Recycling

Approach Name	Recycling's direct activity	Recycling's supply chain activity	Ordinary products' direct and induced activity outside recycling's supply chain
Direct production	○	×	×
Direct and indirect production	○	○	×
Final demand	△	△	×
Recycled content in final demand	▲	▲	▲

Notes: ○ Included. × Not included. △ Partly included (only the final demand sectors' share of recycling).
▲ Partly included (based on recycled content in final demand).

2.2.1. Hypothetical Economy to Illustrate Methods

Figure 2 presents a hypothetical economy to illustrate alternate methods for estimating the economic activity attributable to recycling. The figure highlights four subsectors of the economy (Sectors 1 through 4) that involve a linear set of supply chain relationships. Two of the sectors are involved in recycling activities associated with two materials (Materials A and B).

The hypothetical economy is described as follows:

Sector-to-sector relationships:

- Sector 1 manufactures durable equipment using Material A as an input. The equipment is used by manufacturers in Sector 2 (i.e. it is one of the products shown in the Direct Inputs box beneath Sector 2). The equipment does not become, in a physical sense, part of the product manufactured in Sector 2.
- Sector 2 produces an intermediate product that is used in the Material B recycling process in Sector 3.
- Sector 3 produces a mechanical part that is assembled with other materials and parts during the manufacturing of the final product in Sector 4 (e.g., a part made with recycled aluminum assembled into a car engine). The product of Sector 3 is embedded in a physical sense in the final product manufactured in Sector 4.

Relationships to final consumers:

- Sector 4 produces the final product consumed by households and governments.

- Sectors 1 through 3 are part of the upstream supply chain of the Sector 4 final product.

Recycling activity:

- Sectors 1 and 3 are engaged in recycling activities. At least a portion of the activity within each sector is involved in transforming recyclable materials generated by consumers or other sectors into intermediate products.

For simplicity, this hypothetical segment of the economy does not show the detailed interactions and processes associated with other product and service sectors. These product and service sectors consume inputs and produce the resources, materials, products and services that are used in Sectors 1 through 4 and other parts of the economy. For illustration purposes, it is assumed that recycling does not take place in these other sectors. The other products and services component includes both upstream supply chain sectors and final products and services.

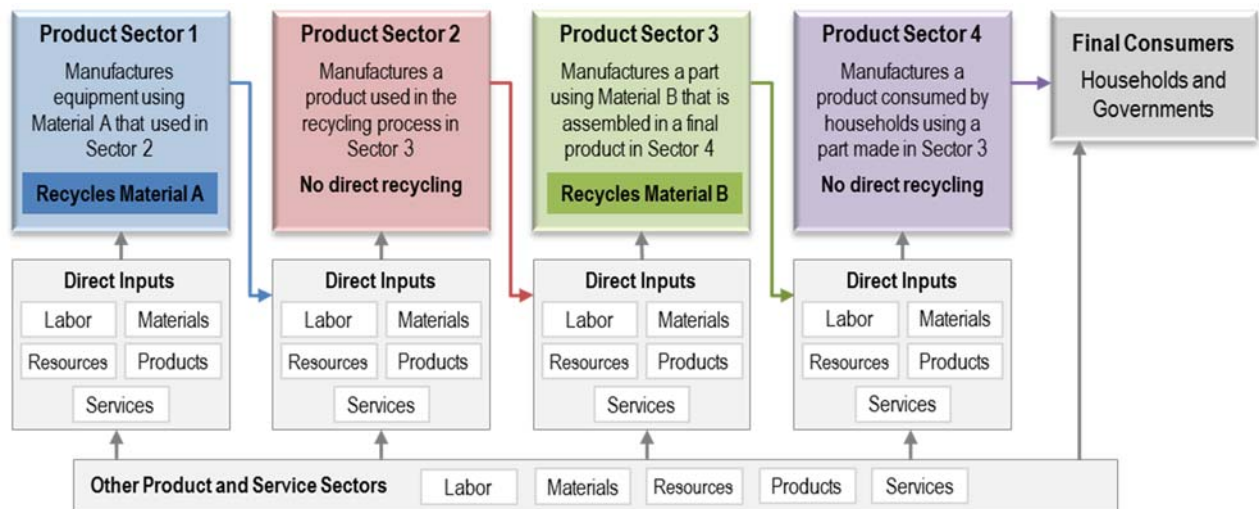


Figure 2: Hypothetical economy to illustrate methods

2.2.2. *Direct production of recycling*

The *direct production of recycling* approach defines the economic activity attributable to recycling in terms of inputs and outputs associated with sectors *directly engaged in recycling*. Using the hypothetical economy, this model consists of the labor inputs (jobs) associated with Sectors 1 and 3. Figure 3 illustrates this approach, partially highlighting the “labor” inputs to indicate the hypothetical situation where not all of the

jobs in these sectors are engaged in recycling processes. Other measures of economic impacts could include percentage of total sales or tax payments attributable to recycling activities in Sectors 1 and 3. The direct

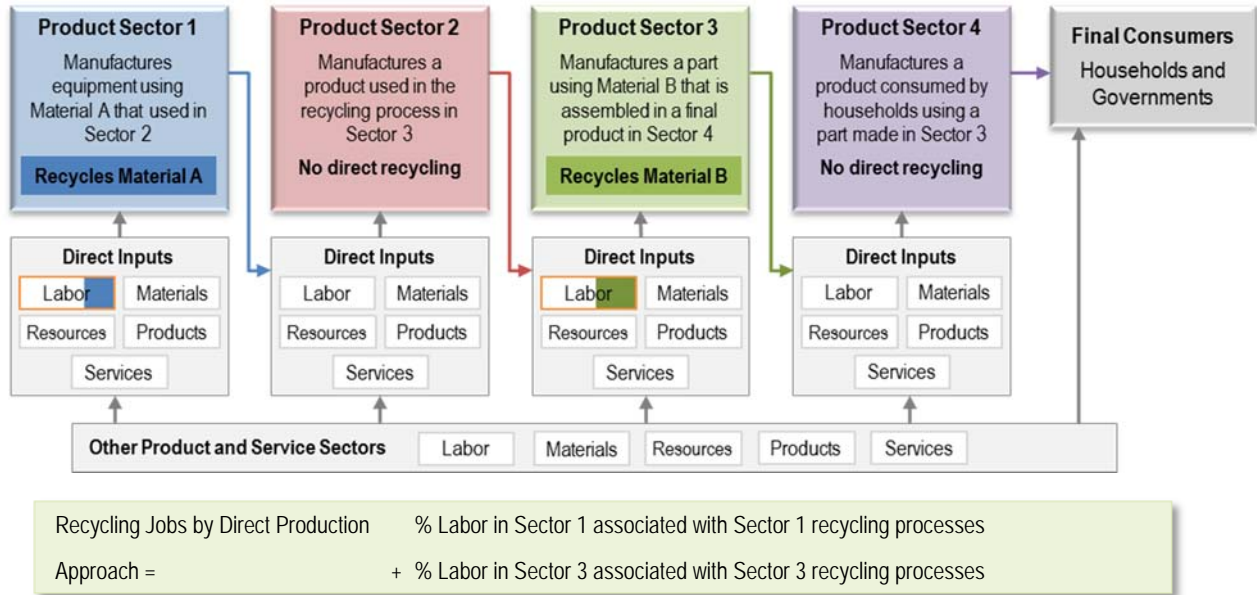


Figure 3: Illustration of direct production approach for estimating recycling economic impacts

method does not include indirect (i.e., supply chain) effects.

2.2.3. Direct and indirect production of recycling approach

The *direct and indirect production of recycling* approach builds on the *direct production approach* and adds the economic activity in the upstream supply chain of recycling processes. Of the four approaches described herein, this methodology is most similar to the approach for estimating direct and indirect economic activity used in the 2001 REI study.

As illustrated in Figure 4 the direct and indirect production approach includes workers directly engaged in recycling in Sectors 1 and 3. It also includes workers engaged in the upstream supply chain of the recycling activities in both Sectors 1 and Sector 3. Workers directly engaged in recycling in Sector 1 and workers engaged in the upstream supply chain of recycling activities in Sector 1 are also be counted in the jobs estimates for Sector 3, which results in double-counting.

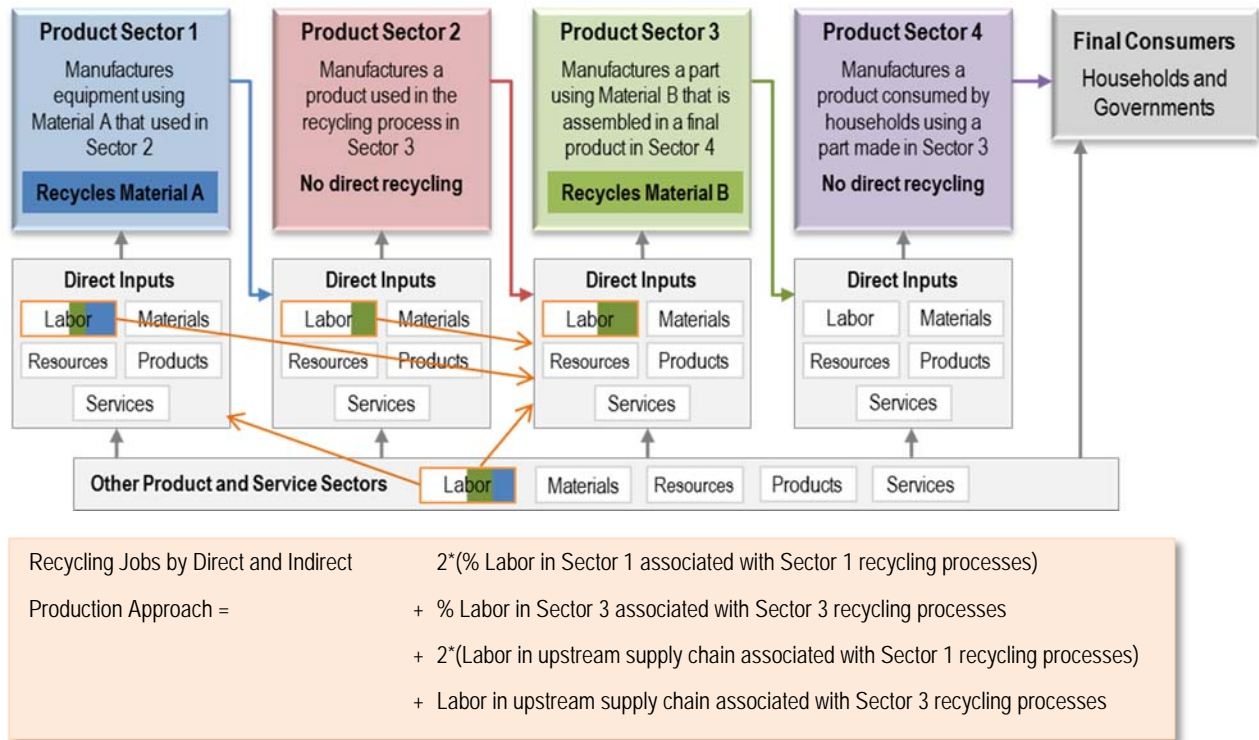


Figure 4: Illustration of direct and indirect production approach for estimating recycling economic impacts

2.2.4. Direct household demand on recycling approach

The *direct household demand on recycling* approach estimates the economic activity attributable to recycling based on final demand by households, governments and exports directly for recycling. Using the jobs example, the approach captures the direct and supply chain labor associated with recycling that is demanded directly by final consumers. The approach applies the primary factor input multipliers included in the I-O model and avoids the issue of double-counting. The approach does not include the economic activity attributable to recycling of materials that are used solely in intermediate products (i.e. that are not physically embedded in final products).

As illustrated in Figure 5, this approach includes the jobs associated with Sector 3 because the product of this sector is embedded in a physical sense in the product of Sector 4. It also includes labor inputs in the supply chain that are pulled by the recycling activities in Sector 3 using the I-O model. It does not include the jobs in the upstream supply chain of the recycling activities in Sector 1, as the equipment produced by this sector does not become part of the final product of Sector 4.

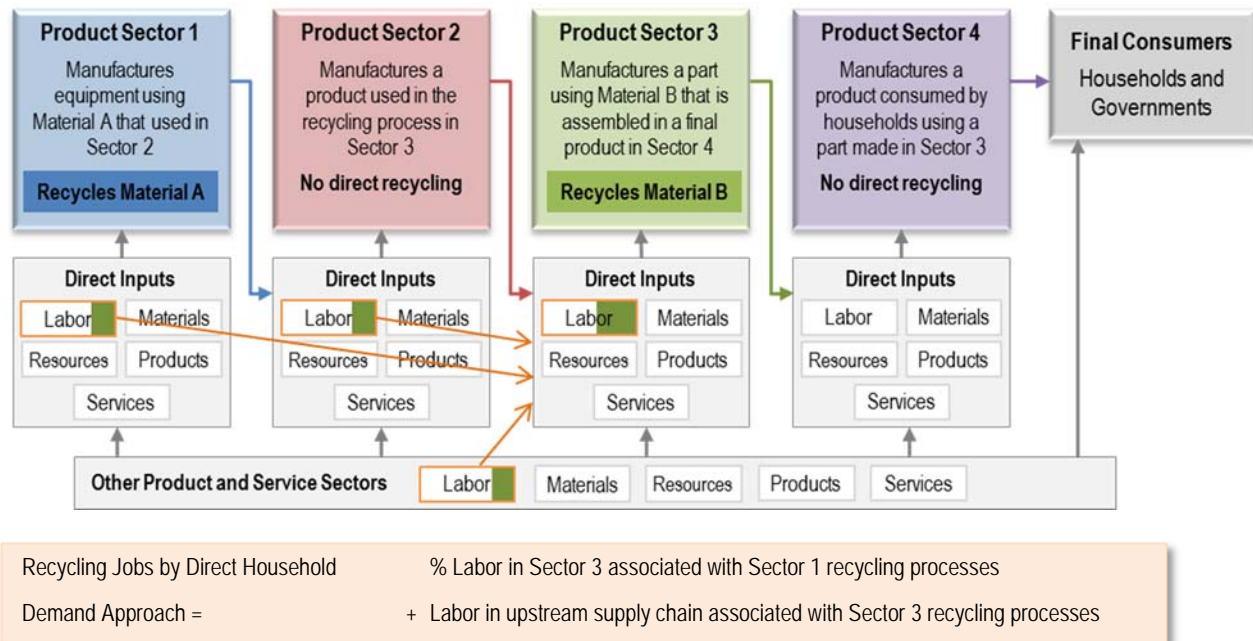


Figure 5: Illustration of direct household demand on recycling approach for estimating recycling economic impacts

2.2.5. Recycled Content in Final Demand Approach

The *recycled content in final demand* approach (referred to herein as the *recycled content* approach for brevity) allocates the economic activity attributable to product proportionally to the recycled content of the products consumed by final consumers (households, government and exports). This approach incorporates the concept that the materials constituting a consumer product harbor the services that the product renders. Therefore, this approach extends the definition of final demand for recycling to the final consumer products that physically incorporate recycled materials based on the recycled material share by mass.

Using the hypothetical example, one can calculate the direct and indirect labor required to produce the final product in Sector 4 including not only direct labor input to Sector 4 but also all of the labor in the upstream supply chain that can be attributed to manufacturing the product. The recycled content approach uses the share of recycled materials in the final consumer product that Sector 4 produces and attributes the direct and indirect labor requirement of Sector 4 to recycling based on the share.

Computationally, recycling economic activity attributable to the final consumption of a product is estimated as the share of the total direct and multiplier impacts associated final consumption that is proportional to the final product's recycled content. The approach applies the primary factor input multipliers and pulls in all recycling activity that has been included in the I-O model. It produces a more complete estimate of the economic activity attributable to recycling while avoiding double-counting. In doing so, it includes the labor inputs to ordinary sectors not directly associated with recycling if the downstream products of those sectors incorporate recycled content.

Using the hypothetical example, the approach would include workers directly engaged in recycling in Sectors 1 and 3. It would also include workers engaged in the upstream supply chain of the recycling activities in both Sectors 1 and 3, without double-counting and is illustrated in Figure 6.

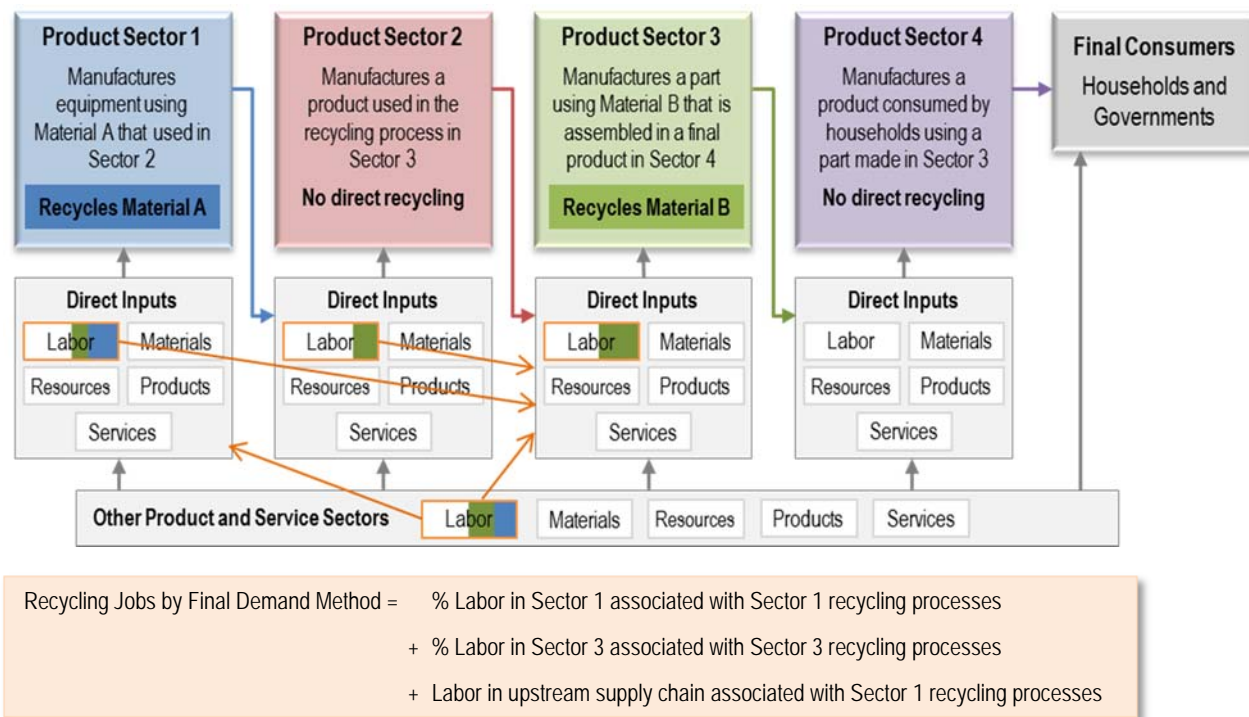


Figure 6: Illustration of recycled content approach for estimating recycling economic impacts

2.3. The Waste Input-Output Model

The WIO model combines the official U.S. input-output tables and more detailed information about recyclable and recycling material flows, process inputs and economic data to create a computational framework for estimating the economic activity attributable to recycling. Developing the WIO model required:

- *Creating the WIO framework*—defining the recycling economy in relation to the rest of the U.S. economy by defining the sectors where recycling occurs, distinguishing recycling activities from other activities within those sectors and translating this information into a computational model.
- *Integrating measures of economic impact*—aligning publicly available and verifiable measures of economic impact, including jobs, wages, occupational classifications and tax revenue, to the resulting WIO framework.

The methodologies used to create the WIO framework and integrate measures of economic impact are described in the following section. The resulting WIO model is the first iteration of the model that leverages publicly available information to estimate the economic activity attributable to recycling in the U.S. The

model provides a framework that can be used to further our understanding of the economic activity attributable to recycling as new information is made available (e.g., through updated federal statistics, state data, and industry sources). It also establishes a sound analytical framework for estimating the broader economic impacts associated with recycling. Section 5 identifies opportunities for further refinements and extensions to the WIO model.

2.3.1. Waste Input-Output Framework

The existing U.S. official input-output table shows flows of transactions between industries, but does not specifically distinguish recyclable and recycled material flows. For example, the I-O table aggregates many of the recyclable material flows addressed in this study in the form of single scrap flow (USBEA 2014). In addition, recycling activities are either embedded in the broader activities of a manufacturing sector (e.g., I-O category “331110, Iron and steel mills and ferroalloy manufacturing”) or combined and included within the I-O category “562000: Waste management and remediation services.” Therefore, the input-output structure specifically for recycling activities is not specified in that framework.

Development of the WIO model involves disaggregation of recyclable and recycled flows in the existing national input-output table, and creation of a hybrid unit table that links physical flows of recycling inputs and outputs to monetary flows in the economy. The following additional types of information were collected and incorporated into a hybrid I-O framework for the nine material categories included in this study to produce the WIO model:

- Estimates and/or modeled flows of scrap, recyclable materials, reusable products and materials and salvaged food produced or donated by industry or households;
- Estimates and/or modeled flows of secondary (recycled, reused and remanufactured) materials consumed by industry and households;
- Unit price data for recyclable materials, reusable products and materials, donated food and secondary (recycled) materials, used to integrate material flows with existing I-O data;
- Statistics on the percentage of scrap, recyclable materials and reusable products and materials generated that enter into recycling, reuse and remanufacturing operations and percentage of donated food that reaches people in need;
- For recycling processes (versus reuse and food donation), secondary material yields; and
- The input used by recycling, reuse, remanufacturing and food donation operations (i.e., amounts of materials and energy consumed).

Section 3 describes data collection efforts in more detail, including sources of information and techniques used to impute missing information.

2.3.2. Integrating Measures of Economic Impact

By defining relationships among businesses and final consumers in the economy, the WIO framework creates a computational approach for estimating the direct and upstream economic inputs and outcomes associated with recycling processes. For consistency with previous REI studies, economic inputs and outcomes incorporated into the WIO model include employment as measured in terms of number of jobs, wages and occupational distribution; and tax revenue generated as a result of recycling operations.

To integrate this information within the WIO framework, data on jobs and wages were collected from publicly available information sources, including the Census Bureau Statistics on U.S. Businesses (SUSB), the U.S. Agricultural Census and the U.S. Census of Governments. Data regarding corporate tax review was collected from the Internal Revenue Service (IRS) Statistics of Income (SOI) program. These sources were used to ensure that the methodology leverages existing public data and can be reproduced and updated in the future as new data become available.

Data were integrated with the WIO framework by associating economic sector classifications in the original data source with the sectors used in the BEA I-O tables. Economic data were attributed to specific recycling processes using the types of material flow information described above to calculate the share of production in recycling industries that can be attributed to recyclables versus materials for which recyclables are substituted to meet the functional requirements of products and services. Section 3 describes the data collection activities in greater detail.

3. Data Collection

Two primary types of data were collected to create the waste input-output (WIO) model: 1) recycling process data, including data used to characterize recyclable material flows, recycling process inputs and outputs and recycled material flows and 2) economic data to enable analysis of the impact of recycling on jobs, wages and tax revenue. Section 3 describes the data collection effort, summarizes collected data and discusses the challenges and limitations associated with the data collection effort.

3.1. Data Collection Approach

Table 3 provides a list of data elements that were targeted for data collection for each of the nine material categories included in the study. Information for most data elements was collected from public data sources. For other information, such as recycling process inputs, that were not as readily available, assumptions based on best judgement were applied. A list of assumptions made to characterize the inputs of recycling processes can be found in Appendix D – Recycling Process Allocation Assumptions. Additionally, detailed information on the quantities of materials recycled/recovered, along with unit prices for recycled materials can be found in Appendix E – Recycling Material Quantity and Price Data.

Table 3: 2016 REI Study Data Elements

Data Element	Description	Units
Recycling Process Inputs, including recyclable materials	Quantity of energy, material, water, transportation, labor and capital inputs to recycling processes, including the recyclable material inputs.	Physical, and if available, monetary unit
Recyclable Material Production	Quantity of recyclable materials produced by industrial sectors and households, which can become inputs to recycling processes depending on the destination of those materials.	Physical, and if available, monetary unit
Distribution of Recyclable Materials	Sectors to which recyclable materials produced by industrial sectors and households are distributed such as recycling, landfill and incineration; including the quantity sourced to each.	Physical, and if available, monetary unit
Recyclable Materials Proportion	Ratio of recyclable material to total material (sum of recyclable material and virgin material for which the recyclable material is used as a substitute) used in processes that involve recycling.	Physical unit
Recycled Material Production	Quantity of recycled materials produced by recycling processes.	Physical, and if available, monetary unit
Distribution of Recycled Materials	Sectors to which recycled materials produced by recycling processes are distributed, including the quantity sourced to each. These materials may be used for consumption by households, or as intermediate inputs by industry for subsequent industrial production processes.	Physical, and if available, monetary unit

Data collection efforts included literature review and outreach to industry associations for the nine material categories selected for the project. EPA contacted representatives at industry associations and organizations through e-mail and telephone calls to describe the project’s data requirements and establish initial communication. Additionally, contact was established with working groups within EPA that could provide

information relevant to this study, including information on electronics recycling, reuse and remanufacturing, food donation and organics recycling. A list of organizations and industry associations contacted is provided in Table 4.

Table 4: 2016 REI Study Data Collection Outreach

Material	Organization / Industry Association
Ferrous Metals	Institute of Scrap Recycling Industries, Inc. (ISRI) Steel Recycling Institute (SRI)
Nonferrous Metals	The Aluminum Association
Plastic	American Chemistry Council (ACC) The Association of Postconsumer Plastic Recyclers (APR) Society of the Plastics Industry (SPI) KW Plastics
Rubber	Rubber Manufacturers Association
Glass	Glass Packaging Institute Container Recycling Institute
Paper	American Forest and Paper Association (AF&PA) American Wood Council (AWC) U.S. Department of Agriculture (USDA)
Construction & Demolition	Construction & Demolition Recycling Association
Electronics	Electronics TakeBack Coalition
Organics	BioCycle

Key data sources included in the literature review include the following U.S. Government Reports:

- EPA ORCR’s Municipal Solid Waste Generation, Recycling and Disposal report for 2012 containing figures for all nine product categories in the United States (USEPA, 2014)
- EPA report on Electronics Waste Management in the United States (USEPA 2011)
- EPA documentation for the Waste Reduction Model (WARM) (USEPA, 2015b)
- EPA studies of food waste loss, diversion and donation in the US (USEPA, 2009b; USEPA 2013; USEPA, 2014b; USEPA 2015b)
- EPA’s Anaerobic Digestion and its Applications (USEPA 2015e)
- USGS Minerals Yearbook containing recycling figures for ferrous and nonferrous metals (USGS, 2006; USGS, 2010a; USGS 2010b; USGS, 2013; USGS, 2014)
- U.S. International Trade Commission’s report on Used Electronic Products (USITC, 2013)

- USDA Consumer-level Food Loss estimates (USDA, 2011)

Industry Association Reports:

- Bureau of International Recycling's world steel recycling reports for ferrous metals (BIR, 2013) and non-ferrous metals (BIR, 2012)
- Reports from the Aluminum Association (Aluminum Association, 2011)
- Reports from the American Chemistry Council on plastics recycling (ACC, 2009; ACC, 2014; ACC, 2015a; ACC, 2015b)
- Publications from the National Renderers Association (Meeker, 2006)
- Container Recycling Institute's report on U.S. beverage container recycling rates and trends (CRI, 2013)
- Rubber Manufacturers Association reports on scrap tire recycling (RMA 2009; RMA, 2014)
- Glass Packaging Institute's report on glass recycling (GPI, 2014)
- Annual Statistical Summary of Recovered Paper Utilization report from the American Forest and Paper Association (AFPA, 2014)

Other Reports:

- Tellus Institute and Sound Resource Management Group, Inc.'s report on Growing the Recycling Economy in the U.S. (Tellus Institute, 2011)
- Institute for Local Self-Reliance's report on the State of Composting in the U.S. (Platt et al. 2014)

These reports were used to collect information on production volumes, recycling statistics and the recyclable material proportions. For information on recycling process inputs, mass-based and monetary-based data were gathered from Life Cycle Inventory datasets such as EcolInvent v.3.0, U.S. LCI and CEDAv.4.8.

Mass-based inputs are direct inputs (in physical units) that go into production of 1 kg of the material, and monetary-based inputs are direct inputs (in dollar values) that go into production of \$1 of the material. Industry associations provided review and comments on the input structure information for their industry and were able to supply alternate data when available. While the input structure in some cases was specific to inputs of a recycled product (such as inputs to 1 kg of 100% recycled graphic paper), in other cases input information was available for the product in general (such as inputs to \$1 of synthetic rubber manufacturing).

The purpose of this exercise was to provide industry associations with an approximation of the input structure for the products being analyzed, and to request more accurate or complete information if available. When better information was not available the existing input structure was used as proxy data to build the WIO model.

In two cases alternate input structure data was available from industry: for aluminum, from the Aluminum Association's report on The Environmental Footprint of Semi-Finished Aluminum Products in North America (2010) (Aluminum Association, 2013) and for corrugated cardboard products from the NCASI report on Life Cycle Assessment of U.S. Average Corrugated Product (NCASI, 2014).

The efforts coordinating with industry yielded data on the production volumes of recyclable and recycled materials, recycling statistics and input structures. However, data describing distribution of recyclables and recycled materials to other sectors and geographically was not readily available.

3.2. Summary of Collected Data

3.2.1. Recycling Process Data

Some recycling process data were obtained directly from industry associations, while other data are supplied as proxy data from life cycle inventory databases. Table 5 summarizes data received by industry associations and data gaps that were filled using proxy data garnered from life cycle data.

Table 5: Type of Data Received

Material	Production of recyclables	Distribution of recyclables	Production of recycled	Distribution of recycled	Inputs and outputs of recycling
Ferrous metals	✓	✓	✓	✓	Proxy data
Nonferrous metals	✓	Proxy data	✓	Proxy data	✓
Plastic	✓	✓	✓	✓	Proxy data
Rubber	✓	✓	✓	✓	Proxy data
Glass	✓	✓	✓	Proxy data	Proxy data
Paper	✓	✓	✓	✓	✓
Construction and demolition material	✓	✓	✓	✓	Proxy data
Electronics	✓	✓	✓	✓	Proxy data
Food and organics	✓	✓	✓	✓	Proxy data

Proxy data are needed when there are incomplete full life cycle analyses done by the particular material sectors. Table 5 demonstrates that only aluminum and paper have complete recycling flow of the inputs and outputs of recycling for their industry. Given the complex, heterogeneous nature of food and organics category material and monetary flows and fundamental differences between food donation and organics recycling, the WIO model (and associated data collection efforts) incorporated a higher level of granularity. Donated food was characterized in terms of three categories: gleaned produce, rescued food and salvaged food.⁴ Recyclable organics were subdivided into nine additional categories, including eight categories

⁴ In some figures and tables used in this report, salvaged food and rescued food are combined into a single category, “salvaged and rescued food” for brevity.

associated with food production, processing, distribution, preparation and waste and one category associated with yard trimmings (e.g., grass clippings and branches). All categories were defined to be mutually exclusive. A high-level depiction of material (and monetary) flows associated with the food and organics category is shown in Figure 7. Definitions of the twelve food and organics categories are included in Appendix D – Recycling Process Allocation Assumptions.

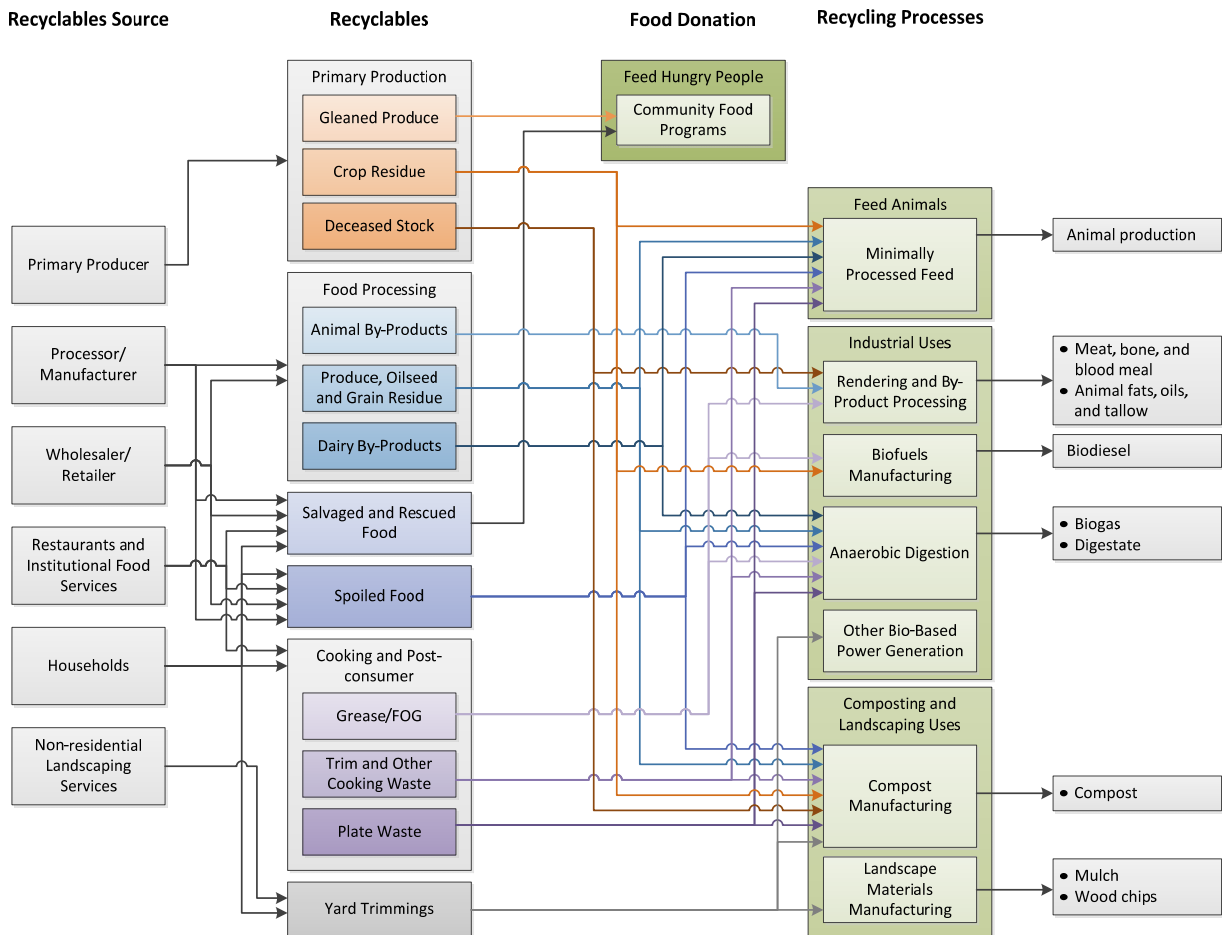


Figure 7: Overview of food and organic material (and monetary) flows

3.2.2. *Economic Data*

Employment, wage, occupation and tax revenue data were collected from publicly available sources for the U.S. economy for the baseline model year 2007. Data were associated with the economic sectors used in the BEA I-O tables to form a model of employment and tax payments for the entire economy as the basis for estimating economic activity attributable to recycling using the four approaches described in. Table 6 lists the sources of employment and tax data. Table 6 summarizes the data, aggregated to major economic sectors. Appendix F – Employment and Tax Revenue Data Compilation describes the economic data collection methodology in greater detail.

Table 6: Economic Data Sources by Economic Sector

Sector	Associated Activities	Jobs and Wages	Occupational Profile	Tax Payments
Agriculture	<ul style="list-style-type: none"> • Crop and animal production 	2007 U.S. Census of Agricultural (USDA 2009)	2007 Occupational and Employment Statistics (USBLS, 2007)	2007 U.S. Statistics of Income (USIRS, 2007)
Nonfarm private industry	<ul style="list-style-type: none"> • Forestry, fishing and agricultural support services • Mining, quarrying, oil and gas extraction, utilities and construction • Manufacturing • Wholesale and retail trade • Transportation and warehousing • Services (except government) 	2007 Statistics of U.S. Businesses (U.S. Census Bureau, 2007b)	2007 Occupational and Employment Statistics (USBLS, 2007)	2007 U.S. Statistics of Income (USIRS, 2007)
Government	<ul style="list-style-type: none"> • Federal government • State government • Local government 	2007 Annual Survey of Public Employment and Payroll (U.S. Census Bureau, 2007a)		

Table 7: Summary of Employment and Tax Revenue Data Used in the WIO Model, U.S. 2007

Sector	Total Employment	Total Wages (\$ million)	* Mgmt	* B&L	* STEM	* S&A	* P&T	* EH&O	Total Tax Payments (\$ million)
Crop and animal production	5,973,955	\$46,235	2%	0%	1%	6%	90%	2%	\$2,916
Forestry, fishing and agricultural support services	172,105	\$5,564	2%	0%	1%	6%	90%	1%	\$976
Mining, quarrying, oil and gas extraction, utilities and construction	8,586,544	\$427,574	5%	3%	3%	12%	77%	0%	\$80,049
Manufacturing	13,275,432	\$624,422	5%	3%	8%	13%	70%	1%	\$158,152
Wholesale and retail trade	20,057,919	\$668,528	3%	2%	2%	64%	23%	6%	\$140,625
Transportation and warehousing	4,351,460	\$173,908	3%	2%	1%	22%	69%	4%	\$28,540
Services (except government)	72,006,244	\$3,063,248	5%	7%	6%	25%	17%	40%	\$342,034
Government	22,116,019	\$942,997	5%	13%	8%	19%	37%	18%	---**
Total	146,539,678	\$5,952,479	5%	6%	6%	27%	34%	23%	\$753,296

* **Occupational Profile** (% employment by category)

* Key to Occupational Profile (see Appendix E for crosswalk with BLS occupational categories):

- Mgmt: Management occupations
- B&L: Business and legal occupations
- STEM: Science, technology and engineering occupations
- S&A: Sales and office administration occupations
- P&T: Production, building services and transportation occupations
- EH&O: Educational, health care and other service occupations

** Does not include inter-governmental transfers

Economic data were allocated to recycling processes based on statistics and other information regarding recyclable material production, distribution and proportions for the nine material categories included in the model. To the extent possible, data were collected to represent conditions as they existed for the baseline model year 2007.

Recyclable material production data were collected from industry sources and publicly available reports, as described in Section 3.1. The distribution of recyclables was modeled by identifying the major consuming sectors of recyclable materials and/or by identifying major intermediate and end-uses of recyclables and the economic sectors in which the associated recycling processes take place. Recycling material proportions were estimated based on statistics and other publicly available information on virgin and recyclable material flows associated with each recycling process.

Material-specific summaries of assumptions were also developed and distributed to the industry organizations listed in Table 7 for review. Feedback from these organizations was used to modify assumptions based on verifiable data sources and/or was used to help interpret the results of the analysis. Appendix D contains the material-specific summaries of assumptions, amended based on comments received from industry associations and other organizations.

3.3.Challenges and Limitations

EPA faced several data challenges and limitations during the data collection process. While best efforts were made, it is acknowledged that data used in the study will need to be refined in the future.

One of the challenges in collecting data for different material categories was that the type of data collected from different sources varies by year, by units (e.g., short tons, pounds) as well as by type (e.g., mass-based or monetary-based). Where data were expressed in different units, conversion factors were applied to convert from one unit to another. For consistency, metric tons was applied throughout as the mass unit and the dollar (USD) was used as the monetary unit. While efforts were made to find and use price data of recyclables and recycled products for the study baseline year – 2007 – in some cases price data were selected from a different year which might not be the best representation of the price of that recyclable/recycled material during 2007. Price data were also challenging due to the varied definitions of recyclable and recycled materials being applied in public sources and reports. Many such reports do not differentiate clearly between recyclable and recycled materials (e.g., the price of “recyclable glass cullet” is described as the price of “recycled glass”). The price of scrap material, in many cases, is represented as the price of the recycled material, which is inaccurate.

During the data collection process, data sources were limited to those found in the public domain. Therefore, proprietary data were outside the scope of the data collection for the study.

Moreover, while nine major material categories were targeted for data collection, obtaining data for each overall category itself, such as for recycled paper or recycled plastics, was fairly uncommon. For instance, production volumes and recyclable and recycled material data for ‘plastics’ was not available. Data availability differed by the type of plastic (i.e. plastic bag and PE films, plastic bottles, postconsumer non-bottle rigid plastics and plastic polymer type such as polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), low density polyethylene (LDPE) or polypropylene (PP)) and were aggregated.

Similarly, for construction and demolition materials, data on recyclable quantities was available by the type of material consumed. For paper, data collection was focused on recycled paperboard, and recycled paper amounts were estimated using commodity outputs of industrial sectors related to paper production. For the glass product category, data collection efforts focused on glass beverage containers as data for other types of glass were not readily available. Data collection for rubber products focused on ground rubber produced from scrap tires and other rubber recovered from scrap tires used in civil engineering, reclamation and agricultural applications. Electronic items such as computers, monitors, hard copy devices, keyboards, mice, televisions and mobile devices were considered for data collection for electronics. Ferrous metals data collection was conducted for steel products, and non-ferrous metals data collection was conducted for aluminum products such as aluminum scrap from used beverage cans, other containers, transportation, construction and other sources.

For food and organics, data were collected for each of the twelve sub-material categories shown in Appendix D – Recycling Process Allocation Assumptions. Donated food and many organic products do not have a price value (e.g., donated food is given away for free, and some food waste and yard trimmings are diverted from municipal solid waste). Unit price information was only available for grease, animal-by-products and dairy-by-products. In addition, obtaining data on physical inputs to recycled material was a challenge and in many cases assumptions were required to estimate inputs (see Appendix D – Recycling Process Allocation Assumptions).

Finally, some of the economic data used in the analysis is only available at an aggregated industry level. For these situations, the project team used other information to allocate data. For example, the U.S. Census of Agriculture reports total farm employment and wage data, but does not break down these data by type of farm product. This finer resolution is required to associate farm employment and wage data to the BEA I-O classification system. The U.S. Census of Agriculture does break down market value of agricultural products at an adequate level to associate the data with specific BEA I-O codes. Therefore, the proportion of market sales associated with different sectors of the agricultural economy was used to apportion total employment and wage data. Additional details regarding the methods used to address these data limitations are described in Appendix A.

4. Results

4.1. Overview

Using the WIO model, for each proposed approach EPA estimated the number of job, wages and tax revenue attributable to recycling.

Table 8 summarizes the estimates of the economic activity attributable to recycling in the base year 2007 using the four approaches described in Section 3. In summary:

- Using the **direct production of recycling approach**, it is estimated that 371,000 of the 147 million jobs in the U.S. economy in 2007 (0.25% of all jobs in the U.S. economy) were directly attributable to recycling. The direct production approach also estimates that recycling activities contributed \$18.7 billion in wages (0.32% of total wages paid) and generated tax revenues of \$3.7 billion (0.50% of the total tax revenues).
- Using the **direct and indirect production of recycling** approach, it is estimated 386,000 jobs can be attributed to indirect activity in the upstream supply chain of recycling. Combining the indirect and direct activities makes a total of 757,000 jobs (0.52% of all jobs in the U.S. economy) attributable to recycling in 2007. The direct and indirect approach also estimates that recycling activities contributed to \$36.6 billion in wages (0.62% of total wages paid) and \$6.7 billion in tax revenues (0.90% of total tax revenues).
- The **recycled content in final demand** approach estimated recycling's contribution to the U.S. economy in 2007 as 3.5 million jobs (2.41% of all jobs in the U.S. economy), \$181 billion wage (3.04% of total wages paid) and \$30.7 billion in tax revenue (4.08% of total tax revenues). This methodology indicates that a more complete accounting of physical flows of recycled material would likely yield higher estimates of recycling's contribution to the U.S. economy than the direct and direct and indirect approaches.
- Looking at the **direct household demand on recycling approach**, the number of jobs, wage and tax revenues attributable to recycling were estimated to be 83,000 (0.06% of all jobs in the U.S. economy), \$3.9 billion (0.07% of total wages paid) and \$694 million (0.09% of total tax revenues), respectively. This low number demonstrates the relative importance of intermediate (direct and indirect), business-to-business flows of recycled materials in the U.S. economy. When intermediate or indirect production is not accounted for, the estimates likely underestimate the contribution of recycling on jobs, wages and taxes.

Table 8: Summary of Overall Job, Wage and Tax Results

Title	Unit	Total Economy	Direct production of recycling approach	Direct and indirect production of recycling approach	Recycled content approach	Direct household demand on recycling approach
Quantity and Value Contribution						
Jobs	# of jobs	146,539,678	371,452	757,325	3,527,304	83,550
Wage	\$1,000	5,952,479,603	18,768,765	36,636,597	181,018,880	3,908,227
Tax	\$1,000	753,296,234	3,743,036	6,795,244	30,747,406	694,178
Percentage Contribution						
Jobs	%	100%	0.25%	0.52%	2.41%	0.06%
Wage	%	100%	0.32%	0.62%	3.04%	0.07%
Tax	%	100%	0.50%	0.90%	4.08%	0.09%
Normalized Contribution Metrics (per metric ton)						
Jobs	# jobs/1000 mt	-	0.85	1.73	8.07	0.19
Wage	\$/1000 mt	-	42,935	83,809	414,097	8,940
Tax	\$/1000 mt	-	8,562	15,544	70,337	1,588

* mt = metric ton

Section 4.2 summarizes the results for the direct and indirect production approach. Section 4.3 compares the results of the 2001 and 2016 REI food salvage studies and discusses the significant differences between the two studies, in terms of methods and underlying assumptions. Results for the other three approaches are presented in greater detail in Appendix C.

4.2. Direct and Indirect Production of Recycling Approach

The results from the analysis under the direct and indirect production of recycling approach is summarized in Figure 8, 9 and Figure 10. C&D provides the largest contribution to all three categories considered (job, wage and tax revenue), followed by ferrous metals and non-ferrous metals (aluminum). It is notable that the relative proportion of shares by the nine materials are kept stable between the *direct production of recycling* and *direct and indirect recycling production* approaches, while the absolute amounts are bigger under the *direct and indirect production of recycling* approach (Figure 11).

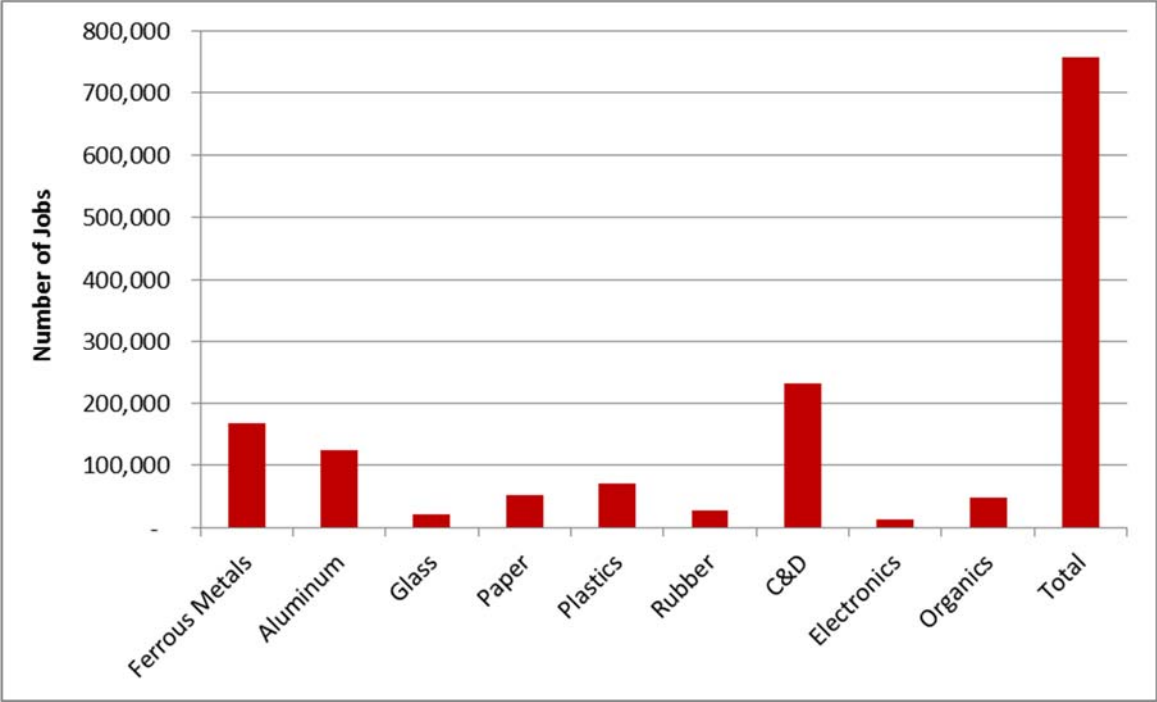


Figure 8: Employment results for the direct and indirect production of recycling approach

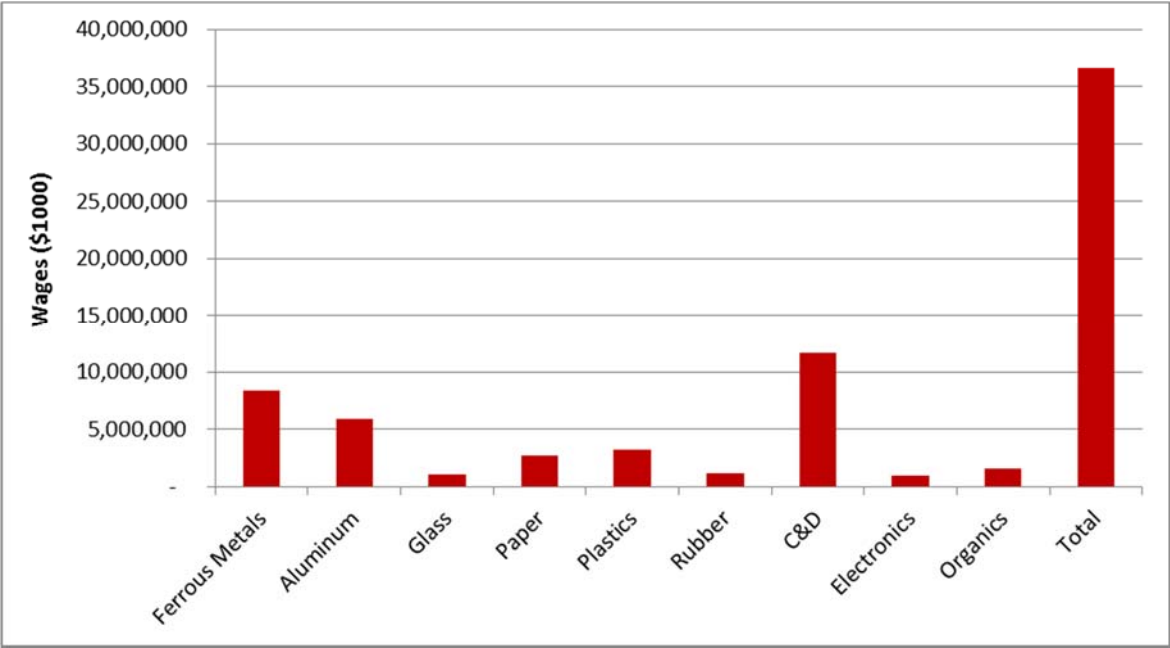


Figure 9: Wage results for the direct and indirect production of recycling approach

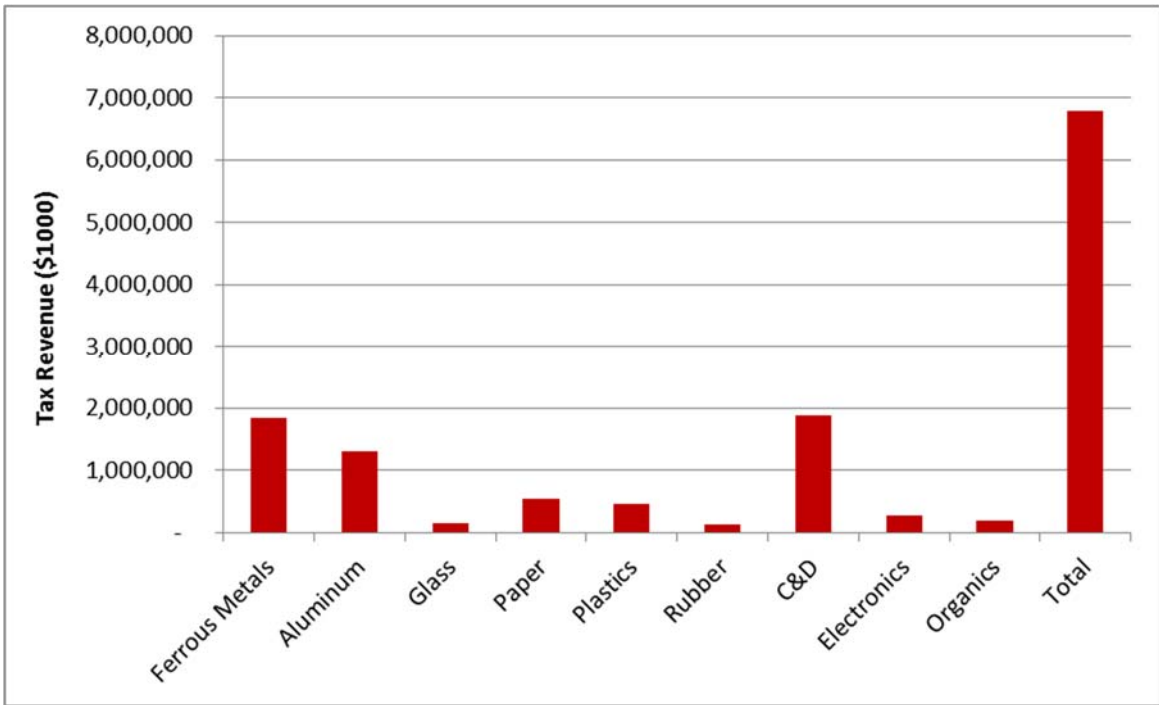
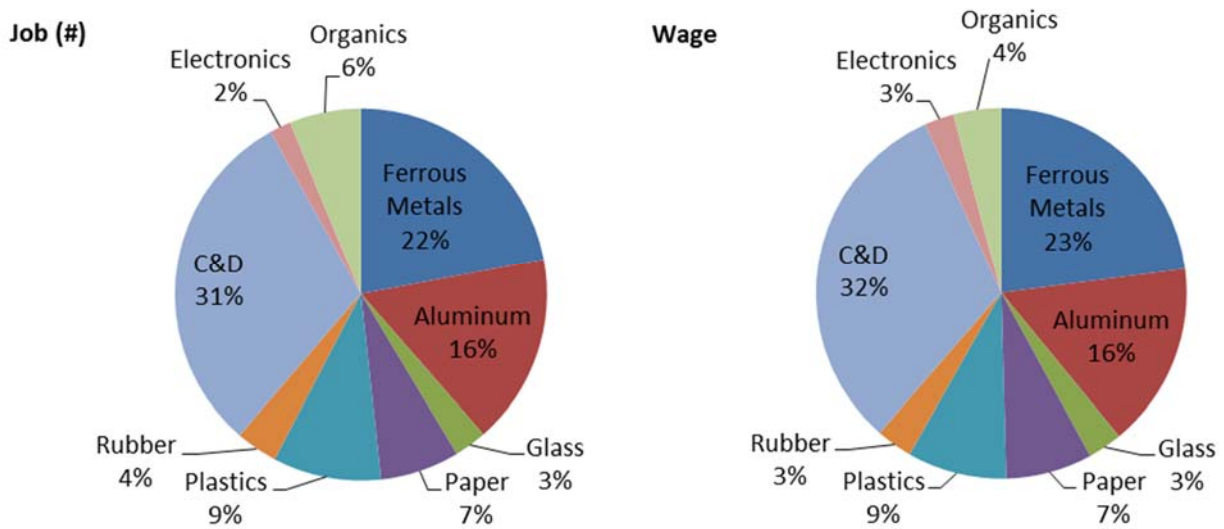


Figure 10: Tax Revenue results for the direct and indirect production of recycling approach



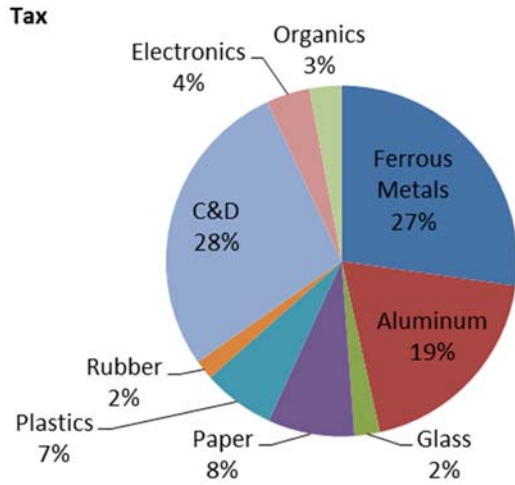
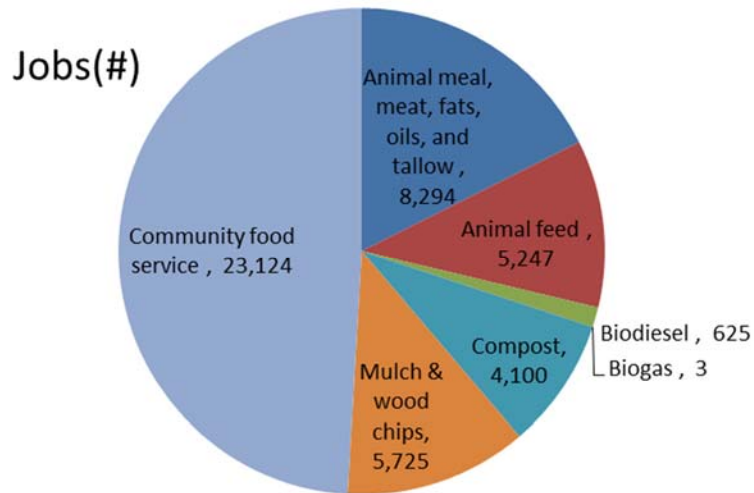


Figure 11: Share of recycling's job creation, wage and tax revenue by material (direct and indirect production of recycling approach)

Since the organics material category comprises a heterogeneous material stream, a breakdown of direct and indirect employment numbers, wages and taxes associated with the seven different sub-material types is shown in Figure 12.⁵ The total direct and indirect employment (# of jobs) by the organics category is around 47,118, associated wages are about \$1.5 billion and associated taxes are about \$200 million.



⁵ Note that this figure refers to animal meal (blood, bone and meat) and animal fats, oils and tallow since these are recycled products from the rendering sector. Fats, oil and grease is a recyclable material flow (see Figure 8).

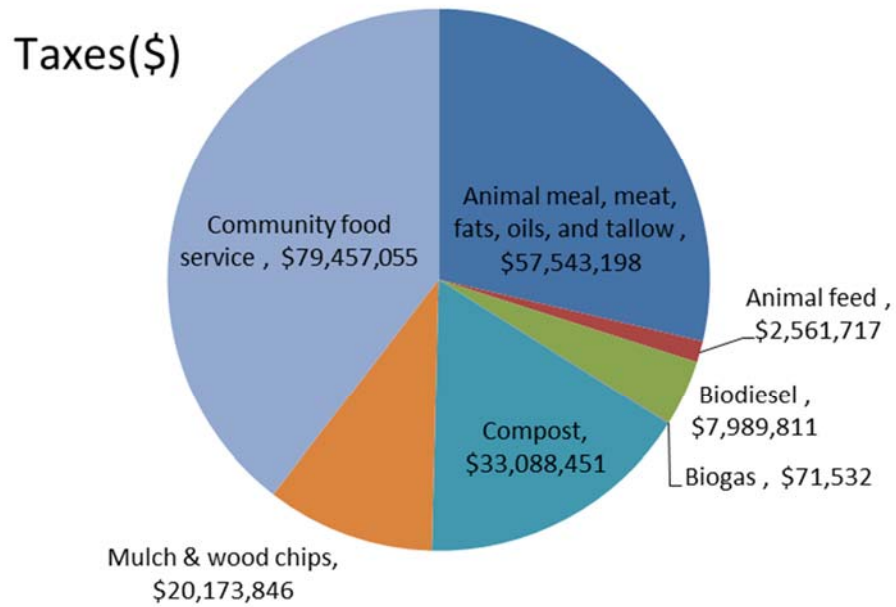
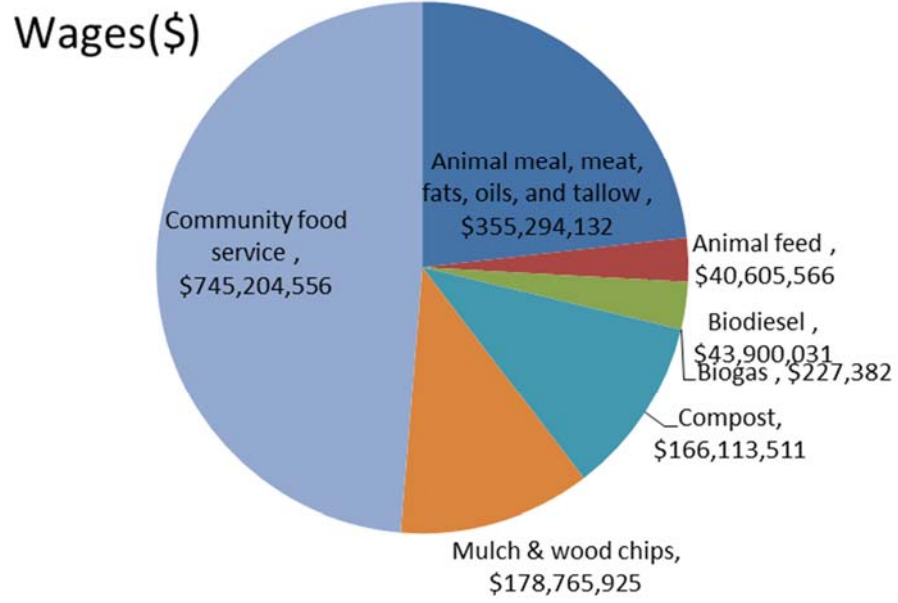


Figure 12: Share of direct and indirect employment numbers (# of jobs), wages (\$) and taxes (\$) by organics recycling

4.3 Comparison of 2016 REI Study and the 2001 REI Study

Of the four approaches included in this current study, the *direct and indirect production of recycling* approach is conceptually most similar to the original 2001 national REI study. However, the current study's estimates of the contributions of recycling to the U.S. economy using the direct and indirect approach are significantly lower than the estimates generated by the 2001 REI study. For example, the 2016 study estimates that recycling activities accounted for 0.5% of the jobs in the U.S. in 2007, directly or indirectly. The 2001 study estimated this figure to be 2.0%. Table 9 summarizes the 2001 REI Report results and the 2016 Report estimates of direct and indirect economic activity attributable to recycling.

Table 9: Comparison Current and Previous REI Studies' Estimates of Contributions of Recycling to U.S. Economic Activity

Metric	2016 REI Report (Direct and Indirect Approach)			2001 REI Report ¹ (Direct and Indirect Estimates)		
	Direct	Indirect	Total	Direct	Indirect	Total
Quantity and Value Contribution						
Jobs	371,452	385,873	757,325	1,121,804	1,377,310	2,499,114
Wage (\$1,000)	\$18,768,765	\$17,867,832	\$36,636,597	\$36,712,482	\$52,275,305	\$88,987,787
Tax Revenue (\$1,000)	\$3,743,036	\$3,052,208	\$6,795,244	\$12,935,000	NR ²	NR ²
Percentage Contribution Relative to Whole U.S. Economy						
Jobs	0.25%	0.27%	0.52%	0.86%	1.06%	1.92%
Wage	0.32%	0.30%	0.62%	1.00%	1.43%	2.43%
Tax	0.50%	0.40%	0.90%	---	---	---

Notes:

¹ Ref. R.W. Beck/NRC (2001), Tables 4-2, 5-1 and 5-6

The 2001 REI study estimates tax revenue associated with direct and total economic activity (direct, indirect and induced); it does not break out a separate estimate tax revenues from indirect activity

As discussed in previous sections of this report, there are several fundamental differences between the original 2001 study and the 2016 REI study that help explain the different results. The most significant differences include:

- *Definition of recycling processes*—the 2001 study included recyclable material collection, processing and related activities (e.g., wholesaling) in its definition of recycling processes and estimates of recycling direct economic contributions. The 2016 study does not classify these activities as recycling processes. Rather, recyclable material collection, processing and related activities are defined as upstream supply chain processes. Using the relationships defined in the WIO model, they are included in the estimates of indirect economic activity attributable to recycling.
- *Scoping approach*—in the 2001 study industry sectors directly or indirectly engaged in recycling were identified *a priori* based on the methodology established in earlier REI studies and recommended by NERC (NERC, 1998). The 2016 study identified the scope of recycling activity using a materials flow approach. Recyclable materials were selected *a priori* and industries directly engaged in recycling were identified based on government and industry information documenting the flows and destination of these materials. Industries indirectly engaged in recycling were identified using the WIO model.
- *Proportioning economic factors*—the two studies used a different approach for apportioning jobs and wages associated with processes that use a mix of recyclable and virgin material feedstocks. The 2001 study counted all jobs (and associated wages) engaged in processing recyclables regardless of the mix of recyclable and virgin materials in the process. The 2016 study apportioned jobs and wages according to the mix of recyclables and the virgin materials for which recycles are used as a substitute.
- *Input-output methodology*—the 2001 REI study used a proprietary set of multiplier models created for local and regional economies using the national economic input-output tables, estimates of non-market transactions and local and regional economic data. The WIO model from the 2016 Report uses national I-O tables with peer-reviewed primary factor input multipliers. These differences affect the magnitude of double-counting in the indirect estimates.
- *Base year and recycling trends*— the 2001 study used a base year of 1997 and the 2016 study uses a base year of 2007 (the most recent national data available) to estimate economic activity attributable to recycling. Differences in absolute and relative contributions of recycling to national economic activity between 1997 and 2007 would be affected by changes in conditions such as economic output and employment in different sectors, recyclables recovery, recyclable and recycled material markets, and recycling technology.

Table 10 compares estimates of jobs directly attributable to recycling generated by the two studies to illustrate sources of difference in the estimates, including differences in the scope of industries identified as engaged in recycling and the apportionment of jobs within an industry to recycling processes.

The 2016 study presents a more conservative estimate of the economic activity in the U.S. economy that is directly or indirectly attributable to recycling. The study likely underestimates the direct activity associated with recycling activities due to the empirical methods used to identify recycling processes, more limited definition of the scope of recycling and conservative assumptions used to apportion economic activity to recycling processes. Underestimates of direct activity will have a ripple effect on estimates of indirect activity, resulting in greater underestimation of the total direct and indirect activity attributable to recycling.

The approach taken in the 2016 REI Report to estimate the direct contributions of recycling minimizes the possibility of double-counting.⁶ The 2001 study estimates of the share of U.S. jobs directly attributable to recycling is 0.75%, which is three times the estimate in the 2016 study. Both the original 2001 REI Report and current 2016 REI Report estimates of direct contributions of recycling as a share of national employment are significantly higher than estimates developed for the European Union using similar methodologies.⁷

In terms of indirect estimates, the *direct and indirect production of recycling* approach used in the 2016 study does not eliminate the double-counting issue inherent in the original 2001 REI study, but may significantly reduce its impact on the estimate. Double-counting will offset some of the conservative factors affecting the current 2016 study's estimates of indirect economic activity.

4.4 Model Approach Selection for Communication Purposes

For purposes of communicating the recycling jobs, wages and taxes numbers and the REI story, it was determined that one approach should be selected. The process of selection involved reviewing the four approaches presented in the 2016 REI Methodology Document: direct, direct and indirect (intermediate approach), recycled material flow and the recycled demand by end consumer. The direct production of recycling approach was too one dimensional and limited in its analysis and missed the impact within indirect and upstream industries. The direct and indirect (intermediate) production of recycling approach is the two dimensional analysis that accounts for not only direct, but also upstream supply chain economic activity. The intermediate approach is the closest methodological approach to the original 2001 REI study, but incorporates advances that improve the estimates and limit double-counting. The recycled content in final demand approach was the newly created three dimensional SMM material flow model that needs considerably more data and further independent review and analysis before becoming the 21st century job analysis tool. The direct household demand on recycling approach was an academic exercise to test the model with limited analytical capability for providing a reliable estimate of the impact recycling has on jobs, wages and taxes. EPA's National Center for Environmental Economics (NCEE) gave an informal preliminary review of the draft 2016 REI Report and found the direct, and direct and indirect methodologies the most

⁶ For example, recycling of nonferrous metals and plastics recovered from disassembly of electronic products was not included in estimates of the recycling activity associated with electronics to minimize possibility of double-counting the jobs, wages and tax revenues associated with nonferrous metals and plastics recycling.

⁷ For further comparison, similar studies of the European Union estimated that recycling directly contributed to 0.09% of all jobs in the EU in 2007 (Ecorys, 2012).

appropriate. With those considerations, the intermediate approach (direct and indirect) was selected for the 2016 REI report.

Table 10: Comparison of 2016 REI Report and the 2001 REI Study based on Direct Employment Estimates

Material Category (2016 Study)	Corresponding Industry Category (2001 Study)	Associated NAICS Industry Classifications	2001 Study Recycling Share of Jobs	2001 Study Estimated Recycling Jobs	2016 Study Recycling Share of Jobs	2016 Study Estimated Recycling Jobs	Difference in Jobs Estimate
Ferrous metals	Iron and steel mills	<ul style="list-style-type: none"> • 331111 	81%	118,544	40%	43,183	-75,361
	Iron and steel foundries	<ul style="list-style-type: none"> • 331511 • 331512 • 331513 	96%	126,313	40%	36,071	-90,242
Nonferrous metals	Nonferrous Secondary Smelting and Refining Mills	<ul style="list-style-type: none"> • 331314 • 331423 • 331492 	62%	12,790	27%	4,788	-8,002
	Nonferrous Product Producers	<ul style="list-style-type: none"> • 331421 • 331315 • 331316 • 331319 	45%	36,363	33%	20,039	-16,324
	Nonferrous Foundries	<ul style="list-style-type: none"> • 331521 • 331522 • 331524 • 331525 • 331528 	74%	69,317	26%	17,936	-51,381
	--- ¹	<ul style="list-style-type: none"> • 331422 • 331491 	---	---	23%	6,017	+6,017
Plastics	Plastics converters	<u>Included in both studies:</u> <ul style="list-style-type: none"> • 326112 • 326113 • 326122 • 326160 • 326199 	22%	178,700	4%	30,535	-148,165
		<u>Included in 2001 REI study only:</u> ² <ul style="list-style-type: none"> • 326111 • 326121 • 326130 • 326140 • 326150 • 326191 • 326192 					
	Plastics reclaimers	<ul style="list-style-type: none"> • 325991 	70%	19,411	0% ²	0	-19,411

	--- ¹	<ul style="list-style-type: none"> • 325222 	---	---	4%	651	+651
Material Category (2016 Study)	Corresponding Industry Category (2001 Study)	Associated NAICS Industry Classifications	2001 Study Recycling Share of Jobs	2001 Study Estimated Recycling Jobs	2016 Study Recycling Share of Jobs	2016 Study Estimated Recycling Jobs	Difference in Jobs Estimate
Rubber	Rubber product manufacturers	<ul style="list-style-type: none"> • 326211 • 326220 • 326291 • 326299 	2%	3,917	17,211	12%	+13,294
	Tire Retreaders	<ul style="list-style-type: none"> • 326212 	100%	7,939	5%	410	-7,529
	--- ¹	<ul style="list-style-type: none"> • 237310 • 237990 • 238910 • 238990 	---	---	12%	119,496	+119,496
Glass	Glass container manufacturing plants	<ul style="list-style-type: none"> • 327213 	90%	19,066	23%	3,451	-15,615
	Glass product producers (other recycled uses)	<ul style="list-style-type: none"> • 327212 	13%	4,723	0% ²	0	-4,723
	--- ¹	<ul style="list-style-type: none"> • 327993 	---	---	30%	5,639	+5,639
Paper	Paper, paperboard and deinked market pulp mills	<ul style="list-style-type: none"> • 322121 • 322122 • 322130 	72%	139,375	14%	17,183	-122,192
	Paper-based product manufacturers	<ul style="list-style-type: none"> • 322299 	54%	12,867	0% ²	0	-12,867
Construction and demolition (C&D) material	Pavement mix producers (asphalt and aggregate)	<ul style="list-style-type: none"> • 324121 	25%	3,460	17%	14,457	-1,069
	--- ¹	<ul style="list-style-type: none"> • 115112 • 321219 • 321918 • 324122 • 327310 • 327420 	---	---	2%	2,278	+2,290
Electronics	Computer and electronic appliance demanufacturers	<ul style="list-style-type: none"> • 421690 • 811212 	1%	3,837	0% ²	0	-3,837

Material Category (2016 Study)							
	--- ¹	<ul style="list-style-type: none"> • 333315 • 334111 • 334119 • 334210 • 334220 • 334310 	---	---	3%	8,025	+8,025
Food and Organics	Compost and miscellaneous organics producers	<u>Specified in 2016 study:</u> ³ <ul style="list-style-type: none"> • 112210 • 221119 • 311613 • 325199 • 325314 • 561730 • 624210 	--- ³	31,718	4%	36,118	+4,400
Other Industries Not Included in 2016 Study	Residential curbside collection	<ul style="list-style-type: none"> • 562111 	24%	32,010	0% ⁴	0	-32,010
	Materials recovery facilities	<ul style="list-style-type: none"> • 562920 	100%	14,155	0% ⁴	0	-14,155
	Recyclable material wholesalers	<ul style="list-style-type: none"> • 421930 	100%	114,992	0% ⁴	0	-114,992
	Other recycling processors/manufacturers	Not specified	--- ³	14,901	0%	0	-14,901
	Motor vehicle parts (used)	<ul style="list-style-type: none"> • 421140 	100%	45,807	0%	0	-45,807
	Retail used merchandise sales	<ul style="list-style-type: none"> • 453310 	100%	97,965	0%	0	-97,965
	Wood reuse (not C&D)	<ul style="list-style-type: none"> • 321920 • 321999 	10%	9,109	0%	0	-9109
	Materials Exchange Services	<ul style="list-style-type: none"> • 541990 	1%	186	0%	0	-186
	Other Reuse	<ul style="list-style-type: none"> • 421810 • 421820 	22%	4,340	0%	0	-4,340

		• 421830					
		Total Direct Employment Estimates	---	1,121,804	---	335,317	-786,487

Notes:

¹ Industry identified in as 2016 study but not 2001 study as including enterprises engaged in recycling (see Appendix C).

² Industry not identified in 2016 study as including enterprises engaged in recycling (see Appendix C).

³ Industrial sectors not specified in original 2001 study; recycling share of jobs in industry(ies) based on the 2001 study cannot be calculated.

⁴ Jobs associated with industry captured as “indirect” employment in 2016 study based on supply chain relationships to recycling processes.

5. Recommendations for Future Studies

5.1. Conclusion

In this study, a waste input-output (WIO) model is developed, which focuses on nine material categories, to estimate related employment, wages and tax revenues attributable to recycling, reuse and food donation in the United States. Four alternative approaches were employed in estimating recycling's impact on the U.S. economy. These approaches include the *direct production of recycling*, *direct and indirect production of recycling*, *recycled content in final demand* and *direct household demand on recycling* approaches. Of the four approaches, the *direct and indirect production of recycling* approach was chosen to communicate the results as it best modeled the impact recycling has on the economy, including intermediate and upstream impacts, while limiting the impact of double-counting on the estimates of jobs, wages and taxes.

The results from the four estimating strategies show that recycling in the nine material categories employs 0.06% (based on the direct household demand on recycling approach), 0.52% (based on the direct and indirect production of recycling approach) and 2.41% (based on the recycled content approach) of the national workforce. Due to the significance of recycling and demand by intermediate industry, the results from the *direct household demand on recycling approach* did not provide useful insights on the overall recycling activities and their roles in the U.S. economy.

Overall, the *recycled content in final demand* approach consistently shows substantially higher estimates of recycling's contributions to economic activity because the approach is based on the physical presence of recycled materials in consumer products. The other approaches are based on the monetary share of recycling activities and the monetary transactions between industries. Given that prices of recyclables and recycled materials are often lower than those of virgin materials, the estimates do not correspond to the physical volume of recycled materials and the production and consumption activities that they enable.

In all cases, the recycling of metals (ferrous and non-ferrous) and construction and demolition (C&D) materials are identified as the most significant contributors to the national economy. The other materials assessed included plastics, rubber, glass, paper, electronics and food and organics.

The results highlight the importance of recycling's role in providing physical materials to the national economy. These impacts may be considerably larger than the volume of monetary transactions indicate.

5.2. Other Applications of the WIO Model

This project is the first attempt to construct a WIO model for the United States. As such, there are several limitations in the 2016 REI Report WIO model (see Section 3). Higher quality data would significantly improve the accuracy of the estimates of the model.

The WIO model could eventually be used to estimate the broader economic and environmental benefits associated with recycling. The model could be used to conduct first-order counterfactual ("what-if") scenario analyses where the economic impacts of different recycling and waste management strategies could be evaluated (e.g., in terms of shifts in employment from extractive to recycling industries). The framework could also be used to quantify the benefits of recycling with regard to greenhouse gas (GHG) emission reduction, energy, employment and other environmental and social metrics.

In other countries, WIO models have been utilized for Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and waste management planning (Nakamura et al., 2007; Nakamura and Kondo, 2009; Kondo and Nakamura, 2004; Takase et al., 2005; Nakamura and Kondo, 2002; Ecorys, 2012).

The basic idea of distinguishing materials, wastes, recyclables and recycled flows in an input-output table can also be applied to sustainable resource management policy. A well-constructed hybrid-unit WIO model serves as a map that shows how resources are extracted, transformed, distributed, deposited and discarded in and out of a national economy. Such a tool is indispensable for understanding the materials metabolism of a national economy and identifying potential areas for resource efficiency improvement.

5.3. Areas for Future Study and Refinement

Resource efficiency is recognized as an important strategy for a competitive economy, and many countries and authorities are actively developing new strategies toward resource efficiency. EPA established a vision for improving resource efficiency in the U.S. in the Sustainable Materials Management, The Road Ahead report (USEPA, 2009a), and is pursuing several strategic initiatives to foster SMM (USEPA, 2015d). The European Commission issued a roadmap toward a circular economy in April 2015 (European Commission, 2015), and a new and comprehensive strategy document and policy to achieve a circular economy (<http://ec.europa.eu/environment/circular-economy>).

Recycling statistics to support future research can be greatly improved with additional data collection efforts focused on the following topics:

- Amount, price and source (producing parties) of recyclables by materials
- Amount, price and destination (consuming parties) of recycled materials
- Inputs needed to process recyclables and to produce recycled materials

In addition, developing a standard definition of recycling processes and system boundaries would be beneficial for future REI studies. The 2016 WIO framework is capable of being continuously updated and maintained with additional data as they become available. While the framework developed in this study can be applied to regional analyses, it is suggested that estimates be substituted by data specific to a particular region of interest for a more sophisticated economic impact analysis.

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7. Appendix A – Recycling Economic Impact Metrics: Guidance for Policymakers

This appendix is designed to assist state and local government to estimate potential economic impacts of recycling activities based on the framework, methods and data presented in this report using a step-by-step approach.

It is important to note that the calculations presented in this document are designed to provide an approximate assessment of recycling's economic impacts. Due to the limitations of the data and the methodology used, the metrics provided in this document may include significant uncertainties. Estimates produced based on the data below cannot therefore be substituted for a more sophisticated economic impact analysis and data tailored to the particular location and question of interest.

While this study establishes a sound analytical framework for estimating the broader economic and environmental impacts associated with recycling, and could be a useful tool for pursuing more sustainable materials management (SMM), it is acknowledged that the purpose of this study is not for future analyses of EPA's regulatory impacts or for more specific regional analyses. For regional analyses, further detailed local data will be required since the high level of aggregation of the data used in the 2016 report can make the report and analysis better suited to applicability at the national scale rather than at a regional scale.

7.1. Step 1: Determine the Objective of the Study

First, consider the objective(s) of the recycling economic impact analysis, including:

- Who is the audience?
- What level of analytic rigor is required to support the study?
- What are the decisions to be supported by the results, if any?

Identifying the objective(s) informs whether the approaches presented in this guidance can sufficiently accomplish the objective(s), and if so, which approach is most appropriate. For example, if the objective of the study is to estimate with absolute precision the amount of additional tax revenue needed for funding a mission-critical program, then the use of this report is not advisable. On the other hand, if the objective of the study is to acquire a first-cut estimate of recycling's economic benefits, then this report can provide useful information.

7.2. Step 2: Determine the Most Suitable Metric Analysis Approach

Based on the objectives determined in Step 1, navigate through the decision tree in Figure 13, and select an approach to be used for the analysis:

- Is the focus of the study to gauge the size of the economy supported by the physical presence of recycled materials in products (go to Approach 1)⁸, or to measure the economic impact of recycling activities (go to 2)

⁸ Recycled materials' physical presence is larger than their monetary representation in our economy. Consumption of products that incorporate recycled materials induces economic impacts. This approach assumes that direct and

- Is the study interested in the consequence of increasing recycling activities (go to③)⁹, or understanding the economic impacts attributable to the current recycling activities (go to④)¹⁰?
- Is the study focusing only on the direct impact (go to Approach 2)¹¹, or both direct and indirect impact of recycling (N/A)¹²
- Is the study focusing only on the direct impact (go to Approach 2), or both direct and indirect impact of recycling (Approach 3)¹³?

indirect economic impacts of a product is attributable to recycling proportional to the recycled material content of the product measured by weight. See Section 3 for details.

⁹ This section is about predicting the changes that increasing recycling activities will induce. Recycling activities can be increased by increasing recycling rate or by building or expanding recycling facilities.

¹⁰ This section is about allocating current level of economic activities to existing recycling operations. It aims at understanding the role of recycling in the economy as it currently stands rather than predicting the impact of recycling in the future.

¹¹ Direct impact refers to the job, wage and tax revenue generation impacts directly from the recycling operation itself.

¹² The methodology used in this report does not support the calculation of direct and indirect economic consequences of increasing recycling activities. The users are advised to consult economic impact analysis professionals in this case.

¹³ This approach calculates the direct and indirect economic impacts attributable to existing recycling operations.

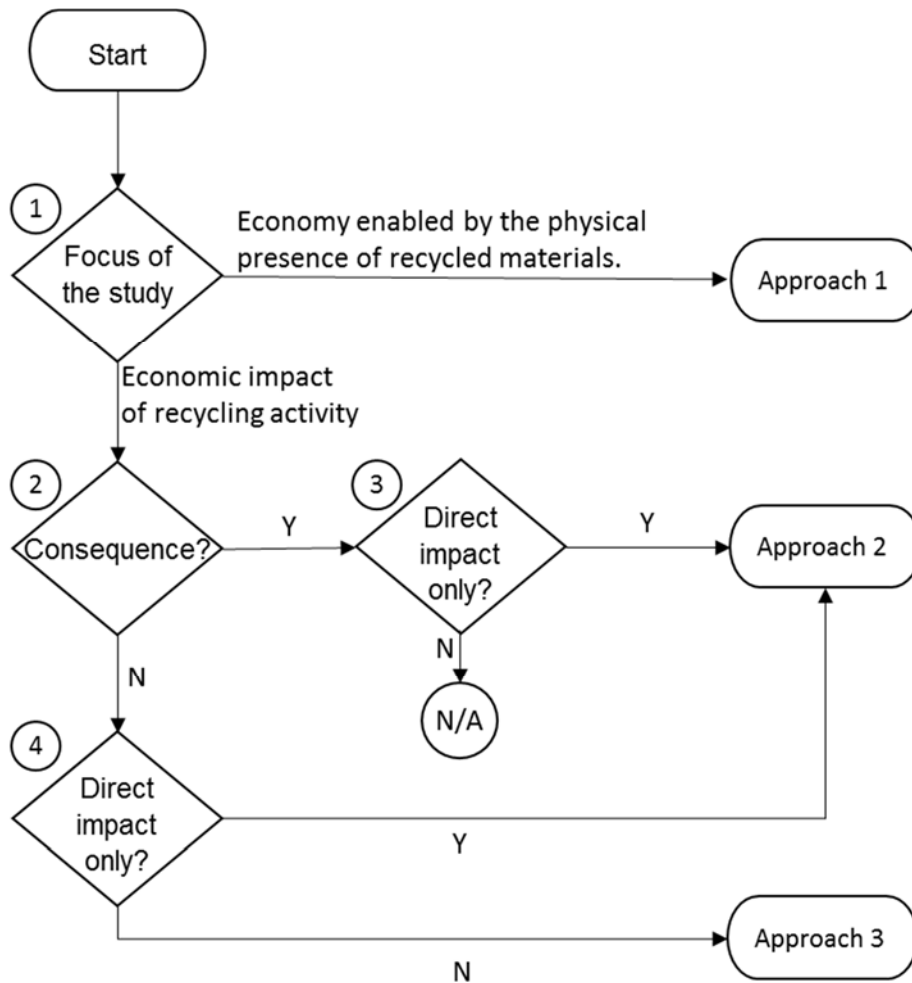


Figure 13: Flow Diagram for Determining the Most Suitable Metrics Approach

7.3.Step 3: Data Preparation

Once the approach is selected in Step 2, required data for calculation needs to be compiled.

- Approach 1 ('recycled content in final demand' approach) requires the amount of products consumed within the system of interest in monetary value (in 2007 dollars). Table 11 shows the list of products for which default recycled material content, job intensity, wage intensity and tax revenue intensity are calculated.
- Approach 2 ('direct production of recycling' approach) requires the amount of additional or current amount of materials recycled for each of the nine material categories in metric tons. Table 12 shows job intensity, wage intensity and tax revenue intensity for Approach 2.
- Approach 3 ('direct and indirect production of recycling' approach) requires the amount of materials recycled for each of the nine material categories in metric tons. Table 13 shows job intensity, wage intensity and tax revenue intensity for Approach 3.

7.4.Step 4: Impact Calculation

Once the required data is prepared, use the corresponding table to calculate the impact of interest.

- For Approach 1 ('recycled content in final demand' approach):
 - Multiply the amount of product consumed in 2007 USD by the percentage of recycled content in Table 11 and by any of the three intensity metrics (Direct and indirect job intensity, Direct and indirect wage intensity (\$/\$), or Direct and indirect tax intensity (\$/\$)) in Table 13.
- For Approach 2 ('direct production of recycling' approach):
 - Multiply the quantity of recycled material of interest, measured in metric tons, by the respective economic impact metrics in Table 12.
- For Approach 3 ('direct and indirect production of recycling' approach):
 - Multiply the quantity of recycled material of interest, measured in metric tons, by the respective economic impact metrics in Table 13.

Table 11: Metrics to Implement Approach #1

Commodity Description	Default recycled content	Direct and Indirect job intensity (job/\$)	Direct and indirect wage intensity (\$/\$)	Direct and indirect tax intensity (\$/\$)
Health care structures	2.8%	1.6E-05	0.74	0.08
Manufacturing structures	2.8%	1.9E-05	0.84	0.09
Power and communication structures	2.8%	6.3E-06	0.32	0.05
Educational and vocational structures	2.8%	1.7E-05	0.76	0.09
Highways and streets	2.8%	8.9E-06	0.47	0.08
Commercial structures, including farm structures	2.8%	1.9E-05	0.86	0.10
Other nonresidential structures	2.8%	7.2E-06	0.35	0.05
Single-family residential structures	2.8%	1.1E-05	0.47	0.06
Multifamily residential structures	2.8%	7.9E-06	0.35	0.05
Other residential structures	2.8%	7.7E-06	0.33	0.05
Mineral wool manufacturing	25.0%	9.2E-06	0.45	0.08
Iron and steel mills and ferroalloy manufacturing	38.5%	8.1E-06	0.43	0.09
Steel product manufacturing from purchased steel	38.5%	1.0E-05	0.48	0.09
Alumina refining and primary aluminum production	19.6%	8.6E-06	0.43	0.09
Aluminum product manufacturing from purchased aluminum	19.6%	1.1E-05	0.54	0.11
Plate work and fabricated structural product manufacturing	50.3%	1.1E-05	0.52	0.09
Ornamental and architectural metal products manufacturing	50.3%	1.2E-05	0.55	0.09
Power boiler and heat exchanger manufacturing	50.3%	9.7E-06	0.50	0.08
Metal tank (heavy gauge) manufacturing	26.0%	1.1E-05	0.51	0.08
Metal can, box and other metal container (light gauge) manufacturing	47.0%	1.0E-05	0.49	0.10
Hardware manufacturing	50.3%	1.1E-05	0.52	0.08
Spring and wire product manufacturing	50.3%	1.2E-05	0.55	0.09
Turned product and screw, nut and bolt manufacturing	50.3%	1.1E-05	0.52	0.07
Valve and fittings other than plumbing	50.3%	9.9E-06	0.49	0.08
Plumbing fixture fitting and trim manufacturing	50.3%	8.5E-06	0.40	0.08
Ball and roller bearing manufacturing	50.3%	9.3E-06	0.45	0.07
Ammunition, arms, ordnance and accessories manufacturing	50.3%	8.7E-06	0.44	0.07
Fabricated pipe and pipe fitting manufacturing	50.3%	9.8E-06	0.47	0.08
Other fabricated metal manufacturing	50.3%	1.1E-05	0.52	0.08
Farm machinery and equipment manufacturing	63.4%	9.4E-06	0.45	0.08

Commodity Description	Default recycled content	Direct and Indirect job intensity (job/\$)	Direct and indirect wage intensity (\$/\$)	Direct and indirect tax intensity (\$/\$)
Lawn and garden equipment manufacturing	63.4%	1.1E-05	0.48	0.09
Construction machinery manufacturing	63.4%	9.3E-06	0.46	0.09
Mining and oil and gas field machinery manufacturing	63.4%	9.4E-06	0.48	0.08
Other industrial machinery manufacturing	63.4%	1.1E-05	0.57	0.08
Plastics and rubber industry machinery manufacturing	63.4%	1.1E-05	0.56	0.08
Semiconductor machinery manufacturing	63.4%	8.7E-06	0.51	0.08
Vending, commercial laundry and other commercial and service industry machinery manufacturing	63.4%	1.0E-05	0.50	0.08
Office machinery manufacturing	63.4%	9.1E-06	0.49	0.08
Optical instrument and lens manufacturing	63.4%	9.9E-06	0.54	0.07
Photographic and photocopying equipment manufacturing	63.4%	7.4E-06	0.39	0.07
Air purification and ventilation equipment manufacturing	63.4%	1.1E-05	0.48	0.08
Heating equipment (except warm air furnaces) manufacturing	63.4%	1.1E-05	0.51	0.08
Air conditioning, refrigeration and warm air heating equipment manufacturing	63.4%	1.0E-05	0.49	0.09
Industrial mold manufacturing	63.4%	1.2E-05	0.60	0.07
Metal cutting and forming machine tool manufacturing	63.4%	1.0E-05	0.56	0.08
Special tool, die, jig and fixture manufacturing	63.4%	1.3E-05	0.65	0.08
Cutting and machine tool accessory, rolling mill and other metalworking machinery manufacturing	63.4%	1.2E-05	0.63	0.08
Turbine and turbine generator set units manufacturing	63.4%	9.0E-06	0.48	0.08
Speed changer, industrial high-speed drive and gear manufacturing	63.4%	9.7E-06	0.48	0.07
Mechanical power transmission equipment manufacturing	63.4%	9.8E-06	0.49	0.08
Other engine equipment manufacturing	63.4%	1.0E-05	0.51	0.09
Pump and pumping equipment manufacturing	63.4%	8.8E-06	0.45	0.08
Air and gas compressor manufacturing	63.4%	8.9E-06	0.45	0.08
Material handling equipment manufacturing	63.4%	9.6E-06	0.48	0.08
Power-driven hand tool manufacturing	63.4%	8.7E-06	0.41	0.08
Other general purpose machinery manufacturing	63.4%	1.1E-05	0.56	0.09
Packaging machinery manufacturing	63.4%	1.1E-05	0.60	0.08
Industrial process furnace and oven manufacturing	63.4%	1.1E-05	0.55	0.08

Commodity Description	Default recycled content	Direct and Indirect job intensity (job/\$)	Direct and indirect wage intensity (\$/\$)	Direct and indirect tax intensity (\$/\$)
Fluid power process machinery	63.4%	1.0E-05	0.52	0.08
Electronic computer manufacturing	24.7%	5.5E-06	0.32	0.07
Computer storage device manufacturing	24.7%	6.7E-06	0.42	0.08
Computer terminals and other computer peripheral equipment manufacturing	24.7%	8.2E-06	0.49	0.11
Telephone apparatus manufacturing	24.7%	7.5E-06	0.55	0.09
Broadcast and wireless communications equipment	24.7%	7.3E-06	0.45	0.08
Other communications equipment manufacturing	24.7%	8.4E-06	0.43	0.08
Audio and video equipment manufacturing	24.7%	8.4E-06	0.42	0.09
Other electronic component manufacturing	24.7%	1.1E-05	0.52	0.08
Semiconductor and related device manufacturing	24.7%	6.5E-06	0.39	0.07
Printed circuit assembly (electronic assembly) manufacturing	24.7%	1.0E-05	0.52	0.10
Electromedical and electrotherapeutic apparatus manufacturing	24.7%	6.9E-06	0.41	0.07
Search, detection and navigation instruments manufacturing	24.7%	7.8E-06	0.47	0.08
Automatic environmental control manufacturing	24.7%	8.8E-06	0.45	0.07
Industrial process variable instruments manufacturing	24.7%	9.1E-06	0.49	0.08
Totalizing fluid meter and counting device manufacturing	24.7%	9.2E-06	0.47	0.09
Electricity and signal testing instruments manufacturing	24.7%	8.1E-06	0.53	0.08
Analytical laboratory instrument manufacturing	24.7%	7.9E-06	0.47	0.08
Small electrical appliance manufacturing	16.6%	9.5E-06	0.45	0.08
Household cooking appliance manufacturing	16.6%	1.0E-05	0.46	0.08
Household refrigerator and home freezer manufacturing	16.6%	8.6E-06	0.42	0.07
Household laundry equipment manufacturing	16.6%	1.0E-05	0.47	0.08
Other major household appliance manufacturing	16.6%	8.7E-06	0.42	0.07
Power, distribution and specialty transformer manufacturing	24.7%	8.6E-06	0.41	0.07
Motor and generator manufacturing	24.7%	1.0E-05	0.49	0.08
Switchgear and switchboard apparatus manufacturing	24.7%	8.8E-06	0.45	0.07
Relay and industrial control manufacturing	24.7%	9.1E-06	0.47	0.07
Storage battery manufacturing	24.7%	9.1E-06	0.45	0.07
Primary battery manufacturing	24.7%	8.4E-06	0.42	0.07
Communication and energy wire and cable manufacturing	24.7%	9.1E-06	0.45	0.09

Commodity Description	Default recycled content	Direct and Indirect job intensity (job/\$)	Direct and indirect wage intensity (\$/\$)	Direct and indirect tax intensity (\$/\$)
Wiring device manufacturing	24.7%	9.0E-06	0.43	0.07
All other miscellaneous electrical equipment and component manufacturing	24.7%	9.8E-06	0.51	0.07
Automobile manufacturing	18.1%	9.2E-06	0.48	0.09
Light truck and utility vehicle manufacturing	18.1%	9.4E-06	0.49	0.09
Heavy duty truck manufacturing	18.1%	1.1E-05	0.52	0.09
Motor vehicle body manufacturing	18.1%	1.2E-05	0.58	0.09
Truck trailer manufacturing	18.1%	1.3E-05	0.56	0.09
Motor home manufacturing	18.1%	1.2E-05	0.57	0.09
Travel trailer and camper manufacturing	18.1%	1.4E-05	0.59	0.09
Motor vehicle gasoline engine and engine parts manufacturing	18.1%	1.1E-05	0.55	0.09
Motor vehicle electrical and electronic equipment manufacturing	18.1%	1.1E-05	0.56	0.09
Motor vehicle steering, suspension component (except spring) and brake systems manufacturing	18.1%	1.1E-05	0.54	0.09
Motor vehicle transmission and power train parts manufacturing	18.1%	1.0E-05	0.54	0.09
Motor vehicle seating and interior trim manufacturing	18.1%	1.2E-05	0.54	0.09
Motor vehicle metal stamping	18.1%	1.0E-05	0.54	0.09
Other motor vehicle parts manufacturing	18.1%	1.1E-05	0.53	0.09
Aircraft manufacturing	11.0%	7.1E-06	0.42	0.06
Aircraft engine and engine parts manufacturing	33.8%	8.0E-06	0.45	0.07
Other aircraft parts and auxiliary equipment manufacturing	33.8%	8.6E-06	0.48	0.06
Guided missile and space vehicle manufacturing	33.8%	7.7E-06	0.51	0.06
Propulsion units and parts for space vehicles and guided missiles	33.8%	8.8E-06	0.56	0.06
Railroad rolling stock manufacturing	41.0%	1.1E-05	0.58	0.09
Ship building and repairing	11.6%	1.2E-05	0.57	0.07
Boat building	7.0%	1.3E-05	0.56	0.09
Motorcycle, bicycle and parts manufacturing	33.8%	9.1E-06	0.46	0.08
Military armored vehicle, tank and tank component manufacturing	33.8%	5.8E-06	0.30	0.06
All other transportation equipment manufacturing	33.8%	1.1E-05	0.51	0.09

Commodity Description	Default recycled content	Direct and Indirect job intensity (job/\$)	Direct and indirect wage intensity (\$/\$)	Direct and indirect tax intensity (\$/\$)
Carpet and rug mills	4.8%	1.3E-05	0.53	0.09
Pulp mills	38.7%	9.1E-06	0.46	0.08
Paper mills	38.7%	9.1E-06	0.46	0.08
Paperboard mills	38.7%	8.9E-06	0.45	0.08
Paperboard container manufacturing	38.7%	1.1E-05	0.54	0.09
Paper bag and coated and treated paper manufacturing	38.7%	9.9E-06	0.49	0.09
Stationery product manufacturing	38.7%	1.0E-05	0.48	0.08
Sanitary paper product manufacturing	38.7%	8.3E-06	0.42	0.08
All other converted paper product manufacturing	38.7%	1.1E-05	0.50	0.08
Asphalt paving mixture and block manufacturing	0.2%	5.3E-06	0.28	0.09
Petrochemical manufacturing	3.4%	5.2E-06	0.27	0.10
Plastics material and resin manufacturing	3.4%	8.0E-06	0.41	0.12
Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	3.4%	9.9E-06	0.47	0.11
Plastics packaging materials and unlaminated film and sheet manufacturing	3.4%	9.8E-06	0.48	0.09
Plastics pipe, pipe fitting and unlaminated profile shape manufacturing	3.4%	1.0E-05	0.49	0.09
Laminated plastics plate, sheet (except packaging) and shape manufacturing	3.4%	8.8E-06	0.43	0.07
Polystyrene foam product manufacturing	3.4%	1.1E-05	0.51	0.09
Urethane and other foam product (except polystyrene) manufacturing	3.4%	1.1E-05	0.48	0.08
Plastics bottle manufacturing	3.4%	9.7E-06	0.45	0.09
Other plastics product manufacturing	3.4%	1.3E-05	0.56	0.08
Tire manufacturing	57.3%	1.1E-05	0.54	0.08
Rubber and plastics hoses and belting manufacturing	1.8%	1.2E-05	0.52	0.07
Other rubber product manufacturing	1.0%	1.2E-05	0.53	0.07

Table 12: Metrics to Implement Approach #2

Material	Employment (jobs / metric ton)	Wages (\$1000 / metric ton)	Tax Revenue (\$1000 / metric ton)
Ferrous metals	0.00238	0.14	0.035
Aluminum	0.03201	1.45	0.415
Glass	0.00443	0.23	0.028
Paper	0.00057	0.04	0.009
Plastics	0.01314	0.51	0.049
Rubber	0.00530	0.22	0.017
Construction and Demolition	0.00038	0.02	0.003
Electronics	0.02066	1.57	0.555
Organics	0.00080	0.02	0.003
Average	0.00085	0.043	0.00856

Table 13: Metrics to Implement Approach #3

Material	Employment (jobs / metric ton)	Wages (\$1000 / metric ton)	Tax Revenue (\$1000 / metric ton)
Ferrous metals	0.0050	0.25	0.056
Aluminum	0.0822	3.87	0.859
Glass	0.0104	0.54	0.077
Paper	0.0017	0.09	0.018
Plastics	0.0295	1.32	0.187
Rubber	0.0076	0.32	0.034
Construction and Demolition	0.00073	0.04	0.006
Electronics	0.0359	2.41	0.701
Organics	0.0010	0.03	0.004
Average	0.00173	0.084	0.01554

8. Appendix B – WIO Model Methodology

8.1. Methodology Introduction

This appendix describes four approaches for measuring the impacts to the U.S. economy attributable to recycling. First, the “direct” approach measures the wage and tax payments made directly by recycling operations. Second, the “final demand” approach uses the multiplier effects of recycling demanded by households, the government and exports. Third, the “recycled content in final demand” approach is a novel method proposed in this report. The approach applies the wage and tax payment multipliers to the portion of the total final demands on material goods that consists of recycled materials. Finally, the “intermediate production” approach applies the wage and tax payment multipliers to the sum of intermediate production for recycled products. To empirically test the differences, a waste input-output (WIO) model is compiled for the U.S., distinguishing recycling operations and recyclable and recycled material flows from other sectors of the economy.

8.2. Methods for measuring the economic impacts of recycling

8.2.1. *Scope and definition of recycling*

The European Environment Agency defines waste recycling as “a method of recovering wastes as resources which includes the collection and often involving the treatment, of waste products for use as a replacement of all or part of the raw material in a manufacturing process” (European Environment Agency 2014). Similarly, the California Department of Resources Recycling and Recovery define recycling as “using waste as material to manufacture a new product” (CalRecycle 2014). Glavič and Lukman (2007) define recycling “as a resource recovery method involving the collection and treatment of waste products for use as raw material in the manufacture of the same or a similar product.”

There are two potential sources of ambiguity in these definitions. First, all of these definitions rely on the term waste. Waste is defined as “objects or materials for which no use or reuse is intended” (CalRecycle 2014). The term waste is not defined in European Environment Agency (2014) or Glavič and Lukman (2007).¹⁴ Given that recycling makes use of what is defined as waste, the no use condition that defines waste in the first place becomes no longer valid as soon as it is intended to be used for recycling.

A way to get around this problem is to assume a temporal gap, in which case recycling can be (re)defined as using what was recognized as waste as material to manufacture a new product. In this case, the temporal dimension becomes important in defining recycling: how many years should one count before recycling becomes a new norm, therefore it can no longer be counted as recycling? Depending on the answer, the

¹⁴ The European Environment Agency’s glossary does provide definitions to related terms such as ‘household waste’ and ‘industrial waste’, which all refer to the term ‘waste’.

entire petrochemical industry, for example, can be characterized as a recycling activity.¹⁵ Likewise, depending on the answer, the use of used aluminum scraps for smelters may no longer be counted as recycling.

The 2007 Communication to the European Parliament distinguishes by-products and wastes (European Commission 2007). In this communication ‘by-product’ is defined as “a production residue that is not a waste” and ‘production residue’ is defined as “a material that is not deliberately produced in a production process.” This definition of by-product conforms well to the term used in production economics and national accounts, where by-products are generally referred to as a potentially marketable product, while the demand of it does not generally increase the overall production activity of the process that produces it (Konijn 1994; United Nations 2008). However, not all by-products are recyclable, and not all recyclable materials are by-products. For example, many recyclable materials are given away for free, or a producer has to pay for hauling recyclable materials away from their facilities, in which case the recyclable materials cannot be referred to as a ‘product.’

Recycling, as it is commonly understood, involves a series of processes such as (1) collection and separation of recyclable materials (collection and pre-processing), (2) transformation of the recyclable materials into marketable products (conversion) and (3) transportation and storage (logistics) associated with them. Many of these processes overlap with ordinary production processes. For example, recycling iron and steel in end-of-life automobile involves dismantling, sorting, compression (hulk making), shredding, cleaning, magnetic separation, transportation and melting through an electric arc furnace (EAF) or basic oxygen furnace (BOF). The question is whether all or only some of these processes should be referred to as recycling. In the literature, recycling is sometimes narrowly defined to include only some of these processes, such as collection and pre-processing, or it can be defined more broadly.

In this report recycling refers to the recovery of useful materials, such as paper, glass, plastic and metals, from the waste stream (e.g., municipal solid waste) to make new products, reducing the amount of virgin raw materials needed to meet consumer demands. Recycling also includes recovery and refurbishing or remanufacturing for reuse of products and materials that have reached the end of their intended useful life.

8.2.2. Direct and multiplier effects

Producing a product requires machinery, raw materials and energy, which in turn requires upstream inputs from their suppliers, the suppliers’ suppliers and so on. The impact of demand on upstream processes throughout the upstream supply chain is referred to as the multiplier effect or ripple effect. The multiplier effect has been commonly calculated using Leontief inverse of an input-output table (Lenzen 2001; Leontief 1951, 1970; Miller and Blair 2009).

Let a product-by-1 vector \mathbf{y} describe the quantity of arbitrary final demand. Let primary factor-by-product matrix \mathbf{B} describe the quantity of primary factor input per a unit product output. Let product-by-product matrix \mathbf{A} describe the quantity of product input per unit of product output. If so, the amount of factor input

¹⁵ Distillation of crude oil for liquid fuel and light oil leaves large volume of ‘waste’, which has been the target for petrochemical industries to identify new uses as feedstock over the last half a century. Under the current definition of ‘recycling’ and ‘waste’, even the entire history of material use in human civilization since Paleolithic era can be said as the history of recycling, i.e., discovery of new uses of ‘waste’ starting from stones.

needed to meet the final demand directly by the production activities that produce them can be noted as \mathbf{By} . The production of these products to meet the final demand will require upstream inputs from their direct suppliers (1st tier upstream input), which can be calculated by \mathbf{Ay} , and the amount of primary factor input directly needed by the 1st tier upstream input can be denoted as \mathbf{BAy} . Likewise, the amount of primary factor input to 2nd, 3rd and n^{th} tier upstream can be denoted as $\mathbf{BA}^2\mathbf{y}$, $\mathbf{BA}^3\mathbf{y}$ and $\mathbf{BA}^n\mathbf{y}$, respectively. If the chain of upstream requirements propagates infinitely, the total factor inputs required to fulfil \mathbf{y} can be calculated as:

$$(1) \quad \mathbf{m} = \mathbf{By} + \mathbf{BAy} + \mathbf{BA}^2\mathbf{y} + \dots + \mathbf{BA}^n\mathbf{y} = \mathbf{B}(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \dots + \mathbf{A}^n)\mathbf{y}$$

for $n \rightarrow \infty$. Let

$$(2) \quad \mathbf{x} = (\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \dots + \mathbf{A}^n)\mathbf{y}.$$

Then, $\mathbf{m} = \mathbf{Bx}$. Multiplying $(\mathbf{I} - \mathbf{A})$ on both sides of (2),

$$(3) \quad (\mathbf{I} - \mathbf{A})\mathbf{x} = (\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \dots + \mathbf{A}^n)\mathbf{y} - (\mathbf{A} + \mathbf{A}^2 + \dots + \mathbf{A}^n)\mathbf{y} = \mathbf{y}.$$

Therefore, $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$ and

$$(4) \quad \mathbf{m} = \mathbf{B}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}.$$

The inverse matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse \mathbf{L} , and \mathbf{BL} is the primary factor multiplier showing direct and indirect primary factor inputs per unit of final demand.

8.2.3. Defining 'demand' in recycling

Multiplier analyses assume that the final and subsequent intermediate demands pull corresponding upstream inputs and that upstream factor inputs are attributable to downstream activities that require them. Therefore, how demand is defined in an input-output table determines the result of a multiplier analysis. In input-output analysis tradition, the supply-demand relationship is easily defined by the flow of payment.

Unlike ordinary products where payment and product flow at the same time in an opposite directions, the flows of recyclables may not always accompany payment or both money and recyclables may flow in the same direction. For example, suppose that a stamping operation for an automotive part produces steel scrap which is hauled away for free by a local recycling center where it is sold to a household light stand manufacturer. In this case, it becomes a question whether the recycling center is the party that demands the recyclable steel from the stamping facility or the stamping facility is the party that demands waste treatment service from the recycling center. If the recycling center is the demanding party, the stamping facility becomes the recycling center's upstream supplier and part of the direct and supply chain impacts of the facility becomes attributable to the recycling center, which will be passed down to the light stand (the question, how much of it is attributable to recycling center will be treated later). If the stamping facility is the

party that demanded the waste management service, part of the recycling center's direct and supply chain impacts are attributable to the stamping facility. The impacts will be passed down to automobiles, but not to light stands.

In this report, the party that makes the payment is assumed to be the demanding party regardless of the direction of the physical flow. In case of no payment, corresponding physical flow is split and allocated equally to waste management service and recyclable material rows of the two columns in the use matrix that represent the two parties (see Section 3.3. for details). For instance, the stamping facility is assumed to have purchased waste treatment service from the recycling center for the half of the stamping scrap it generated, and the recycling center is assumed to have purchased half of the stamping scrap as a recyclable by-product from the stamping facility (c.f., Lenzen and colleagues 2007). For a household and the government the payment for waste management service is assumed to be included either in the tax payment or in the purchase price of the goods from which recyclable products are generated. Therefore, a household and the government are assumed to be the demanding party for all recyclable material flows originating from them.

Another important issue to consider in multiplier analysis is the definition of vector \mathbf{y} in equation (4). Factor multipliers in input-output analysis are designed to be pre-multiplied to a vector of final demand \mathbf{y} . Therefore, the amount of recycled materials produced or the amount of recyclable materials consumed by recycling operations are not proper entry to \mathbf{y} vector in multiplier analyses. It is well known in input-output literature that such a practice generates grossly exaggerated impact results, which have been unfortunately misused in some program evaluation studies and are referred to as "the sin of exaggerating sectorial impacts" (Oosterhaven and Stelder 2002; Dietzenbacher 2005). The reason why the use of intermediate production or consumption leads to an exaggerated multiplier result is that gross production values are counted multiple times. Consider a \mathbf{y} vector of a closed economy for a multiplier analysis using total production volume of glass (\$50 million), steel (\$200 million), engine and automotive parts (\$100 million) and automobile (\$300 million). Among the \$300 million of automobile production, \$100 million engine and automotive parts and part of the \$200 million steel might have been already included and among the \$100 engine and automotive parts production, part of \$200 million steel and \$50 million glass might have been included. When such a \mathbf{y} vector is used, the direct and indirect factor inputs attributable to automobile, the engine and automotive parts, steel and glass create multiple double-counting, resulting in an exaggeration.

The only methodologically sound approach to avoid double-counting in a multiplier analysis is to use only final demand values for \mathbf{y} .

Figure 14: Direct, indirect and induced impact and double-counting in multiplier analyses

Suppose that the economic and employment impacts attributable to an iron and steel recycling plant in the suburb of Pittsburgh, PA ("Facility A", hereafter) are being estimated. The plant receives end-of-life vehicles in the form of hulk, processes them through crushing and magnetic separation and finally hauls out separated iron and steel to smelters in the neighborhood. The entire revenue, value-added and employment accredited to the operation itself, is referred to as *direct impact*. Direct impacts are easily attributable to this recycling operation.

Suppose further that Facility A requires heavy equipment, electricity, fuel, ground freight services, as well as automobile disassembly and compression services in order to produce the

hulk. In this case, the value-added and employment from those upstream supply chain industries needed to provide such inputs to Facility A would be attributable to iron and steel recycling to the extent that they are utilized by Facility A, which constitute *indirect impact*.

The wages paid to the employees of Facility A and its upstream supply chain industries will spend their income earned in relation to the operation of Facility A on various items including groceries, housing, automobiles, *etc.* and such expenditures and associated supply chain would induce another round of economic and employment impact, which is referred to as *induced impact*.

These direct, indirect and induced impacts have been widely quantified using regional multipliers. However, regional multipliers such as IMPLAN and RIMS II are designed to be used to estimate the impact of changes in *final demand* not in *intermediate sectors*. When they are used for intermediate sectors, economic and employment impacts are (more than) double-counted across the supply chain.

Suppose that the recycled steel from Facility A sent to smelters are used to produce hot-rolled coil, which is used for suspension of a motor vehicle ultimately purchased by a household. Each and every industry in the downstream supply chain of Facility A (*i.e.*, smelters, hot-rolled coil maker, suspension maker and automaker) can claim the entire direct, indirect and induced economic and employment impact of Facility A as a part of their contributions to the economy. Industries upstream from Facility A can do the same: each industry can also claim their upstream suppliers' economic and employment impacts as part of their contributions. Summing these up across the supply chain produces the impact figures that well exceed the regional or national total due to the double-counting effect throughout the supply chain.

Efforts have been made to mitigate the double-counting effect of gross multipliers, and proposed various approaches, which generally involve some form of normalization to dilute the double-counting. But the very origin of the problem is the misuse of these multipliers, which are designed to be used with final demand changes rather than intermediate changes. The reason why there is no double-counting problem when these multipliers are used for final demand changes only is because the final demands are considered in an input-output framework at the end-point of supply chains and therefore all economic and employment impacts are attributed to final demands only once in a mutually exclusive and collectively exhaustive manner (Lenzen et al., 2007).

8.2.4. *Four approaches for modeling the impact of recycling on a national economy*

It is important to note that the results from multiplier analyses are the results of a model (as opposed to observation), and therefore depend on the approaches and assumptions employed by a modeler. More than one approach is possible in measuring the impact of recycling in a national economy, and such alternative

approaches may allow complementary insights. When interpreting the results, it is important to understand the differences in underlying assumptions employed in a model.

Direct production of recycling approach

First, this approach measures the primary factor inputs directly to recycling operations (see also Box 1). The direct primary factor input to recycling, \mathbf{m}_1 , is calculated by:

$$(5) \quad \mathbf{m}_1 = \mathbf{B}\hat{\mathbf{r}}\mathbf{x},$$

where \mathbf{r} is a column vector of recycling fraction of production activity ($r_i \in [0, 1]$). I.e., $r_i = 1$ for all recycling activities, 0 for non-recycling activities and between 0 and 1 for the activities that contribute partly to recycling. For example, a paper production that produces 60% recycled paper gets 0.6 of recycling fraction. Hat ($\hat{\cdot}$) diagonalizes a vector. This approach does not include any multiplier effects.

Direct household demand on recycling approach

The direct household demand on recycling approach uses the amount of final demand on recycling (waste management service in the form of recycling in physical unit) by household, government and export (\mathbf{y}_2) (4)

$$(6) \quad \mathbf{m}_2 = \mathbf{B}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}_2,$$

While the calculation is methodologically consistent, this approach limits the impact of recycling only to the ones that are demanded directly by the final consumers.

Recycled Content in Final Demand Approach

The recycled content in final demand approach applies the primary factor input multipliers to the portion of the total final demands to the extent that they consist of recycled materials. Total primary factor input can be calculating following this approach by:

$$(7) \quad \mathbf{m}_3 = \mathbf{B}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{c}\mathbf{y},$$

Where \mathbf{c} is a diagonalized vector of recycled content in final consumption ($c_i \in [0, 1]$). I.e., $c_i = 1$ for 100% recycled product, and 0 for 0% recycled product by mass. For example, a typical automobile contains 60-80% recycled content by mass (Ward 2012), and therefore the corresponding element in \mathbf{c} becomes 0.6-0.8. In this case 60%-80% of the total direct and multiplier impacts of automobile is attributed to recycling. Under this approach, the materials constituting a consumer product are considered to harbor the services that the product renders, and therefore it views that the direct, and multiplier impacts associated with the final consumption of the product are attributable to recycling proportional to their recycled content. Because it uses a portion of final demand, this approach avoids the double-counting problem discussed earlier.

Direct and Indirect Production of Recycling Approach

This approach applies the primary factor input multipliers to the sum of intermediate and final demands on recycling. In a matrix equation, this can be calculated by:

$$(8) \quad \mathbf{m}_4 = \mathbf{B}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{x}_4,$$

Where \mathbf{x}_4 is the total (direct and indirect) production of recycled products in physical unit. This approach exaggerates the results and is not methodologically sound. Post-multiplying production to Leontief inverse in equation (8) is known to create double-counting (Oosterhaven and Stelder 2002; Dietzenbacher 2005).

8.2.5. Causality and interpretation of multiplier analysis results

Multiplier analyses aim at quantifying the amount of factor inputs that are attributable to certain final demand based on the allocation scheme employed, and the results of a multiplier analysis does not imply a cause-effect relationship. For example, suppose that total compensation to employees attributable to total final demand on recycling is calculated to be \$X. It does not mean that increasing the recycling rate by 10% will increase the compensation to employees by 10% of \$X, because such a change may potentially affect various elements of an economy such as price, input structure and wages, and therefore the underlying economic structure used for the calculation of the multiplier effect becomes no longer valid.

Such changes can be, in principle, captured by using computable general equilibrium (CGE) models (Lofgren and colleagues 2002; Partridge and Rickman 1998; Jorgenson and Wilcoxon 1993). CGE models simultaneously derive quantity and price based on a new supply-and-demand equilibrium after a shock to the economy. The underlying principles of CGE models are well in line with those of mainstream economics, and it may provide useful insights on the direction of changes in response to a large-scale policy intervention. In reality, however, the sector resolution in such a model is generally very poor (generally less than 60 sectors for a national economy), and statistically significant substitution elasticity functions specifically derived for the given region, technology and time of a study are rare (see also Duchin 2014; Rose 1995; Suh and Yang 2014).

8.3. Waste Input-Output Model

The official U.S. input-output tables by the Bureau of Economic Analysis (BEA) distinguish a limited number of categories for recyclables and recycling operations (see Appendix F) hampering adequate understanding of recycling's contribution to the national economy. To address the problem, a waste input-output (WIO) model is compiled for the U.S.

8.3.1. WIO model

WIO model is a mixed-unit input-output model that highlights the flows of wastes in a national economy (Nakamura and colleagues 2007; Nakamura and Kondo 2009, 2002). The underlying flow table for the WIO model distinguishes flows of wastes and recyclables and activities of recycling and waste management in addition to the flows of ordinary products and sectors described in official input-output tables. Table 14 shows the general structure of the flow table used in WIO model.

Table 14: General structure of the flow table used in WIO model*

		Intermediate sectors				Waste management activities				Final demand		
		Sector 1	Sector 2	...	Sector n	Activity 1	Activity 2	...	Activity p	Household	Government	Export
Intermediate sectors	Sector 1	$n \times n$ matrix of intermediate inputs to intermediate sectors (\$)				$n \times p$ matrix of intermediate inputs to waste management activities (\$)				$n \times 3$ matrix of final consumption of intermediate products (\$)		
	Sector 2											
	⋮											
	Sector n											
Waste flows	Waste 1	$q \times n$ matrix of waste generated by intermediate sectors (ton)				$q \times p$ matrix of waste generated by waste management activities (ton)				$q \times 3$ matrix of waste generated by final consumers (ton)		
	Waste 2											
	⋮											
	Waste q											
Primary factors	Wage	$3 \times n$ matrix of primary factor inputs by intermediate sectors (\$)				$3 \times p$ matrix of primary factor inputs to waste management activities (\$)						
	Tax											
	Profit											

* Shaded area contains additional information that is not well represented in an ordinary input-output. The framework can accommodate any number of final demand sectors and primary factors. Only three final demand sectors and primary factors are shown here for the sake of simplicity.

The underlying flow table for WIO model can be rectangular, and the square direct input coefficient matrix is derived using the allocation matrix from the flow table. Here the basic analytical framework of the 2001 REI Report WIO model is summarized without discussing the derivation of the analytical tables, which will be done in the next section.

Let \mathbf{A}^* be the direct input coefficient matrix of the WIO model by Nakamura and Kondo (2009). \mathbf{A}^* consists of four concatenated matrices such that:

$$(9) \quad \mathbf{A}^* = \begin{pmatrix} \mathbf{A}_{11}^* & \mathbf{A}_{12}^* \\ \mathbf{A}_{21}^* & \mathbf{A}_{22}^* \end{pmatrix},$$

where \mathbf{A}_{11}^* is an intermediate sector-by-intermediate sector matrix, of which i - j th element shows the input from sector i to sector j per unit of out from j (\$/\$), \mathbf{A}_{12}^* is an intermediate sector-by-waste management activity matrix, of which i - j th element shows the input from sector i to waste management activity j per unit of out from j (\$/ton), \mathbf{A}_{21}^* is a waste management activity-by-intermediate sector matrix, of which i - j th element shows the use of waste management service or product (such as solid waste landfill service or recycled paper) i by intermediate sector j per unit of out from j (ton/\$), and finally \mathbf{A}_{22}^* is a waste management activity-by-waste management activity matrix, of which i - j th element shows the use of waste management service or product i by waste management activity j per unit of out from j (ton/ton). The elements of \mathbf{A}^* may take a negative sign, in which case it shows production of product or service (instead of consumption).

The general analytical framework can be considered a special case of the integrated hybrid framework (Suh 2004; Suh et al. 2004; Suh and Huppel 2005; Suh and Lippiatt 2012), where the foreground system describes waste management processes in the WIO model. The integrated hybrid approach of Suh (2004) is based on a product-by-product matrix derived from supply and use (S&U) framework, while the 2001 WIO model in Nakamura and Kondo (2002) follows an industry-by-industry (or activity) framework.

WIO multiplier analyses can be performed by using \mathbf{A}^* in the place of \mathbf{A} in equations (6) to (8).

8.3.2. Derivation of the WIO analytical tables

The supply and use framework separates product flows of products from the institutions or activities (sectors) that house their production (supply) and consumption (use) (Stone 1961; Konijn 1994; United Nations 2008). The separation enables higher statistical quality in underlying flow tables used for input-output analyses, while it also necessitates the use of models to convert the flow tables to symmetric analytical tables such as commodity-technology model and industry-technology model (Konijn 1994).

Built upon such developments, the use of supply and use framework in the hybrid input-output setting was introduced by Suh (2004), which was extended to a generalized supply and use calculus for process-level details represented in physical units by Suh and colleagues (2010).

Suh and colleagues (2010) observed that the use of an allocation matrix to convert waste flows to waste management activities in the 2001 WIO framework by Nakamura and Kondo (2002, 2009) is a special case of standard supply and use calculus. Lenzen and Reynolds (2014) recently confirmed the earlier observation by (Suh et al. 2010) and further elaborated on the relationship between the WIO model and supply and use framework. The official input-output tables of Japan, where the 2001 WIO model originates, are not using a supply and use framework, and therefore Nakamura and Kondo (2002, 2009) treated the conversion between the waste flows and activities separately from the rest of the economy.

In the U.S., the official input-output tables are published in the form of supply and use tables. Therefore, it is natural to embed the derivation of analytical tables for WIO on a supply and use framework.

The flow table for WIO model shown in Table 14 is separated into two tables, namely the supply table (Table 15) and the use table (Table 16). The supply table shows the production of ordinary products (goods and services) by ordinary sectors as well as the production of waste management services by waste management activities. It is very important to carefully define production, especially for the flows involving waste management services. The 2001 WIO model (Nakamura and Kondo 2002) assumes that generation of wastes means consumption (use) of waste management service. For recyclables, however, producers of recyclable materials may be able to sell such materials. In this case the recyclables are in fact by-products that need to be registered in the supply table not in the use table.

Table 15: Supply table for WIO model of the U.S.

		Intermediate products				Waste management services			
		Product 1	Product 2	...	Product n	Service 1	Service 2	...	Service q
Intermediate sectors	Sector 1	$n \times n$ matrix of intermediate product produced by intermediate sectors (\$)				$n \times q$ matrix of waste management services produced by intermediate sectors (ton) (≈ 0)			
	Sector 2								
	⋮								
	Sector n								
Waste management activities	Activity 1	$p \times n$ matrix of intermediate products produced by waste management activities (\$) (≈ 0)				$p \times q$ matrix of waste management services produced by waste management activities (ton)			
	Activity 2								
	⋮								
	Activity p								

* Shaded area contains additional information that is not well represented in an ordinary supply table. The framework can accommodate any number of final demand sectors and primary factors. Only three final demand sectors and primary factors are shown here for the sake of simplicity.

The intermediate and waste management portion of the supply and use tables forms **V** and **U** matrices, respectively, which can be subsequently manipulated to produce product-by-product or industry-by-industry (or activity-by-activity) analytical tables following a standard supply and use framework.

Table 16: Use table for WIO model of the U.S.

		Intermediate sectors				Waste management activities				Final demand		
		Sector 1	Sector 2	...	Sector n	Activity 1	Activity 2	...	Activity p	Household	Government	Export
Intermediate products	Product 1	$n \times n$ matrix of intermediate inputs to intermediate sectors (\$)				$n \times p$ matrix of intermediate inputs to waste management activities (\$)				$n \times 3$ matrix of final consumption of intermediate products (\$)		
	Product 2											
	⋮											
	Product n											
Waste management services	Service 1	$q \times n$ matrix of waste management services purchased by intermediate sectors (ton)				$q \times p$ matrix of waste management services purchased by waste management activities (ton)				$q \times 3$ matrix of waste management services purchased by final consumers (ton)		
	Service 2											
	⋮											
	Service q											
Primary factors	Wage	$3 \times n$ matrix of primary factor inputs by intermediate sectors (\$)				$3 \times p$ matrix of primary factor inputs to waste management activities (\$)						
	Tax											
	Profit											

* Shaded area contains additional information that is not well represented in an ordinary use table. The framework can accommodate any number of final demand sectors and primary factors. Only three final demand sectors and primary factors are shown here for the sake of simplicity.

8.3.3. Use of WIO Model to Calculate Tax Revenue Associated with Recycling and Reuse

The WIO methodology allows for a refinement to the approach used to calculate tax revenue associated with recycling and reuse. In the 2001 REI study, U.S. Census of Governments data were used to estimate total state and local government general revenue (e.g., exclusive of Social Security and retirement tax revenue, public utility revenue, etc.). Effective tax rates for each level of government were calculated by dividing general revenue by total personal income data collected from the U.S. Bureau of Economic Analysis. These effective rates were multiplied by the modelled estimates of total personal income attributed to recycling and reuse to estimate state and local revenue attributable to recycling.

In addition to eliminating the double-counting issues inherent in the approach used in 2001, the WIO methodology allows for further refinements to these estimates. A key assumption of the 2001 REI Report methodology was that all establishments in the U.S. are taxed at the same rate and that the total amount of taxes associated with a sector is proportional to personal income taxes paid. However, the federal government, and many states, has established tax brackets and marginal tax rates for personal and corporate income taxes, meaning that total taxes vary non-linearly with output. Industries in different sectors differ significantly with respect to the average size and distribution of establishments. Industries in different sectors also differ significantly with respect to labor intensity per output, with implications for the assumption that total taxes are proportional to personal income.

By associating recycled material flows with the national IO framework, the WIO methodology helps to address these sources of uncertainty in the 2001 REI Report model by allowing for the introduction of industry-specific tax revenue data. Data from the U.S. Internal Revenue Service (IRS), U.S. Census of Governments and U.S. Economic Census can be used to allocate personal and corporate tax revenues to different sectors of the economy, allowing the WIO model to more precisely estimate the proportion of these revenues attributable to recycling and reuse. Further review will be conducted to assess differences in resolution between IO tables and tax revenue data sources, crosswalk data tables and explore the possibility of introducing geographic variation (by state or region) into the analysis.

9. Appendix C – Results for Alternate WIO Approaches

The results of the three alternate approaches, other than the intermediate production approach are summarized below.

9.1. Direct Production of Recycling Approach

The results of the direct production of recycling approach is summarized in this section. Construction and demolition (C&D) contributed most significantly to job creation and wages, followed by ferrous metals. Ferrous metals were the most significant source of tax revenue among the eight materials studied, followed closely by C&D. Figure 15, Figure 16 and Figure 17 present the employment, wage and tax revenue results for this approach. Figure 18 shows the relative contribution by the nine materials to job creation, wage and tax revenue under this approach.

Figure 15: Employment results for the direct production of recycling approach

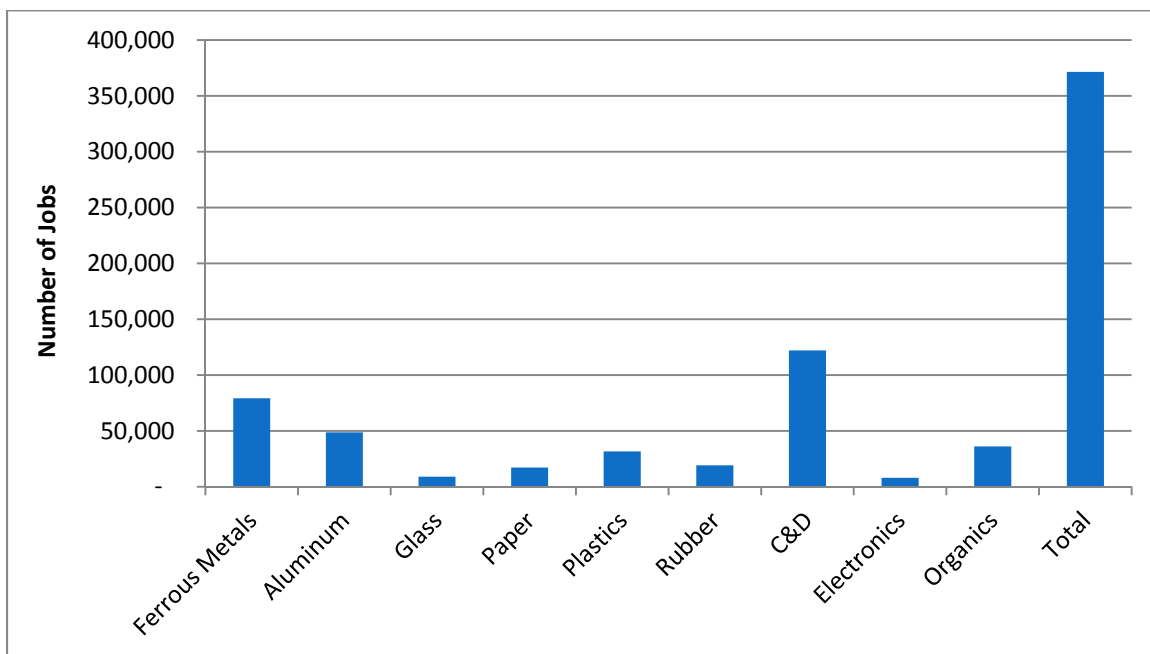


Figure 16: Wage results for the direct production of recycling approach

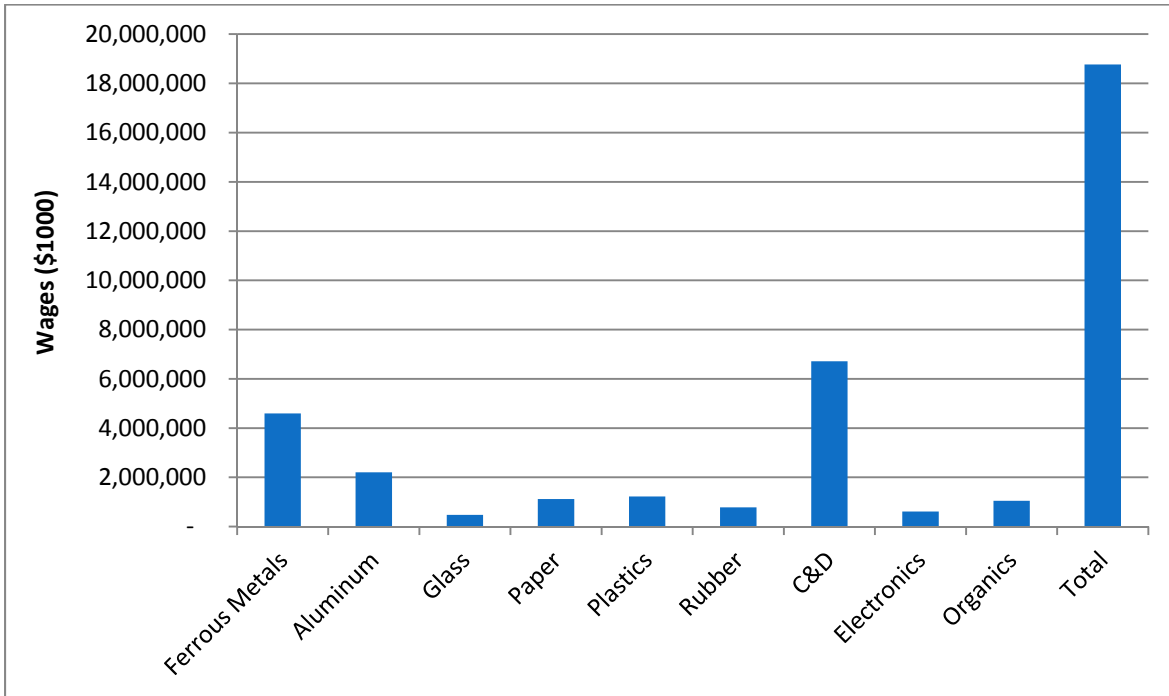
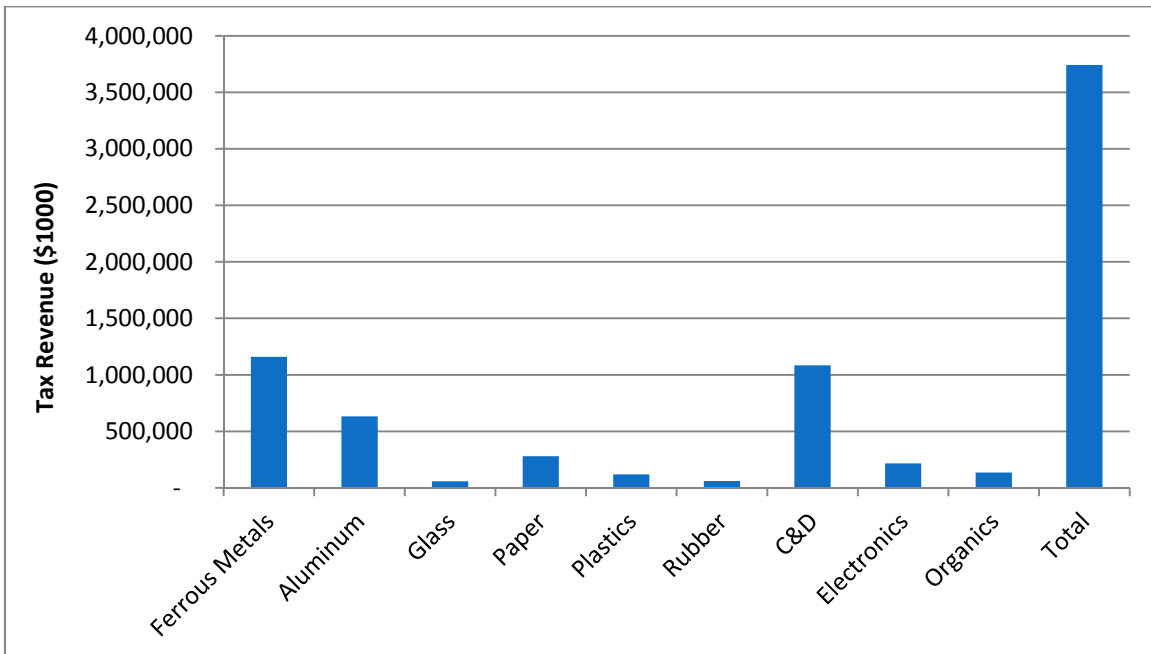
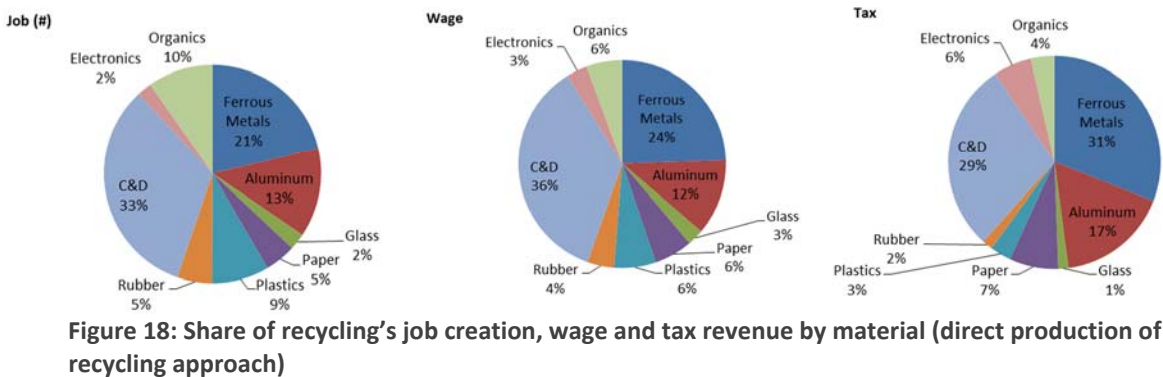
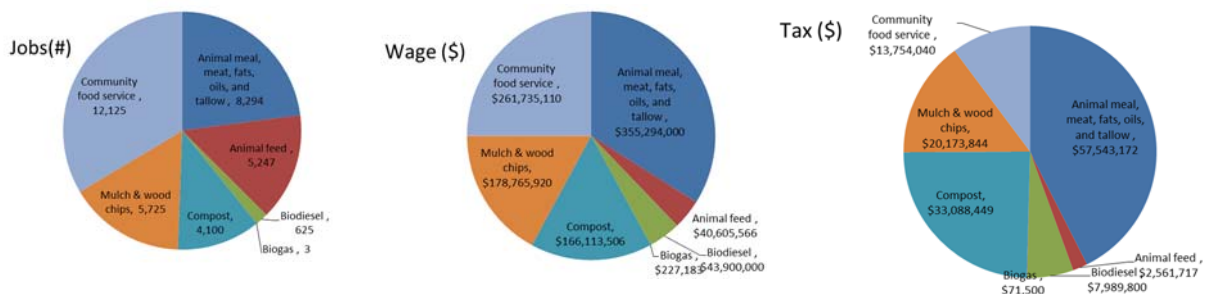


Figure 17: Tax revenue results for the direct production of recycling approach





A breakdown of direct and indirect employment numbers, wages and taxes associated with the seven different sub-material types is shown in Figure 19 below. The total direct employment (# of jobs) by the organics category is around 36,118, associated wages are about \$1.04 billion and associated taxes are about \$135 million.



9.2. Recycled Content in Direct Household Demand on Recycling Approach

Unlike the *direct production of recycling* and the *direct and indirect production of recycling* approaches, the results of the analysis under the *recycled content in final demand* approach do not fall only under the nine material categories. Therefore the results from the analysis under the *recycled content in final demand* approach are organized according to the final demand categories in a decreasing order of contribution per each measure (Figure 20, Figure 21, Figure 22). The results show that consumption of various recycled material-enabled products contributes significantly to job creation, wage payment and tax revenue generation. Motor vehicles, and machinery and equipment categories are ranked high in these tables due to their uses of various recycled materials such as ferrous metals, non-ferrous metals, plastics and rubber.

Figure 20: Contribution of recycled material-enabled final demand to job creation (Top 10)

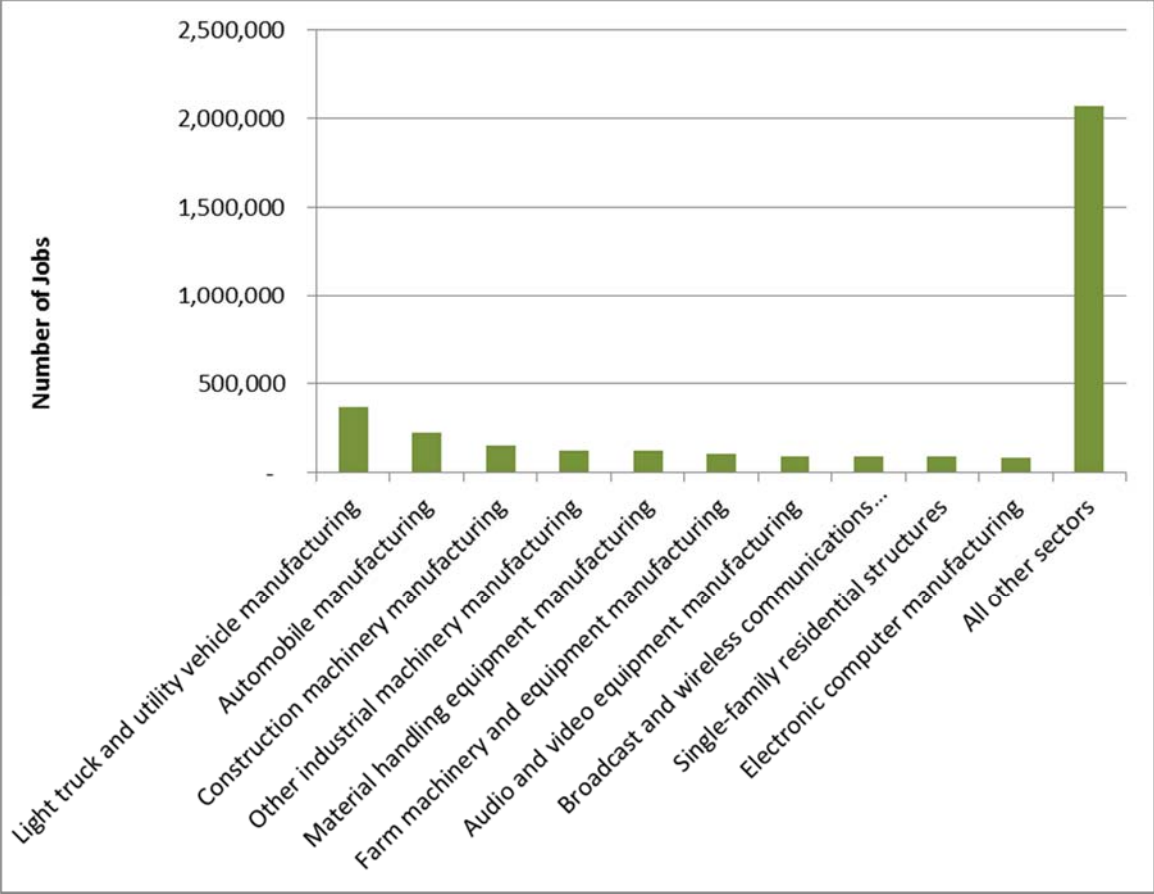


Figure 21: Contribution of recycled material-enabled final demand to wage payment (Top 10)

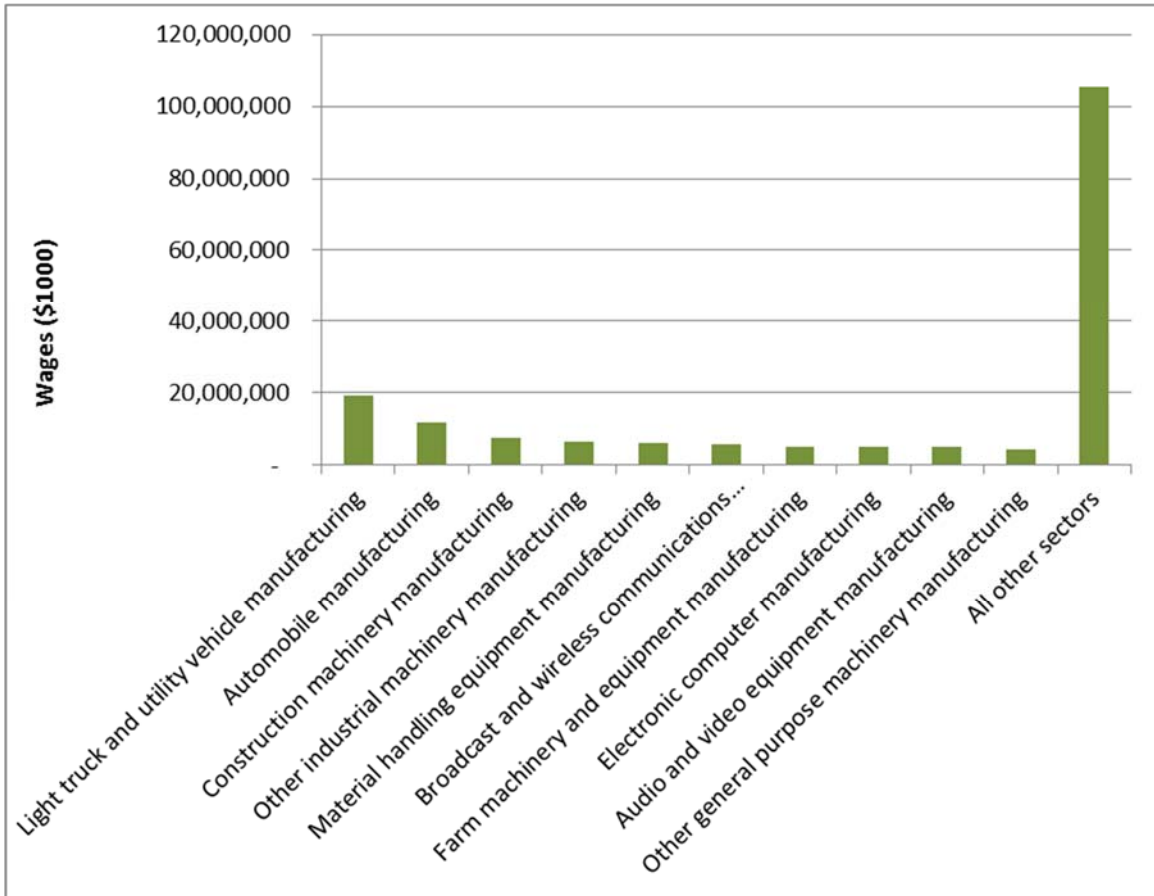
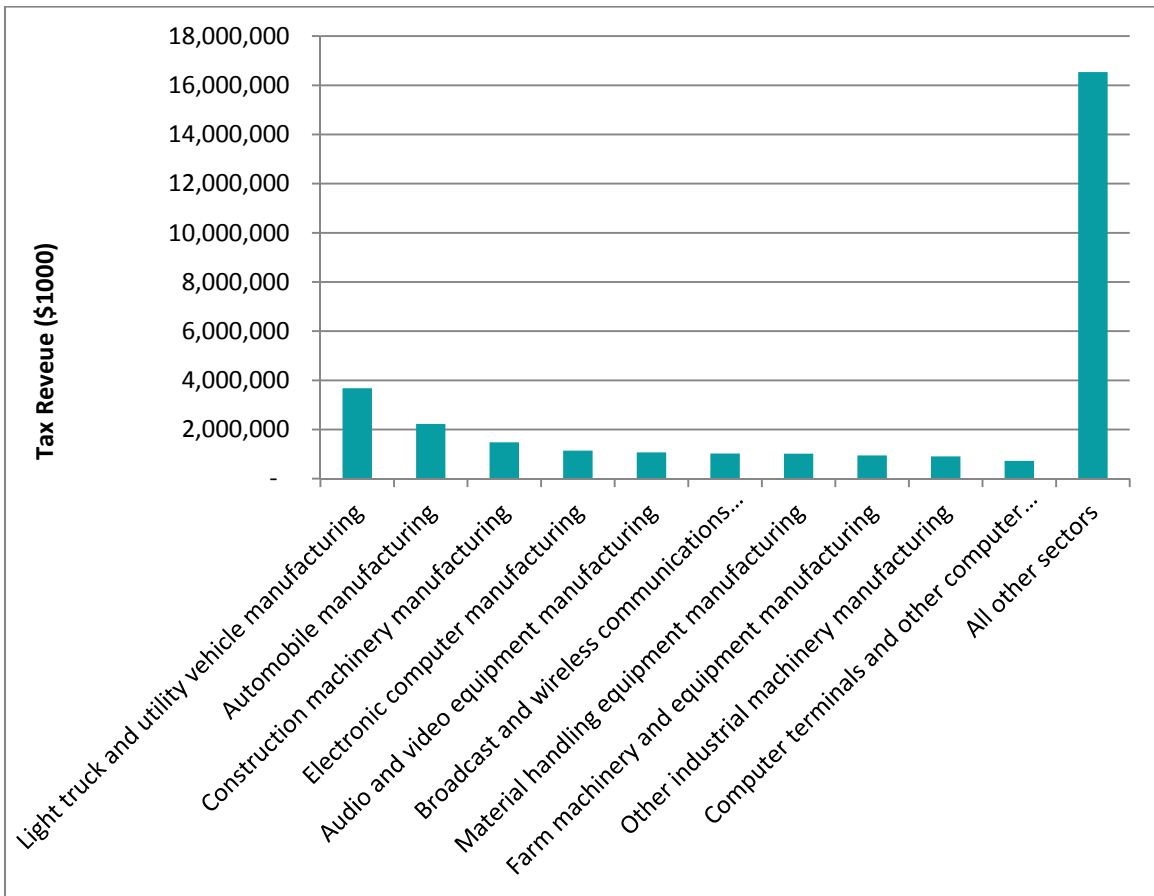


Figure 22: Contribution of recycled material-enabled final demand to tax revenue (Top 10)



It is notable that the contributions from motor vehicles, machinery manufacturing and electronic and electrical equipment stand out under the *recycled content approach* because of the combination of (1) the significant share of recycled ferrous and nonferrous metals and recycled plastics by weight, and (2) the significant consumption quantity of these products.

9.3. Direct Household Demand on Recycling Approach

The results from the analysis under the *direct household demand on recycling* approach is summarized in Figure 23, Figure 24 Figure 25. Recycling of paper provides the largest contribution to all three categories considered (job, wage and tax revenue).

Figure 23: Employment results for recycling as direct household demand on recycling approach

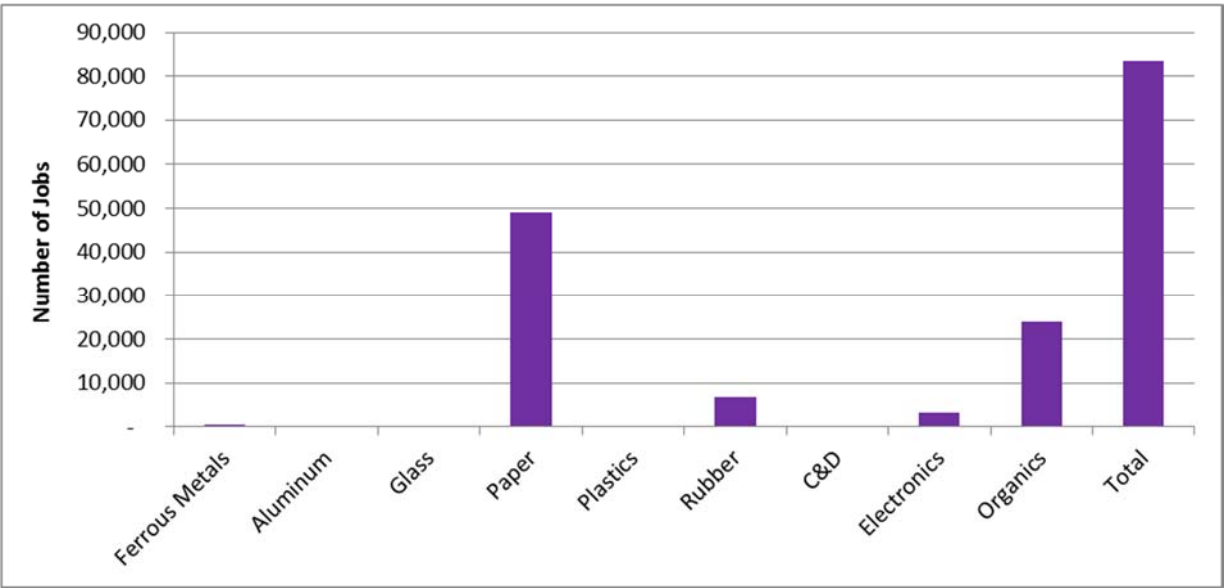


Figure 24: Wage results for recycling as direct household demand on recycling approach

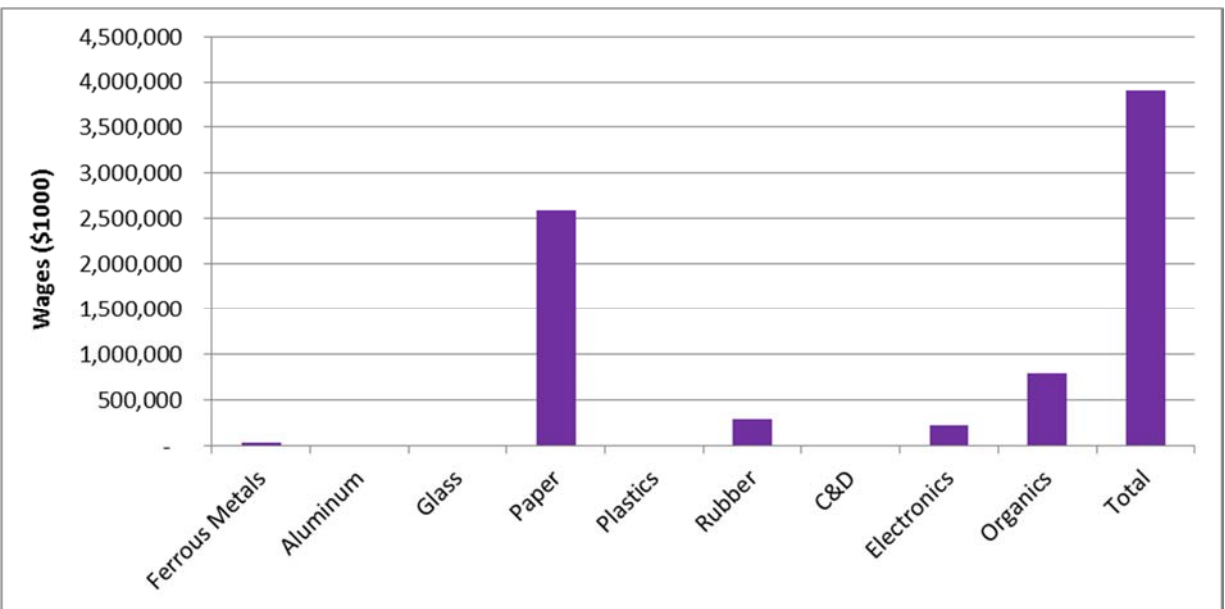
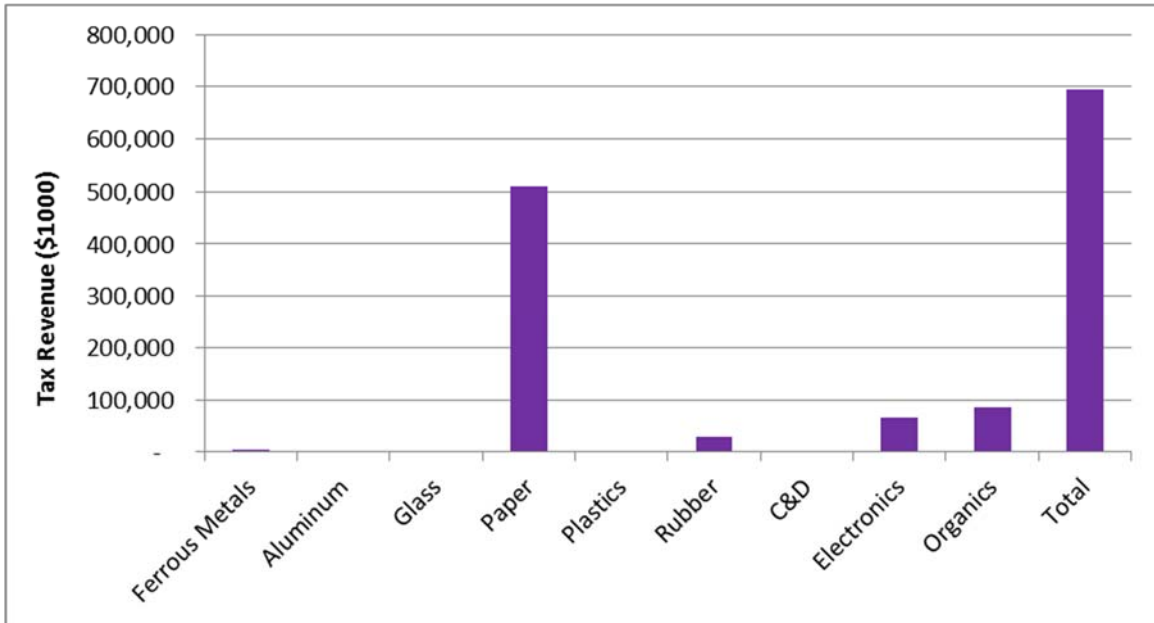


Figure 25: Tax revenue results for direct household demand on recycling approach



10. Appendix D – Recycling Process Allocation Assumptions

10.1. Overview

The following tables summarize assumptions used to define recycling processes within the larger I-O framework. The tables identify assumptions and data sources for the following:

- **Recycled material quantity and price**—used to express recyclable and recycling material flows in monetary units to allow integration with official I-O statistical tables.
- **Major consumers of and processes consuming recyclable material**—identifies economic sectors where recycling activities occur or processes where recyclable materials are consumed, by material, where a recycling activity is defined as the transformation of scrap or recovered materials and products into a useful intermediate or final product.
- **Recyclable material proportion**—ratio of scrap/recovered material/products to the sum of the scrap/recovered material/products and the virgin material/new products for which the scrap/recovered material/products is used as a substitute.

These three bullets correspond to the three heading in each section below. The rationale for the approach is that it provides a means of defining recyclable material flows. This accomplishes two things: 1) it lays the foundation for a data-based approach for identify sectors where recycling occurs (versus identifying them *a priori* like in the previous REI studies); and 2) sets up a proportional flow approach for allocating economic factors across manufacturing and recycling processes. If instead of a proportional flow approach, we try to define specific recycling activities, this would suggest a hybrid LCA approach, which would require significantly more effort to create and maintain. Ferrous Metals

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Iron and Steel	Ferrous metals recovered from appliances (such as washing machines, water heaters, refrigerators, etc.), automobiles, steel containers, construction material and other sources	Material amounts recovered and recycled	33,287,587 mt	USGS (2014)
		Unit price of recycled material ¹⁶	\$795.65 /mt	USGS (2013), p. 72

¹⁶ Based on average annual unit price for hot rolled steel bar

mt = metric ton

Major Consumers of Recyclable Material

- Manufacturers of pig iron and raw steel and castings (NAICS 331111)
- Manufacturers of steel castings (NAICS 331512, 331513)
- Iron foundries and miscellaneous users (NAICS 331511)

Data source: USGS (2010), Table 1

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Manufacturers of pig iron and raw steel and castings	Ferrous scrap used as feedstock to manufacturing process	40.1%	World industry-wide average share of total crude steel production from scrap, 2007	BIR (2012), p. 9
Manufacturers of steel castings	Ferrous scrap used as feedstock to manufacturing process	40.1%	World industry-wide average share of total crude steel production from scrap, 2007	BIR (2012), p. 9
Iron foundries and miscellaneous users	Ferrous scrap used as feedstock to manufacturing process	40.1%	World industry-wide average share of total crude steel production from scrap, 2007	BIR (2012), p. 9

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USGS (2013). *Metal Prices in the United States Through 2010*. Reston, Virginia: U.S. Geological Survey. Retrieved May 21, 2015, from <http://pubs.usgs.gov/sir/2012/5188/sir2012-5188.pdf>

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10.2. Nonferrous Metals (Aluminum)

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Aluminum	Aluminum scrap from used beverage cans, other containers, transportation, construction and other sources	Material amounts recovered and recycled	1,524,071 mt	USGS (2010)
		Unit price of recycled material ¹⁷	\$2,640 /mt	Index Mundi (2015)

mt = metric ton

Major Consumers of Recyclable Material

- Secondary aluminum smelters (NAICS 331314)
- Independent mill fabricators and other (NAICS 331315, 331316, 331319)
- Aluminum foundries (NAICS 331521, 331524)

Data sources: USGS (2010), Table 3; USGS (2006), Figure 1

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Secondary aluminum smelters	Aluminum scrap used as feedstock to manufacturing process	40%	Percentage of total U.S. aluminum supply recovered from scrap	USGS (2010)
Independent mill fabricators and other	Aluminum scrap used as feedstock to manufacturing process	40%	Percentage of total U.S. aluminum supply recovered from scrap	USGS (2010)

¹⁷ Based on LME spot price for aluminum, 99.5% purity; comparable to unit price from USGS (2013), p. 5

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Aluminum foundries	Aluminum scrap used as feedstock to manufacturing process	40%	Percentage of total U.S. aluminum supply recovered from scrap	USGS (2010)

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10.3. Plastics

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Plastic	Recycled plastics	Material amounts recovered and recycled	2,413,112 mt	EPA (2014)
		Unit price of recycled material	\$1,208.68 /mt	Block (2012)

mt = metric ton

Major Consumers of Recyclable Material

- PET

- Non-cellulosic fibers (NAICS 325222)
- Sheet, film and strapping (NAICS 326112, 326113)
- Food and non-food bottles (NAICS 326160)
- HDPE
 - Non-food bottles (NAICS 326160)
 - Pipe (NAICS 326122)
 - Automotive products (NAICS 326199)
 - Lawn and garden products (NAICS 326220)
 - Sheet and film (NAICS 326112, 326113)
 - Composite lumber (NAICS 326199)
 - Pallets, crates and buckets (NAICS 326199)
- LDPE
 - Composite lumber (NAICS 326199)

Data sources: ACC (2009), ACC (2014a), ACC (2015a), ACC (2015a), NAPCOR (2014)

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
PET Non-cellulosic fibers	Recovered PET used as substitute for virgin PET during non-cellulosic fiber manufacturing	24.6%	National “recycling rate” (ratio of plastic recycled to total resin sales) for PET	ACC (2009)
PET Sheet, film and strapping	Recovered PET used as substitute for virgin PET during PET sheet, film and strapping manufacturing	24.6%	National “recycling rate” (ratio of plastic recycled to total resin sales) for PET	ACC (2009)
PET Food and non-food bottles	Recovered PET used as substitute for virgin PET during food and non-food bottle manufacturing	24.6%	National “recycling rate” (ratio of plastic recycled to total resin sales) for PET	ACC (2009)
HDPE Non-food bottles	Recovered HDPE used as substitute for virgin HDPE during non-food bottle manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
HDPE Pipe	Recovered HDPE used as substitute for virgin HDPE during HDPE pipe manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
HDPE Automotive products	Recovered HDPE used as substitute for virgin HDPE during automotive plastic parts manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
HDPE Lawn and garden products	Recovered HDPE used as substitute for virgin HDPE during lawn and garden products manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
HDPE Sheet and film	Recovered HDPE used as substitute for virgin HDPE during HDPE sheet and film manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
HDPE Composite lumber	Recovered HDPE used as substitute for virgin HDPE during composite lumber manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
HDPE Pallets, crates and buckets	Recovered HDPE used as substitute for virgin HDPE during durable plastic products manufacturing	26.0%	National “recycling rate” (ratio of plastic recycled to total resin sales) for HDPE	ACC (2009)
LDPE Composite lumber	Recovered LDPE used as substitute for virgin LDPE during composite lumber manufacturing	25%	Assumption based on LDPE:HDPE share (and other materials) and relatively high average recycled content	

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10.4. Rubber

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Rubber crumb	Ground rubber produced from scrap tires	Material amounts recovered and recycled	1,100,016 mt	RMA (2014)
		Unit price of recycled material	\$374.79 /mt	ProfitableRecycling (2015)
Other recycled rubber	Other rubber recovered from scrap tires used in civil engineering, reclamation and agricultural applications.	Material amounts recovered and recycled	971,218 mt	RMA (2014)
		Unit price of recycled material	\$385.81 /mt	ProfitableRecycling (2015)

mt = metric ton

Major Consumers of Recyclable Material

- Molded/extruded rubber products (NAICS 326291)
- Athletic field construction (NAICS 237990)

- Artificial turf installation (NAICS 238990)
- Playground construction (NAICS 237990)
- Tire manufacturing (NAICS 326211)
- Tire retreading (NAICS 326212)
- Rubber hoses and belting (NAICS 326220)
- Rubber-modified asphalt (NAICS 324121)
- Road subgrade (NAICS 237310)
- Light rail construction (NAICS 237990)
- Septic drain fields and construction fill (NAICS 238910)

Data sources: RMA (2009)

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Molded/extruded rubber products	Ground rubber substituted for virgin rubber in molded rubber products (e.g., carpet underlay, dock bumpers, etc.)	30%	Assumption based on general literature review and heterogeneity of products	RW (2012)
Athletic field construction	Direct application of crumb rubber as substitute for other material on field/track surface	<1%	Assumption based on general literature review	
Artificial turf installation	Direct application of crumb rubber as substitute for other material as cushion layer beneath artificial turf	80%	Assumption based on general literature review	MadeHow (2015)
Playground construction	Direct application of crumb rubber as substitute for other material for playground surfacing	20%	Assumption based on general literature review	
Tire manufacturing	Ground rubber substituted for virgin rubber in tire manufacturing	5%	Recycled content achieved based on performance/technical limitations	TiE50 (2015)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Tire retreading	Ground rubber substituted for virgin rubber in new tread; does not include retreadable casings	5%	Recycled content achieved based on performance/technical limitations	TiE50 (2015)
Rubber hoses and belting	Ground rubber substituted for virgin rubber in hose/belt manufacturing	30%	Assumption based on general literature review	
Rubber-modified asphalt	Crumb rubber substituted for other material during asphalt manufacturing	<1%	Assumption based on characterization of minimal use/market demand	RMA (2009), p. 11
Road subgrade	Direct application of crumb rubber as substitute for other material in road subgrade	<1%	Assumption based on general literature review and amounts of non-rubber material used in this application	
Light rail construction	Direct application of crumb rubber as substitute for other material to create vibration dampening layer for light rail	<1%	Assumption based on general literature review and amounts of non-rubber material used in this application	
Septic drain fields and construction fill	Direct application of crumb rubber as substitute for other material in septic drain fields and construction fill	<1%	Assumption based on general literature review and amounts of non-rubber material used in this application	

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10.5. Glass

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Glass	Glass cullet recovered from glass bottles and jars	Material amounts recovered and recycled	2,053,020 mt	GPI (2014)
		Unit price of recycled material	\$32.50 /mt	Popular Mechanics (2008)

mt = metric ton

Major Consumers of Recyclable Material

- Glass container manufacturing (NAICS 327213)
- Fiberglass manufacturing (NAICS 327993)

Data sources: GPI (2015); Waste360 (2015)

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Glass container manufacturing	Glass cullet used as feedstock during container manufacturing process	23%	Mix of production from virgin and recycled inputs for glass manufacturing, 2015	EPA (2015), Exhibit 9
Fiberglass manufacturing	Fiberglass manufacturing	30%	Average recycled content of fiberglass	TNet (2015)

Sources Cited

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10.6. Paper

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Paper	Recovered and recycled paper and paperboard	Material amounts recovered and recycled	30,290,546 mt	AFPA (2014)
		Unit price of recycled material	\$126.77 /mt	Popular Mechanics (2008)

mt = metric ton

Major Consumers of Recyclable Material

- Paper mills, except newsprint (NAICS 322121)
- Newsprint mills (NAICS 322122)
- Paperboard mills (NAICS 322130)

Data sources: AFPA (2014)

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Paper mills, except newsprint	Paper manufacturing using pulp produced from recycled paper, either in integrated pulp-paper mill or in pulp mill that processes recycled paper ¹⁸	4%	From WARM model % production from recycled inputs (ref. products: magazines/ third class mail, office paper and textbooks)	EPA (2015)
Newsprint mills	Newsprint manufacturing using pulp produced from recycled newsprint, either in integrated pulp-newsprint mill or in pulp mill that processes recycled newsprint ²	23%	From WARM model % production from recycled inputs (ref. product: newspaper)	EPA (2015)
Paperboard mills	Paperboard manufacturing using pulp produced from recycled paperboard, either in integrated pulp-paperboard mill or in pulp mill that processes recycled paperboard ²	35%	From WARM model % production from recycled inputs (ref. product: corrugated containers)	EPA (2015)

Sources Cited

AFPA (2014). *Annual Statistical Summary of Recovered Paper Utilization 2014*. Washington, DC: American Forest & Paper Association.

¹⁸ This definition of the recycling process assumes that production of pulp from recycled paper materials occurs separately from production of pulp from virgin material (EPA 2012). Therefore, pulping is defined as a “processing” step that transforms the paper material into a form usable as a substitute for pulp from virgin materials. Recycling takes place when the pulp from recycled material is used to make paper, newsprint or paperboard.

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10.7. Construction and Demolition (C&D) Material

Recycled Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Recycled C&D Material	Recycled concrete, asphalt, gypsum and wood recovered from construction and demolition waste ¹⁹	Material amounts recovered and recycled	318,419,727 mt	Modeled based on estimates of C&D generation amounts, recycling rates, recovery rates and recycled amounts for Mixed C&D, bulk aggregate and Reclaimed Asphalt Pavement (RAP) from CDRA whitepaper (CDRA 2014), NAPA survey (NAPA 2014) and personal communication with K. Janjic. (EPA)
	Unit price assumptions			
Recycled C&D Material	Recycled concrete	Unit price of recycled material	\$9.50 /mt	USGS (2000)

¹⁹ C&D metal waste is included in ferrous and nonferrous metals recycling analysis.

Material	Description	Assumptions (2007 Basis)		Data Sources
	Brick (recycled aggregate)	Unit price of recycled material	\$27.78 /mt	Kurtz (2015)
	Wood (recycled wood chips)	Unit price of recycled material	\$24.80 /mt	NETI (2015)
	Asphalt (recycled asphalt shingles)	Unit price of recycled material	\$44.09 /mt	Crushcrete (2015)
	Gypsum (drywall)	Unit price of recycled material	\$15.98 /mt	Bauer (2012)

mt = metric ton

Major Consuming Processes/Applications of Recyclable Material

- C&D concrete
 - Aggregate for road base (NAICS 212319)
 - Aggregate for ready mix concrete (NAICS 212319)
 - Construction fill (NAICS 238910)
 - Other construction applications (e.g., soil stabilization, pipe bedding and landscaping) (NAICS 238910)

Data Sources: CDRA (2015b); USGS (2010), p. 71.3

- C&D asphalt pavement
 - Aggregate for asphalt pavement (NAICS 237310, 324121)

Data Source: NAPA (2014); USGS (2010), p. 71.3

- C&D asphalt shingles
 - Asphalt pavement (NAICS 324121)
 - Asphalt roofing products (NAICS 324122)

Data Source: SRO (2014); ARMA (2015)

- C&D gypsum wallboard
 - New drywall (NAICS 327420)
 - Portland cement (NAICS 327310)
 - Soil amendment (NAICS 115112)
 - Fertilizer (NAICS 325314)

Data Source: CDRA (2015c); USGS (2010)

- Wood
 - Engineered wood products (NAICS 321219)
 - Wood flooring (NAICS 321918)
 - Mulch, animal bedding and compost amendment (NAICS 325314)

Data sources: Bratkovich et al. (2014); Falk and McKeever (2004)

Recyclable Material Proportion

Consuming Process	Process Description	Recyclable Material	Basis for Proportion	Data Source
Concrete				
Aggregate for road base	Crushed/processed concrete used as substitute for crushed stone in road base	10.2%	Ratio of recycled concrete in 2008 (14.8 mmt) consumed to sum of graded road base and crusher run, fill or waste consumed (145.4 mmt)	USGS (2010), Tables 9 and 15
Aggregate for ready mix concrete	Crushed/processed concrete used as substitute for other materials in concrete for road surfacing	1%	Assumption based on general literature review and considerations in Obla et al. (2007)	
Construction fill	Recovered concrete used as substitute for other material in construction fill	10.2%	Ratio of recycled concrete in 2008 (14.8 mmt) consumed to sum of graded road base and crusher run, fill or waste consumed (145.4 mmt)	USGS (2010), Tables 9 and 15
Other construction applications	Recovered concrete used as substitute for other material in other construction applications	<1%	Assumption based on general literature review	

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Asphalt pavement				
Asphalt pavement aggregate (on-site)	Reclaimed/milled asphalt used as substitute for new aggregate in on-site hot mix asphalt process	16.2%	National average all mixes based on RAP tons used in HMA/WMA, 2009	NAPA (2014), Table 4, p. 11
Asphalt pavement aggregate (plant)	Reclaimed/milled asphalt used as substitute for new aggregate in asphalt manufacturing plant	16.2%	National average all mixes based on RAP Tons used in HMA/WMA, 2009	NAPA (2014), Table 4, p. 11
Asphalt shingles				
Asphalt pavement additive	Reclaimed/crushed asphalt shingles added as substitute for other material in asphalt paving manufacturing	1%	Assumption based on general literature review	
Asphalt roofing products	Reclaimed/crushed asphalt shingles added as substitute for other material in asphalt shingle manufacturing	3%	Assumption based on general literature review	
Gypsum wallboard				
New drywall	Gypsum from scrap drywall used as substitute for virgin gypsum in manufacturing new drywall	15%	Midpoint of typical recycled amounts of scrap drywall in new products (10%-20%)	CDRA (2015a)
Portland cement	Gypsum from scrap drywall used as substitute for other material in manufacturing of Portland cement	1%	Assumption based on general literature review, including USGS (2010a), p. 33.2 and EPA (2015)	
Soil amendment	Reclaimed gypsum from scrap drywall applied to soil as substitute for other nutrients or texture amendments	1%	Assumption based on general literature review, including USGS (2010a), p. 33.2 and EPA (2015)	
Fertilizer additive	Gypsum from scrap drywall used as substitute for other nutrient sources in fertilizer manufacturing	1%	Assumption based on general literature review, including USGS (2010a), p. 33.2 and EPA (2015)	

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Wood				
Engineered wood products	Reclaimed C&D wood chipped and used as substitute for other wood in engineered wood product manufacturing	1%	Assumption based on general literature review, including Bratkovich et al. (2014) and Falk and McKeever (2004)	
Wood flooring	Reclaimed C&D flooring and lumber processed and used as substitute for flooring made from virgin wood	1%	Assumption based on general literature review, including Bratkovich et al. (2014) and Falk and McKeever (2004)	
Mulch, animal bedding and compost amendment	Reclaimed C&D wood chipped and used as substitute for other material in mulch, animal bedding and compost manufacturing	1%	Assumption based on general literature review, including Bratkovich et al. (2014) and Falk and McKeever (2004)	

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10.8. Electronics

Recycled Material Quantities and Price

Material	Description		Assumptions (2007 Basis)	Data Sources
Recycled Electronics	Recycled computers, computer displays, printers, fax machines, keyboards, televisions and mobile devices	Material amounts recovered and recycled	388,404 mt	EPA (2011)
	Unit price assumptions			
Recycled Electronics	Recycled UEP - Computers and computer peripheral devices	Unit price (weight basis)	\$702.25 /mt	ITC (2013), Table 3.2
	Recycled UEP - Monitors	Unit price (weight basis)	\$798.93 /mt	ITC (2013), Table 3.2
	Recycled UEP - Hard Copy Devices	Unit price (weight basis)	\$116.87 /mt	On-line marketplace prices ²⁰
	Recycled UEP - Keyboards & Mice	Unit price (weight basis)	\$44.24 /mt	On-line marketplace prices ¹
	Recycled UEP – Televisions	Unit price (weight basis)	\$73.99 /mt	ITC (2013), Table 3.2
	Recycled UEP - Mobile Devices	Unit price (weight basis)	\$2,741.39 /mt	ITC (2013), Table 3.2

mt = metric ton

Major Consuming Processes/Applications of Recyclable Material

- Computer refurbishers, remanufacturers, resellers (NAICS 334111)
- Computer monitor refurbishers, remanufacturers, resellers (NAICS 334119)
- Printer, scanner and multi-function device refurbishers, remanufacturers and resellers (NAICS 334119)
- Fax machine refurbishers, remanufacturers and resellers (NAICS 334210)
- Digital copier refurbishers, remanufacturers and resellers (NAICS 333315)
- Keyboard and mouse refurbishers, remanufacturers and resellers (NAICS 334119)
- Television refurbishers, remanufacturers and resellers (NAICS 334310)
- Mobile device refurbishers, remanufacturers and resellers (NAICS 334220)

²⁰ Calculated based on average price of top 10 "new & popular" on Amazon.com

Data sources: IDC (2011); EPA (2011)

Recyclable Material Proportion

Consuming Process	Process Description ²¹	Recyclable Material Proportion (2007)	Basis for Proportion (2007) ²²	Data Source
Computers	Used computers refurbished, remanufactured and resold as substitute for new computers	9.1%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Computer displays	Used computer displays refurbished, remanufactured and resold as substitute for new computer displays	9.2%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Hard copy devices: printers, scanners, multi-function devices	Used hard copy devices refurbished, remanufactured and resold as substitute for new hard copy devices	7.7%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Hard copy devices: fax machines	Used hard copy devices refurbished, remanufactured and resold as substitute for new hard copy devices	7.7%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Hard copy devices: digital copiers	Used hard copy devices refurbished, remanufactured and resold as substitute for new hard copy devices	7.7%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Keyboards and mice	Used keyboards and mice refurbished, remanufactured and resold as substitute for new keyboards and mice	2.5%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)

²¹ For the purposes of this analysis, electronics recycling includes the recovery, refurbishing/remanufacturing and resale of electronics devices. It does not include the processing of used electronics into commodity-grade scrap, such as ferrous metals, nonferrous metals, glass and plastic. To avoid double-counting, commodity-grade scrap is included in estimates of recycling of the respective commodity.

²² The ratio is calculated by multiplying tons of products collected for recycling (EPA 2011, Table 11) by percentage recycled from IDC (2011) (30% for all products except mobile devices; 42% for mobile devices) and dividing this number by the total weight of comparable products sold, derived by multiplying total sales from EPA (2011), Table 1, by average device weight from EPA (2011), Table 2, and converting units. E.g., Recyclable Material Proportion for computers (2007) = $(143,000 * 30\%) / (((34,210,000 * 22) + (30,020,000 * 6.4)) / 2000) = 9.1\%$.

Consuming Process	Process Description ²¹	Recyclable Material Proportion (2007)	Basis for Proportion (2007) ²²	Data Source
Televisions	Used televisions refurbished, remanufactured and resold as substitute for new televisions	3.9%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)
Mobile devices	Used mobile devices refurbished, remanufactured and resold as substitute for new mobile devices	3.0%	Ratio of weight of recycled devices sold to all devices sold	EPA (2011), Tables 1, 2 and 11; IDC (2011)

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10.9. Food and Organics

Donated Food Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Gleaned produce	Produce that would not have been harvested by farmers for commercial sale and was gleaned for donation to community food programs. Does not include unusable parts of fruits, vegetables and grains that are unsuitable for human consumption (see "crop residue").	Material amounts recovered and donated	19,654 mt	EPA (2009), Exhibit 5

Material				
Rescued food	Food that was prepared by restaurants and institutional food services that would have been wasted but was diverted and recovered for use in community food programs.	Material amounts recovered and donated	17,378 mt	EPA (2009), Exhibit 5
Salvaged food	Food, including manufactured food products nearing expiration and fresh produce nearing spoilage, that would have been wasted but was diverted and recovered for use in community food programs. Does not include food that would not have been wasted if it was not donated (e.g., canned goods collected as part of a food drive).	Material amounts recovered and donated	265,268 mt	EPA (2009), Exhibit 5

Recyclable Organic Material Quantities and Price

Material	Description	Assumptions (2007 Basis)		Data Sources
Animal by-products	By-products of livestock slaughtering operations and fish and other seafood processing operations and processing scraps (e.g., trimmed fat) from grocery stores and butcher shops.	Material amounts recovered and recycled	21,858,700 mt	Jekanowski (2011)
Crop residue	Parts of fruit and vegetables such as stalks, leaves and roots that are not normally sold for food products as well as misshapen, bruised or undersized fruit and vegetables that are separated out on the farm as unsuitable for sale or food donation. Does not include "gleaned produce," as defined herein.	Material amounts recovered and recycled	3,533 mt	Sapkota et al. (2007); Platt et al. (2014)
Dairy by-products	By-products of milk and cheese production, including buttermilk and whey that would be wasted if not diverted for recycling.	Material amounts recovered and recycled	15,518 mt	NARA (2009); BSR (2013); USEPA (2014)

Material				
Deceased stock	Animals that are condemned and/or non-ambulatory prior to slaughter and dead aquatic animals from aquaculture operations that, therefore, cannot be processed for human food.	Material amounts recovered and recycled	952,350 mt	Jekanowski (2011)
Grease/FOG	Natural by-products of the cooking process, derived from animal fats, vegetable oils, baked goods, dairy products and other foods. Includes yellow grease rendered from spent filtered cooking oil and brown grease that has been processed to remove contaminants.	Material amounts recovered and recycled	1,159,146 mt	Jekanowski (2011); USEPA (2014)
Plate waste	Uneaten food served in restaurants, institutional food service facilities and homes that is not saved as leftovers for future human consumption.	Material amounts recovered and recycled	495,517 mt	USEPA (2007); NARA (2009); USEPA (2014)
Produce, oilseed and grain residue	Residues from food manufacturing and processing operations, including inedible trimmings, other fruit and vegetable material left-over after processing and residues from grain and oilseed processing. Does not include edible produce that is salvaged for feeding people (see "salvaged food") or "spoiled food," as defined herein.	Material amounts recovered and recycled	463,530 mt	NARA (2009); BSR (2013); USEPA (2014)
Spoiled food	Food, including fruits, vegetables, meat and semi-perishable manufactured products, which spoil or expire and cannot be sold, donated or processed for human consumption.	Material amounts recovered and recycled	445,595 mt	NARA (2009); BSR (2013); USEPA (2014)
Trim and other cooking waste	Food scraps resulting from food preparation, including inedible and/or trimmed parts of fruits and vegetables, trimmings from preparing meat and burned or otherwise inedible cooking products.	Material amounts recovered and recycled	428,565 mt	USEPA (2007); NARA (2009); USEPA (2014)
Yard trimmings	Grass, leaves and tree and brush trimmings from residential, institutional and commercial sources.	Material amounts recovered and recycled	17,505,100 mt	EPA (2007); CalRecycle (2010); Platt et al. (2013)

Material	Description	Assumptions (2007 Basis)		Data Sources
Unit price assumptions (only for recyclable organic products sold on the market)				
Animal by-products	Estimated the average annual price of selected rendered products in 2007. The rendered products include materials such as inedible tallow and greases, edible tallow and lard and protein meals (meat and bone meal, pork meat and bone meal, blood meal, pork blood meal).	Unit price of 1 metric ton of rendered products	\$545.30/mt	NRA (2012)
Dairy by-products	Estimated the average price of dairy by-products whey and buttermilk in 2007.	Unit price of 1 metric ton of dairy by-products	\$2481.76/mt	USDA (2008)
Grease	Estimated the average price of recovered grease product.	Unit price of 1 metric ton of grease	\$224.87/mt	Centrec (2014)

mt = metric ton

Recycled Organic Material Quantities

Material	Description	Assumptions (2007 Basis)		Data Sources
Animal meal, meat, fats, oils and tallow	Primary products of animal rendering processes. Different types of meat and bone meal is a protein product used to produce livestock, poultry, aquaculture feed and pet food. Animal fats, oils and tallow are used as intermediate products for animal feed; industrial products like fatty acids, lubricants, plastics, printing inks and explosives; and consumer products such as soap, cosmetics, shaving cream, deodorants, perfumes, polishes, cleaners, paints, candles, fertilizer and caulking compounds. Special rendering processes are used to produce edible products, such as lard, from specially sourced animal by-products.	Material amounts recycled	8,364,137 mt	Jekanowski (2011)

Material				
Animal feed for animal production	Keeping, grazing, breeding or feeding animals, including livestock and aquatic animals, for sale.	Material amounts recycled	2,742,531 mt	EPA (2009)
Biodiesel	A replacement fuel for diesel engines made from used cooking oils, vegetable oils and/or animal fats and oils; usually made up of a blend of pure biodiesel and petroleum-based diesel.	Material amounts recycled	2,524,963 mt	NRA (2007)
Biogas	A renewable energy fuel gas consisting mainly of methane and carbon dioxide that is produced through anaerobic digestion.	Material amounts recycled	17,402,653 mt	American Biogas Council (2014)
Compost	Material produced from the aerobic decomposition of organic material. Compost is used as a soil amendment and surface dressing for agricultural, silvicultural, horticultural, landscaping and construction applications.	Material amounts recycled	5,830,932 mt	Platt et al. (2013)
Mulch & wood chips	Mulch: Organic, non-composted product created by chipping or grinding woody yard trimmings, land clearing debris, crop residuals and other natural wood, used as a ground cover around or over plants to enrich or insulate the soil. Wood Chips: Organic, non-composted product created by chipping or grinding woody yard trimmings, land clearing debris and other natural wood, used as a ground cover, boiler fuel or as an intermediate product for animal bedding and other value-added applications.	Material amounts recycled	5,532,740 mt	Assumption

mt = metric ton

Sources and Uses of Donated Diverted Food Waste

- Gleaned produce
 - Community food programs (NAICS 624210, Community Food Services)

Data Sources: USEPA and USDA (1999)

- Salvaged and rescued food
 - Community food programs (NAICS 624210, Community Food Services)

Data sources: USEPA (1999); USEPA (2009); USEPA (2013a); USEPA (2014); USEPA (2015a)

Sources and Uses of Recyclable Organics

- **Animal by-products**

- Rendering and animal by-product processing (NAICS 311613, Rendering and Meat Byproduct Processing)
- Other bio-based materials manufacturing (not specified – see Note 1)

Data Sources: Meeker (2006); Jekanowski (2011); Centrec (2014); USEPA (2014)

- **Crop residue**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Biofuels manufacturing (NAICS 325199, All Other Basic Organic Chemical Manufacturing)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)
- Other bio-based materials manufacturing (not specified – see Note 1)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data Sources: Sapkota et al. (2007); Platt et al. (2014)

- **Dairy by-products**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)

Data sources: Sapkota et al. (2007); NREL (2013); USEPA (2015b); USDA (2008)

- **Deceased stock**

- Rendering and animal by-product processing (NAICS 311613, Rendering and Meat Byproduct Processing)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data Sources: Meeker (2006); Jekanowski (2011); Platt et al. (2014)

- **Grease/FOG**

- Rendering and animal by-product processing (NAICS 311613, Rendering and Meat Byproduct Processing)
- Biofuels manufacturing (NAICS 325199, All Other Basic Organic Chemical Manufacturing)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)

Data sources: IWMRC (2006); USEPA (2009); Jekanowski (2011); USDA (2011); USEPA (2014); USEPA (2015a); USEPA (2015b)

- **Plate waste**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data sources: Sapkota et al. (2007); USEPA (2008); USEPA (2009); CalRecycle (2010); USDA (2011); USEPA (2013b); NREL (2013); Platt et al. (2014); Themelis and Arsova (2015); USEPA (2014); USEPA (2015a); USEPA (2015b)

- **Produce, oilseed and grain residue**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)
- Other bio-based materials manufacturing (not specified – see Note 1)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data sources: Sapkota et al. (2007); BSR (2013); NREL (2013); Platt et al. (2014); USEPA (2014); USEPA (2015a); USEPA (2015b)

- **Spoiled food**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data sources: Sapkota et al. (2007); USEPA (2008); USEPA (2009); CalRecycle (2010); USDA (2011); BSR (2013); USEPA (2013b); NREL (2013); Platt et al. (2014); USEPA (2014); USEPA (2015a); Themelis and Arsova (2015); USEPA (2015b)

- **Trim and other cooking waste**

- Minimally processed animal feed (NAICS 112210, Hog and Pig Farming)
- Anaerobic digestion (NAICS 221119, Other Electric Power Generation)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)

Data sources: Sapkota et al. (2007); USEPA (2008); USEPA (2009); CalRecycle (2010); USDA (2011); USEPA (2013b); NREL (2013); Platt et al. (2014); USEPA (2014); Themelis and Arsova (2015); USEPA (2015a); USEPA (2015b)

- **Yard trimmings**

- Other biomass-based power generation (NAICS 221119, Other Electric Power Generation)
- Compost manufacturing (NAICS 325314, Fertilizer (Mixing Only) Manufacturing)
- Landscape materials application (NAICS 561730, Landscaping Services)

Data sources: USEPA (2008); CalRecycle (2010); Platt et al. (2013); USEPA (2013b); Platt et al. (2014); SCDHEC (2014); Themelis and Arsova (2015)

Note 1: The WIO model includes production of bio-based materials and chemicals as an output of recycling through two processes: 1) rendering and animal by-products processing, and 2) biofuels manufacturing. It is recognized that bio-based materials are produced through other recycling processes. However, due to the diffuse nature of these processes and lack of data to model them, they are not included quantitatively in the analysis.

Donated Food Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Gleaned produce				
Community food programs	Gleaned produce from farms without which community food programs would need to find another source of produce (e.g., purchased produce) to meet their needs.	2.3%	Ratio of estimated amount of gleaned produce to total food donated in 2008, where 10% of produce donated in 2008 is assumed to be gleaned	USEPA (2009)
Salvaged and rescued food				
Community food programs	Salvaged and rescued food without which community food programs would need to find another source of food (e.g., purchased) to meet their needs.	33.2%	Ratio of estimated amount of salvaged and rescued food to total food donated in 2008, where 90% of produce donated in 2008 is assumed to be from food salvage or rescue	USEPA (2009)

Recyclable Materials Proportion

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Animal by-products				
Rendering and animal by-product processing	By-products from slaughterhouses, grocery stores and butcher shops rendered to produce usable products	91.3%	Ratio of estimated amount of animal by-products to total raw material, 2008	Jekanowski (2011)
Other bio-based materials manufacturing ¹	Animal by-products recovered and used (without intermediate rendering) to produce bio-based products (e.g., oyster shells as landscaping material)	---	---	---
Crop residue				
Minimally processed animal feed	Crop residue recovered and used as substitute for other sources of feed used in hog and pig farming	<0.1%	Ratio estimated crop residue diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)
Biofuels manufacturing ²	Crop residue recovered and used as feedstock for biofuels manufacturing	---	---	---
Anaerobic digestion	Dairy by-products recovered and used as substitute for other feedstock in off-farm, commercial anaerobic digestion operations	0.3%	Percentage anaerobic digestion feedstock from crop residue based on European study (5%)	ABDA (2015)
Other bio-based materials manufacturing ¹	Crop residue recovered and used to produce bio-based products	---	---	---
Compost manufacturing	Crop residue recovered and used to produce compost in off-farm commercial composting operations	<0.1%	Ratio of estimated crop residue recovered for off-farm composting to total compost feedstock	Platt et al. (2014)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Dairy by-products				
Minimally processed animal feed	Dairy by-products recovered and used as substitute for other sources of feed used in hog and pig farming	<0.1%	Ratio estimated dairy by-products diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)
Anaerobic digestion	Dairy by-products recovered and used as substitute for other feedstock in off-farm, commercial anaerobic digestion operations	0.5%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; dairy products assumed 10% of this recyclables stream	ABDA (2015)
Deceased stock				
Rendering and animal by-product processing	Deceased stock rendered to produce usable products	4.0%	Ratio of estimated amount of dead stock to total raw material, 2008	Jekanowski (2011)
Compost manufacturing	Deceased stock recovered and used to produce compost in off-farm commercial composting operations	<0.1%	Ratio of estimated crop residue recovered for off-farm composting to total compost feedstock	Platt et al. (2014)
Grease/FOG				
Rendering and animal by-product processing	Recovered restaurant grease rendered to produce usable products	4.7%	Ratio of estimated amount of recovered restaurant grease to total raw material, 2008	Jekanowski (2011)
Biofuels manufacturing ²	Recovered restaurant grease used as feedstock for biofuels manufacturing	---	---	---

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Anaerobic digestion	Recovered restaurant grease used as substitute for other feedstock in commercial anaerobic digestion operations	1.0%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; grease/FOG assumed 20% of this recyclables stream	ABDA (2015)
Plate waste				
Minimally processed animal feed	Plate waste recovered and diverted and used as substitute for other sources of feed used in hog and pig farming	0.7%	Ratio estimated plate waste diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)
Anaerobic digestion	Recovered plate waste used as substitute for other feedstock in commercial anaerobic digestion operations	0.5%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; grease/FOG assumed 20% of this recyclables stream	ABDA (2015)
Compost manufacturing	Plate waste recovered and used to produce compost in off-farm commercial composting operations	2.9%	Ratio of food waste composted in 2007 to total compost feedstock; apportioned equally between plate waste and trim and other cooking waste	EPA (2007); Platt et al. (2014)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Produce, oilseed and grain residue				
Minimally processed animal feed	Produce, oilseed and grain processing residue recovered and used as substitute for other sources of feed used in hog and pig farming	0.2%	Ratio estimated produce, oilseed and grain residue diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)
Anaerobic digestion	Produce, oilseed and grain processing residue recovered and used as substitute for other feedstock in commercial anaerobic digestion operations	2.0%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; produce, oilseed and grain residue assumed 40% of this recyclables stream	ABDA (2015)
Other bio-based materials manufacturing ¹	Produce, oilseed and grain processing residue recovered and used to produce bio-based products	---	---	---
Compost manufacturing	Produce, oilseed and grain processing residue recovered and used to produce compost in off-farm commercial composting operations	3.0%	Ratio of estimated diverted food waste from manufacturing sector to total compost feedstock	BSR (2013); Platt et al. (2014)
Spoiled food				
Minimally processed animal feed	Spoiled food recovered and used as substitute for other sources of feed used in hog and pig farming	0.2%	Ratio of estimated spoiled food diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Anaerobic digestion	Spoiled food recovered and used as substitute for other feedstock in commercial anaerobic digestion operations	0.5%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; spoiled food assumed 10% of this recyclables stream	ABDA (2015)
Compost manufacturing	Spoiled food recovered and used to produce compost in off-farm commercial composting operations	3.3%	Ratio of estimated diverted food waste from food wholesale/retail sector to total compost feedstock	BSR (2013); Platt et al. (2014)
Trim and other cooking waste				
Minimally processed animal feed	Trim and other cooking waste recovered and used as substitute for other sources of feed used in hog and pig farming	0.3%	Ratio estimated trim and other cooking waste diverted for animal feed to animal feed required to support hog inventory, 2007	NARA (2009); Feedstuffs (2011)
Anaerobic digestion	Trim and other cooking waste recovered and used as substitute for other feedstock in commercial anaerobic digestion operations	0.5%	Percentage anaerobic digestion feedstock from food waste based on European study (5%) apportioned across food waste categories in study; trim and other cooking waste assumed 10% of this recyclables stream	ABDA (2015)
Compost manufacturing	Trim and other cooking waste recovered and used to produce compost in off-farm commercial composting operations	2.9%	Ratio of food waste composted in 2007 to total compost feedstock; apportioned equally between plate waste and trim and other cooking waste	EPA (2007); Platt et al. (2014)

Consuming Process	Process Description	Recyclable Material Proportion	Basis for Proportion	Data Source
Yard trimmings				
Other biomass-based power generation	Diverted natural wood waste processed by chipping and grinding and used as boiler fuel for energy production	0.1%	Industrial biomass energy consumption and electricity net generation by industry and energy source, 2007	EIA (2012), Table 1.8
Compost manufacturing	Yard trimmings (grass and woody waste) recovered and used to produce compost in off-farm commercial composting operations	83.8%	Ratio of estimated tons of yard waste composted to total compost feedstock	EPA (2007); Platt et al. (2013); Platt et al. (2014)
Landscape materials application	Diverted natural wood waste processed by chipping and grinding (not composted) and applied for landscape cover (e.g., “mulch” and “wood chips”)	1.0%	Assumption based on reasoning that most bio-based landscaping materials are produced in the forest products manufacturing industry (not from wood waste diverted from MSW)	---

Notes:

- ¹ Economic activity associated with recycling of organics via bio-based materials manufacturing processes were not quantified due to diffuse nature of activities and lack of supporting data.
- ² Economic activity associated with biofuels manufacturing was not included in the scope of the study.

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11. Appendix E – Recycling Material Quantity and Price Data

Table 17: Recycling Material Quantity and Price Data

Material	Description	Assumptions (2007 Basis)	Data Sources	Comments	
Iron and Steel	Total ferrous metals recovered from appliances (such as washing machines, water heaters, refrigerators etc.), automobiles, steel containers, construction material and other sources	Material amounts recovered and recycled	35,039,566 mt	USGS (2014)	This tonnage is the sum of all ferrous metal products recovered. The recycled ferrous metal amount was estimated from this number by assuming a material loss of 5% during the recycling process meaning that 95% of the recovered ferrous metal is assumed to be recycled
Iron and Steel	Appliances (washing machines, water heaters, air conditioners, refrigerators, dryers)	Material amounts recovered and recycled	2,600,000 mt	USGS (2014)	See pg. 38.1 of source USGS (2014)
Iron and Steel	Automobiles	Material amounts recovered and recycled	14,800,000 mt	USGS (2014)	See pg. 38.1 of source USGS (2014)
Iron and Steel	Steel containers	Material amounts recovered and recycled	17,000,000 mt	USGS (2014)	See pg. 38.1 of source USGS (2014)
Iron and Steel	Construction materials and other	Material amounts recovered and recycled	639,566 mt	EPA (2003), Tellus Institute (2011)	The amount of ferrous metals that comprise all of the metal amount recovered from construction and demolition activities (EPA, 2003) was estimated using the Tellus Institute report (Tellus Institute 2011). Acc. to the report approx. 75% of metal waste in C&D activities is comprised of ferrous metals and 12.5% of waste is comprised of non-ferrous metals while the remaining 12.5% is comprised of other metals. Pg. B-18 of source EPA (2003) provides metal amounts recycled from C&D waste as 940,000 short tons/yr which when converted is

Material	Description	Assumptions (2007 Basis)	Data Sources	Comments	
				852,754 mt, of which 75% is ferrous metal amount, i.e., 639,566 mt	
Iron and Steel	-	Unit price of recycled material	\$795.65 /mt	USGS (2013), p. 72	Based on average annual unit price for hot rolled steel bar. The source reports the price as \$36.09/100 lbs., converted to \$795.65/mt
Aluminum	Aluminum scrap from used beverage cans, other containers, transportation, construction and other sources	Material amounts recovered and recycled	1,524,071 mt	Aluminum Association (2011)	According to personal communications with the Aluminum Association, the recycled proportion in the US metal supply was approx. 40%. Quantities of recovered material from scrap recycling in 2007 were 4.2 million tons which converted is 3,810,177 mt, 40% of which is 1,524,071 mt.
Aluminum	-	Unit price of recycled material	\$2,640 /mt	Index Mundi (2015)	Based on the London Metal Exchange spot price for aluminum in 2007, 99.5% purity; comparable to unit price of aluminum in 2007 from USGS (2013), p. 5
Glass	Glass cullet recovered from glass bottles and jars	Material amounts recovered and recycled	2,053,020 mt	GPI (2014)	According to source, glass cullet recovered is approx. 2,263,067 short ton which converted is 2,053,020 mt
Glass	-	Unit price of recycled material	\$32.50 /mt	Popular Mechanics (2008)	Price converted from \$/short ton to \$/mt
Paper	Recovered and recycled paper and paperboard	Material amounts recovered and recycled	13,508,892 mt	AFPA (2014)	According to source AFPA (2014), recycled paperboard production in year 2007 was 14,891,000 short tons which converted is 13,508,892 mt. However, for WIO calculations, recycled paper production amounts were calculated by dividing the recycled paperboard production amounts by the sum of commodity output of industrial sectors - 'Paperboard mills' and 'Paperboard container manufacturing', multiplied with the sum of commodity output of all industrial sectors related to paper production such as 'Paper mills', 'Paperboard mills', 'Paperboard container manufacturing', 'Paper bag manufacturing', 'Stationery product manufacturing',

Material	Description	Assumptions (2007 Basis)		Data Sources	Comments
					'Sanitary product manufacturing' and 'All other converted paper product manufacturing'.
Paper	-	Unit price of recycled material	\$126.77 /mt	Popular Mechanics (2008)	Price converted from \$/short ton to \$/mt
Plastic	Total Recycled plastics	Material amounts recovered and recycled	2,540,118 mt	EPA (2014)	This is the sum of all plastics recovered and recycled
Plastic	Durable goods	Material amounts recovered and recycled	698,532 mt	EPA (2014)	According to source EPA (2014), material amounts of durable goods (PET, HDPE, PVC, LDPE/LLDPE, PP, PS and other resins) are reported as 770,000 short tons which converted is 698,532 mt
Plastic	Nondurable goods	Material amounts recovered and recycled	117,934 mt	EPA (2014)	According to source EPA (2014), material amounts of nondurable goods (plastics in clothing, footwear, disposable diapers, etc.) are reported as 130,000 short tons which converted is 117,934 mt
Plastic	Plastic containers and packaging	Material amounts recovered and recycled	1,723,652 mt	EPA (2014)	According to source EPA (2014), material amounts of plastic containers and packaging (such as bottles, jars, other containers, bags, sacks, wraps and other plastic packaging) are reported as 1,900,000 short tons which converted is 1,723,652 mt
Plastic	-	Unit price of recycled material	\$1,208.68 /mt	Block (2012)	The source Block (2012) provides recycled resin prices in ¢/lb. which after averaging out is converted into \$/mt
Rubber crumb	Ground rubber produced from scrap tires	Material amounts recovered and recycled	1,100,016 mt	RMA (2014)	The source RMA (2014) provides information on ground rubber and rubber used in civil engineering projects. Both estimates were used to calculate the ground rubber amounts produced from scrap tires
Rubber crumb	-	Unit price of recycled material	\$374.79 /mt	ProfitableRecycling (2015)	Price converted from \$/short ton to \$/mt

Material	Description	Assumptions (2007 Basis)		Data Sources	Comments
Other recycled rubber	Other rubber recovered from scrap tires used in civil engineering, reclamation and agricultural applications.	Material amounts recovered and recycled	971,218 mt	RMA (2014)	The source RMA (2014) provides information on different types of recycled rubber amounts including recycled rubber used in tire derived fuel. Estimates of other rubber recovered were derived by subtracting the sum of ground rubber and tire derived fuel rubber from the total recycled rubber amounts
Other recycled rubber	-	Unit price of recycled material	\$385.81 /mt	ProfitableRecycling (2015)	Price converted from \$/short ton to \$/mt
Recycled Construction & Demolition Material	Recycled concrete, asphalt, gypsum and wood recovered from construction and demolition waste	Material amounts recovered and recycled	863,050,913 mt	Modeled based on estimates of % contribution of C&D to end uses	C&D metal waste is included in ferrous and nonferrous metals recycling analysis. Recycled construction and demolition amounts were calculated by dividing the total commodity output of the C&D sectors by the price of total recycled C&D material in \$/mt
Recycled Construction & Demolition Material	Recycled concrete	Unit price of recycled material	\$9.50 /mt	USGS (2000)	Averaged out the price of aggregate products made from recycled concrete
Recycled Construction & Demolition Material	Brick (recycled aggregate)	Unit price of recycled material	\$27.78 /mt	Kurtz (2015)	Recycled bricks are often placed in mixed aggregate markets, with concrete and block and are used in aggregate production. Therefore the price of recycled bricks is assumed to be the same as price of recycled aggregates \$25.20/short ton which converted is \$27.78/mt
Recycled Construction & Demolition Material	Wood (recycled wood chips)	Unit price of recycled material	\$24.80 /mt	NETI (2015)	Averaged out the price of wood chips in source NETI (2005), \$22.50/short ton which converted is \$24.80/mt
Recycled Construction & Demolition Material	Asphalt (recycled asphalt shingles)	Unit price of recycled material	\$44.09 /mt	Crushcrete (2015)	According to the source, recycled asphalt shingles are \$40/short ton which converted is \$44.09/mt
Recycled Construction &	Gypsum (drywall)	Unit price of recycled material	\$15.98 /mt	Bauer (2012)	According to the source, pg. 30, recycled gypsum is on an average \$14.5/short ton which converted is \$15.98/mt

Material	Description	Assumptions (2007 Basis)		Data Sources	Comments
Demolition Material					
Recycled Electronics	Total Recycled computers, computer displays, printers, fax machines, keyboards, televisions and mobile devices	Material amounts recovered and recycled	388,404 mt	EPA (2011)	This is the sum of all electronic products recovered and recycled
Recycled Electronics	Computers	Material amounts recovered and recycled	100,589 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of computer products collected for recycling is 168,000 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 110,880 short tons which converted is 100,589 mt
Recycled Electronics	Monitors	Material amounts recovered and recycled	116,156 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of electronic products - monitors collected for recycling is 194,000 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 128,040 short tons which converted is 116,156 mt
Recycled Electronics	Hard Copy Devices	Material amounts recovered and recycled	58,078 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of electronic products - hard copy devices collected for recycling is 97,000 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 64,020 short tons which converted is 58,078 mt
Recycled Electronics	Keyboards and Mice	Material amounts recovered and recycled	3,868 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of electronic products - keyboards and mice - collected for recycling is 6460 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 4,264 short tons which converted is 3,868 mt
Recycled Electronics	Televisions	Material amounts recovered and recycled	108,372 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of electronic products - televisions - collected for recycling is 181,000 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 119,460 short tons which converted is 108,372 mt

Material	Description	Assumptions (2007 Basis)		Data Sources	Comments
Recycled Electronics	Mobile Devices	Material amounts recovered and recycled	1,341 mt	EPA (2011)	According to source EPA (2011) pg. 26, material amounts of electronic products - mobile devices - collected for recycling is 2,240 short tons. Of these roughly 66% were recycled (pg. 20) amounting to 1,478 short tons which converted is 1,341 mt
Recycled Electronics	Recycled UEP - Computers and computer peripheral devices	Unit price (weight basis)	\$702.25 /mt	ITC (2013), Table 3.2	According to source ITC (2013), Table 3.2, pg. 3-7, the price of computers and computer peripheral devices was estimated by dividing the value (in million \$) by volume (in short tons) and then converting the resulting price in \$/short tons to \$/mt
Recycled Electronics	Recycled UEP - Monitors	Unit price (weight basis)	\$798.93 /mt	ITC (2013), Table 3.2	According to source ITC (2013), Table 3.2, pg. 3-7, the price of monitors was estimated by dividing the value (in million \$) by volume (in short tons) and then converting the resulting price in \$/short tons to \$/mt
Recycled Electronics	Recycled UEP - Hard Copy Devices	Unit price (weight basis)	\$116.87 /mt	On-line marketplace prices	Calculated based on average price of top 10 "new & popular" on Amazon.com
Recycled Electronics	Recycled UEP - Keyboards & Mice	Unit price (weight basis)	\$44.24 /mt	On-line marketplace prices	Calculated based on average price of top 10 "new & popular" on Amazon.com
Recycled Electronics	Recycled UEP – Televisions	Unit price (weight basis)	\$73.99 /mt	ITC (2013), Table 3.2	According to source ITC (2013), Table 3.2, pg. 3-7, the price of televisions was estimated by dividing the value (in million \$) by volume (in short tons) and then converting the resulting price in \$/short tons to \$/mt
Recycled Electronics	Recycled UEP - Mobile Devices	Unit price (weight basis)	\$2,741.39 /mt	ITC (2013), Table 3.2	According to source ITC (2013), Table 3.2, pg. 3-7, the price of mobile devices was estimated by dividing the value (in million \$) by volume (in short tons) and then converting the resulting price in \$/short tons to \$/mt
Donated Food	Donated gleaned produce	Material amounts recovered and recycled	19,654 mt	EPA (2009)	Calculated based on the assumption that 10% of produce donated in 2007 from EPA (2009), Exhibit 5, was from gleaned produce.
Donated Food	Donated rescued food	Material amounts recovered and recycled	17,378 mt	EPA (2009)	"Prepared food" from EPA (2009), Exhibit 5, based on alignment between definitions of rescued food herein and prepared food in EPA (2009).

Material	Description	Assumptions (2007 Basis)	Data Sources	Comments	
Donated Food	Donated salvaged food	Material amounts recovered and recycled	265,268 mt	EPA (2009)	Calculated as "salvaged food" plus remaining 90% of donated produce from EPA (2009), Exhibit 5.
Recycled Organics	Animal meal, meat, fats, oils and tallow	Material amounts recovered and recycled	8,364,137 mt	Jekanowski (2011)	Reported information.
Recycled Organics	Animal feed for animal production	Material amounts recovered and recycled	2,742,531 mt	EPA (2009)	Reported information.
Recycled Organics	Biodiesel	Material amounts recovered and recycled	2,524,963 mt	NRA (2007)	Reported information.
Recycled Organics	Biogas	Material amounts recovered and recycled	17,402,653 mt	American Biogas Council (2014)	Reported information.
Recycled Organics	Compost	Material amounts recovered and recycled	5,830,932 mt	Platt et al. (2013)	Reported information.
Recycled Organics	Mulch & wood chips	Material amounts recovered and recycled	5,532,740 mt	Assumption	Calculated based on estimated recovered yard trimmings and process loss assumptions.

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12. Appendix F – Employment and Tax Revenue Data Compilation

12.1. Overview of Methodology

This appendix describes the methodology used to compile employment and tax data for estimating the jobs, wages, occupational profile and tax revenue associated with recycling. All data were obtained from official U.S. Government sources, which are listed in Table 18. All data represent a 2007 baseline for consistency with the economic information used in the WIO model. Methods used to associate publicly available data to the BEA I-O structure used in the WIO model are described in the following sections of this appendix.

Table 18: Data Sources by Economic Sector

Sector	Associated Activities	Jobs and Wages	Occupational Profile	Tax Payments
Agriculture	<ul style="list-style-type: none"> • Crop production • Animal production 	2007 U.S. Census of Agricultural (USDA, 2007)	2007 Occupational and Employment Statistics (BLS, 2007)	2007 U.S. Statistics of Income (IRS, 2007)
Nonfarm private industry	<ul style="list-style-type: none"> • Mining and logging • Construction • Manufacturing • Trade, transportation and utilities • Services 	2007 Statistics of U.S. Businesses (Census, 2007)		
Government	<ul style="list-style-type: none"> • Federal government • State government • Local government 	2007 Annual Survey of Public Employment and Payroll (Census, 2007)		

12.2. Employment and Wages

The U.S. Government collects information regarding employment and wages through a number of different programs. For the purposes of this analysis, the following sources were used:

- *U.S. Census of Agriculture*—The U.S. Department of Agriculture (USDA) conducts the Census of Agriculture every 5 years to gather information regarding U.S. farms and ranches, including information about operators, hired labor and wages, total sales and farm/ranch income.²³

²³ Ref. <http://www.agcensus.usda.gov/>

- *Statistics of U.S. Businesses (SUSB)*—SUSB is an annual series developed by the U.S. Census Bureau from the Business Register, Company Organization Survey, other Census Bureau programs (e.g., Annual Survey of Manufactures and Current Business Surveys) and records of the Internal Revenue Service, Social Security Administration and Bureau of Labor Statistics. The SUSB provides national data on jobs, wages, sales and other factors, covering most of the country's economic activity. The series does not cover agricultural production, non-employer businesses, private households, railroads and most government entities.²⁴
- *Annual Survey of Public Employment & Payroll*—the U.S. Census Bureau conducts the Annual Survey of Public Employment & Payroll to provide statistics on federal, state and local employment and payroll. The survey covers governmental functions including education, police and fire protection, financial administration, judicial and legal, public works and utilities, including solid waste management, public transit, social services and other functions.²⁵

Employment, wage and other data were compiled and linked to BEA codes for integration with the WIO model as described in Section 8.

12.2.1. Agriculture (Crop and Animal Production)

Data from the Census of Agriculture and the Statistical Abstract of the United States were used to estimate employment and wages associated with crop and animal production. The Census of Agriculture provides total employment and farm payroll data. The Statistical Abstract of the United States provides information on household earnings from farm income. Neither source disaggregates this information by NAICS code in publicly available datasets.

The Census of Agriculture does provide statistics at a 4- to 6-digit NAICS resolution on the market value of agricultural products sold. Therefore, employment and wage estimates were apportioned to NAICS categories based on the assumption that they are proportional to sales. Specific data sources include:

- *Market value of agricultural products sold, 2007*—USDA (2007), Table 46.
- *Total agricultural employment, 2007*—Sum of total operators, 2007 (USDA 2012, Table 45) and total hired farm labor, 2007 (USDA 2012, Table 7).
- *Total agricultural earnings and wages, 2007*—Sum of:
 - Total farm household earnings from farm income, calculated as product of total family farms, 2007 (Census 2012, Table 830) and average net earnings from farm income, 2007 (Census 2012, Table 830) and
 - Farm payroll for hired labor, 2007 (USDA 2012, Table 7).

Data were associated with NAICS categories and aggregated to BEA codes using the 2007 NAICS-to-BEA concordance table, Table 19.

²⁴ Ref. <http://www.census.gov/econ/susb/>

²⁵ <http://www.census.gov/govs/apes/>

12.2.2. Private Nonfarm Goods and Services

Estimates of employment and wages associated with nonfarm goods and services sectors were obtained from the 2007 Statistics of U.S. Businesses. Employment and wage data are available at 6-digit NAICS resolution. For some NAICS sectors, data were not reported in the 2007 SUSB because data were withheld to avoid disclosing data for individual businesses or they were deemed by the Census to be of insufficient quality. Where data were missing for a critical sector (e.g., employment and wage data for Glass Container Manufacturing, NAICS 327213), data were imputed from information reported at the 5-digit NAICS resolution.

Data were associated with NAICS categories and aggregated to BEA codes using the 2007 NAICS-to-BEA concordance table, Table 19.

12.2.3. Government

Data regarding public sector employment were compiled from the 2007 Annual Survey of Public Employment and Payroll. Federal, state and local employment data and wages are not associated with specific NAICS codes and were associated directly with BEA codes without using the NAICS concordance table. The data do not include statistics for federal defense employment and wages.

12.2.4. NAICS-to-BEA Concordance Table

The majority of publicly available data sources report 2007 according to the 2007 NAICS classification system. Generally, NAICS 6-digit codes represent a finer level or the same level of resolution than BEA codes, creating one-to-many or one-to-one (NAICS-to-BEA) relationships. These types of relationships can be mapped using a concordance table and data at finer NAICS resolutions can be rolled-up to BEA codes. For the construction and real estate sectors, NAICS and BEA codes have a many-to-many relationship. Additional data sources were required to associate NAICS-level data to multiple BEA codes.

Table 19 presents the NAICS-to-BEA concordance table used to compile employment and tax data in a way that enabled alignment and integration with the WIO model.

Table 19: NAICS-to-BEA Concordance Table

BEA Code	Description	Corresponding NAICS Codes
	Crop and Animal Production	
1111A0	Oilseed farming	111110, 111120
1111B0	Grain farming	111130, 111140, 111150, 111160, 11119
111200	Vegetable and melon farming	111211, 111219
111300	Fruit and tree nut farming	111310, 111320, 111331, 111332, 111333, 111334, 111335, 111336, 111339
111400	Greenhouse, nursery and floriculture production	11141, 111421, 111422
111900	Other crop farming	111910, 111920, 111930, 111940, 11199
1121A0	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming	112111, 112112
112120	Dairy cattle and milk production	11212
112A00	Animal production, except cattle and poultry and eggs	1122, 112410, 112420, 1125, 112910, 112920, 112930, 112990

BEA Code	Description	Corresponding NAICS Codes
112300	Poultry and egg production	112310, 112320, 112330, 112340, 112390
	Forestry, Fishing and Agricultural Support Services	
113000	Forestry and logging	113110, 113210, 113310
114000	Fishing, hunting and trapping	114111, 114112, 114119, 114210
115000	Support activities for agriculture and forestry	115111, 115112, 115113, 115114, 115115, 115116, 115210, 115310
	Mining, Quarrying, Oil and Gas Extraction, Utilities and Construction	
211000	Oil and gas extraction	211111, 211112
212100	Coal mining	212111, 212112, 212113
2122A0	Iron, gold, silver and other metal ore mining	212210, 212221, 212222, 212291, 212299
212230	Copper, nickel, lead and zinc mining	212231, 212234
212310	Stone mining and quarrying	212311, 212312, 212313, 212319
2123A0	Other nonmetallic mineral mining and quarrying	212321, 212322, 212324, 212325, 212391, 212392, 212393, 212399
213111	Drilling oil and gas wells	213111
21311A	Other support activities for mining	213112, 213113, 213114, 213115
221100	Electric power generation, transmission and distribution	221111, 221112, 221113, 221119, 221121, 221122
221200	Natural gas distribution	221210
221300	Water, sewage and other systems	221310, 221320, 221330
230301	Nonresidential maintenance and repair	236210, 236220, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
230302	Residential maintenance and repair	236118
233210	Health care structures	236220, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
233230	Manufacturing structures	236210, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
233240	Power and communication structures	237130
233262	Educational and vocational structures	236220, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990

BEA Code	Description	Corresponding NAICS Codes
233293	Highways and streets	237310
2332A0	Commercial structures, including farm structures	236220, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
2332B0	Other nonresidential structures	237110, 237120, 237990
233411	Single-family residential structures	236115, 236117, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
233412	Multifamily residential structures	236116, 236117, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
2334A0	Other residential structures	236115, 236116, 236117, 237210, 238110, 238120, 238130, 238140, 238150, 238160, 238170, 238190, 238210, 238220, 238290, 238310, 238320, 238330, 238340, 238350, 238390, 238910, 238990
	Manufacturing	
321100	Sawmills and wood preservation	321113, 321114
321200	Veneer, plywood and engineered wood product manufacturing	321211, 321212, 321213, 321214, 321219
321910	Millwork	321911, 321912, 321918
3219A0	All other wood product manufacturing	321920, 321991, 321992, 321999
327100	Clay product and refractory manufacturing	327111, 327112, 327113, 327121, 327122, 327123, 327124, 327125
327200	Glass and glass product manufacturing	327211, 327212, 327213, 327215
327310	Cement manufacturing	327310
327320	Ready-mix concrete manufacturing	327320
327330	Concrete pipe, brick and block manufacturing	327331, 327332
327390	Other concrete product manufacturing	327390
327400	Lime and gypsum product manufacturing	327410, 327420
327910	Abrasive product manufacturing	327910
327991	Cut stone and stone product manufacturing	327991
327992	Ground or treated mineral and earth manufacturing	327992
327993	Mineral wool manufacturing	327993
327999	Miscellaneous nonmetallic mineral products	327999
331110	Iron and steel mills and ferroalloy manufacturing	331111, 331112
331200	Steel product manufacturing from purchased steel	331210, 331221, 331222
33131A	Alumina refining and primary aluminum production	331311, 331312

BEA Code	Description	Corresponding NAICS Codes
331314	Secondary smelting and alloying of aluminum	331314
33131B	Aluminum product manufacturing from purchased aluminum	331315, 331316, 331319
331411	Primary smelting and refining of copper	331411
331419	Primary smelting and refining of nonferrous metal (except copper and aluminum)	331419
331420	Copper rolling, drawing, extruding and alloying	331421, 331422, 331423
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	331491, 331492
331510	Ferrous metal foundries	331511, 331512, 331513
331520	Nonferrous metal foundries	331521, 331522, 331524, 331525, 331528
33211A	All other forging, stamping and sintering	332111, 332112, 332117
332114	Custom roll forming	332114
33211B	Crown and closure manufacturing and metal stamping	332115, 332116
332200	Cutlery and hand tool manufacturing	332211, 332212, 332213, 332214
332310	Plate work and fabricated structural product manufacturing	332311, 332312, 332313
332320	Ornamental and architectural metal products manufacturing	332321, 332322, 332323
332410	Power boiler and heat exchanger manufacturing	332410
332420	Metal tank (heavy gauge) manufacturing	332420
332430	Metal can, box and other metal container (light gauge) manufacturing	332431, 332439
332500	Hardware manufacturing	332510
332600	Spring and wire product manufacturing	332611, 332612, 332618
332710	Machine shops	332710
332720	Turned product and screw, nut and bolt manufacturing	332721, 332722
332800	Coating, engraving, heat treating and allied activities	332811, 332812, 332813
33291A	Valve and fittings other than plumbing	332911, 332912, 332919
332913	Plumbing fixture fitting and trim manufacturing	332913
332991	Ball and roller bearing manufacturing	332991
33299A	Ammunition, arms, ordnance and accessories manufacturing	332992, 332993, 332994, 332995
332996	Fabricated pipe and pipe fitting manufacturing	332996
33299B	Other fabricated metal manufacturing	332997, 332998, 332999
333111	Farm machinery and equipment manufacturing	333111
333112	Lawn and garden equipment manufacturing	333112
333120	Construction machinery manufacturing	333120
333130	Mining and oil and gas field machinery manufacturing	333131, 333132
33329A	Other industrial machinery manufacturing	333210, 333291, 333292, 333293, 333294, 333298
333220	Plastics and rubber industry machinery manufacturing	333220
333295	Semiconductor machinery manufacturing	333295

BEA Code	Description	Corresponding NAICS Codes
33331A	Vending, commercial laundry and other commercial and service industry machinery manufacturing	333311, 333312, 333319
333313	Office machinery manufacturing	333313
333314	Optical instrument and lens manufacturing	333314
333315	Photographic and photocopying equipment manufacturing	333315
33341A	Air purification and ventilation equipment manufacturing	333411, 333412
333414	Heating equipment (except warm air furnaces) manufacturing	333414
333415	Air conditioning, refrigeration and warm air heating equipment manufacturing	333415
333511	Industrial mold manufacturing	333511
33351A	Metal cutting and forming machine tool manufacturing	333512, 333513
333514	Special tool, die, jig and fixture manufacturing	333514
33351B	Cutting and machine tool accessory, rolling mill and other metalworking machinery manufacturing	333515, 333516, 333518
333611	Turbine and turbine generator set units manufacturing	333611
333612	Speed changer, industrial high-speed drive and gear manufacturing	333612
333613	Mechanical power transmission equipment manufacturing	333613
333618	Other engine equipment manufacturing	333618
33391A	Pump and pumping equipment manufacturing	333911, 333913
333912	Air and gas compressor manufacturing	333912
333920	Material handling equipment manufacturing	333921, 333922, 333923, 333924
333991	Power-driven hand tool manufacturing	333991
33399A	Other general purpose machinery manufacturing	333992, 333997, 333999
333993	Packaging machinery manufacturing	333993
333994	Industrial process furnace and oven manufacturing	333994
33399B	Fluid power process machinery	333995, 333996
334111	Electronic computer manufacturing	334111
334112	Computer storage device manufacturing	334112
33411A	Computer terminals and other computer peripheral equipment manufacturing	334113, 334119
334210	Telephone apparatus manufacturing	334210
334220	Broadcast and wireless communications equipment	334220
334290	Other communications equipment manufacturing	334290
334300	Audio and video equipment manufacturing	334310
33441A	Other electronic component manufacturing	334411, 334412, 334414, 334415, 334416, 334417, 334419
334413	Semiconductor and related device manufacturing	334413
334418	Printed circuit assembly (electronic assembly) manufacturing	334418

BEA Code	Description	Corresponding NAICS Codes
334510	Electromedical and electrotherapeutic apparatus manufacturing	334510
334511	Search, detection and navigation instruments manufacturing	334511
334512	Automatic environmental control manufacturing	334512
334513	Industrial process variable instruments manufacturing	334513
334514	Totalizing fluid meter and counting device manufacturing	334514
334515	Electricity and signal testing instruments manufacturing	334515
334516	Analytical laboratory instrument manufacturing	334516
334517	Irradiation apparatus manufacturing	334517
33451A	Watch, clock and other measuring and controlling device manufacturing	334518, 334519
334610	Manufacturing and reproducing magnetic and optical media	334611, 334612, 334613
335110	Electric lamp bulb and part manufacturing	335110
335120	Lighting fixture manufacturing	335121, 335122, 335129
335210	Small electrical appliance manufacturing	335211, 335212
335221	Household cooking appliance manufacturing	335221
335222	Household refrigerator and home freezer manufacturing	335222
335224	Household laundry equipment manufacturing	335224
335228	Other major household appliance manufacturing	335228
335311	Power, distribution and specialty transformer manufacturing	335311
335312	Motor and generator manufacturing	335312
335313	Switchgear and switchboard apparatus manufacturing	335313
335314	Relay and industrial control manufacturing	335314
335911	Storage battery manufacturing	335911
335912	Primary battery manufacturing	335912
335920	Communication and energy wire and cable manufacturing	335921, 335929
335930	Wiring device manufacturing	335931, 335932
335991	Carbon and graphite product manufacturing	335991
335999	All other miscellaneous electrical equipment and component manufacturing	335999
336111	Automobile manufacturing	336111
336112	Light truck and utility vehicle manufacturing	336112
336120	Heavy duty truck manufacturing	336120
336211	Motor vehicle body manufacturing	336211
336212	Truck trailer manufacturing	336212
336213	Motor home manufacturing	336213
336214	Travel trailer and camper manufacturing	336214

BEA Code	Description	Corresponding NAICS Codes
336310	Motor vehicle gasoline engine and engine parts manufacturing	336311, 336312
336320	Motor vehicle electrical and electronic equipment manufacturing	336321, 336322
3363A0	Motor vehicle steering, suspension component (except spring) and brake systems manufacturing	336330, 336340
336350	Motor vehicle transmission and power train parts manufacturing	336350
336360	Motor vehicle seating and interior trim manufacturing	336360
336370	Motor vehicle metal stamping	336370
336390	Other motor vehicle parts manufacturing	336391, 336399
336411	Aircraft manufacturing	336411
336412	Aircraft engine and engine parts manufacturing	336412
336413	Other aircraft parts and auxiliary equipment manufacturing	336413
336414	Guided missile and space vehicle manufacturing	336414
33641A	Propulsion units and parts for space vehicles and guided missiles	336415, 336419
336500	Railroad rolling stock manufacturing	336510
336611	Ship building and repairing	336611
336612	Boat building	336612
336991	Motorcycle, bicycle and parts manufacturing	336991
336992	Military armored vehicle, tank and tank component manufacturing	336992
336999	All other transportation equipment manufacturing	336999
337110	Wood kitchen cabinet and countertop manufacturing	337110
337121	Upholstered household furniture manufacturing	337121
337122	Nonupholstered wood household furniture manufacturing	337122
33712A	Other household nonupholstered furniture	337124, 337125, 337129
337127	Institutional furniture manufacturing	337127
33721A	Office furniture and custom architectural woodwork and millwork manufacturing	337211, 337212, 337214
337215	Showcase, partition, shelving and locker manufacturing	337215
337900	Other furniture related product manufacturing	337910, 337920
339112	Surgical and medical instrument manufacturing	339112
339113	Surgical appliance and supplies manufacturing	339113
339114	Dental equipment and supplies manufacturing	339114
339115	Ophthalmic goods manufacturing	339115
339116	Dental laboratories	339116
339910	Jewelry and silverware manufacturing	339911, 339912, 339913, 339914
339920	Sporting and athletic goods manufacturing	339920
339930	Doll, toy and game manufacturing	339931, 339932
339940	Office supplies (except paper) manufacturing	339941, 339942, 339943, 339944

BEA Code	Description	Corresponding NAICS Codes
339950	Sign manufacturing	339950
339990	All other miscellaneous manufacturing	339991, 339992, 339993, 339994, 339995, 339999
311111	Dog and cat food manufacturing	311111
311119	Other animal food manufacturing	311119
311210	Flour milling and malt manufacturing	311211, 311212, 311213
311221	Wet corn milling	311221
31122A	Soybean and other oilseed processing	311222, 311223
311225	Fats and oils refining and blending	311225
311230	Breakfast cereal manufacturing	311230
311300	Sugar and confectionery product manufacturing	311311, 311312, 311313, 311320, 311330, 311340
311410	Frozen food manufacturing	311411, 311412
311420	Fruit and vegetable canning, pickling and drying	311421, 311422, 311423
31151A	Fluid milk and butter manufacturing	311511, 311512
311513	Cheese manufacturing	311513
311514	Dry, condensed and evaporated dairy product manufacturing	311514
311520	Ice cream and frozen dessert manufacturing	311520
31161A	Animal (except poultry) slaughtering, rendering and processing	311611, 311612, 311613
311615	Poultry processing	311615
311700	Seafood product preparation and packaging	311711, 311712
311810	Bread and bakery product manufacturing	311811, 311812, 311813
3118A0	Cookie, cracker, pasta and tortilla manufacturing	311821, 311822, 311823, 311830
311910	Snack food manufacturing	311911, 311919
311920	Coffee and tea manufacturing	311920
311930	Flavoring syrup and concentrate manufacturing	311930
311940	Seasoning and dressing manufacturing	311941, 311942
311990	All other food manufacturing	311991, 311999
312110	Soft drink and ice manufacturing	312111, 312112, 312113
312120	Breweries	312120
312130	Wineries	312130
312140	Distilleries	312140
312200	Tobacco product manufacturing	312210, 312221, 312229
313100	Fiber, yarn and thread mills	313111, 313112, 313113
313200	Fabric mills	313210, 313221, 313222, 313230, 313241, 313249
313300	Textile and fabric finishing and fabric coating mills	313311, 313312, 313320
314110	Carpet and rug mills	314110
314120	Curtain and linen mills	314121, 314129
314900	Other textile product mills	314911, 314912, 314991, 314992, 314999
315000	Apparel manufacturing	315111, 315119, 315191, 315192, 315211, 315212, 315221, 315222, 315223, 315224,

BEA Code	Description	Corresponding NAICS Codes
		315225, 315228, 315231, 315232, 315233, 315234, 315239, 315291, 315292, 315299, 315991, 315992, 315993, 315999
316000	Leather and allied product manufacturing	316110, 316211, 316212, 316213, 316214, 316219, 316991, 316992, 316993, 316999
322110	Pulp mills	322110
322120	Paper mills	322121, 322122
322130	Paperboard mills	322130
322210	Paperboard container manufacturing	322211, 322212, 322213, 322214, 322215
322220	Paper bag and coated and treated paper manufacturing	322221, 322222, 322223, 322224, 322225, 322226
322230	Stationery product manufacturing	322231, 322232, 322233
322291	Sanitary paper product manufacturing	322291
322299	All other converted paper product manufacturing	322299
323110	Printing	323110, 323111, 323112, 323113, 323114, 323115, 323116, 323117, 323118, 323119
323120	Support activities for printing	323121, 323122
324110	Petroleum refineries	324110
324121	Asphalt paving mixture and block manufacturing	324121
324122	Asphalt shingle and coating materials manufacturing	324122
324190	Other petroleum and coal products manufacturing	324191, 324199
325110	Petrochemical manufacturing	325110
325120	Industrial gas manufacturing	325120
325130	Synthetic dye and pigment manufacturing	325131, 325132
325180	Other basic inorganic chemical manufacturing	325181, 325182, 325188
325190	Other basic organic chemical manufacturing	325191, 325192, 325193, 325199
325211	Plastics material and resin manufacturing	325211
3252A0	Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	325212, 325221, 325222
325310	Fertilizer manufacturing	325311, 325312, 325314
325320	Pesticide and other agricultural chemical manufacturing	325320
325411	Medicinal and botanical manufacturing	325411
325412	Pharmaceutical preparation manufacturing	325412
325413	In-vitro diagnostic substance manufacturing	325413
325414	Biological product (except diagnostic) manufacturing	325414
325510	Paint and coating manufacturing	325510
325520	Adhesive manufacturing	325520
325610	Soap and cleaning compound manufacturing	325611, 325612, 325613
325620	Toilet preparation manufacturing	325620
325910	Printing ink manufacturing	325910
3259A0	All other chemical product and preparation manufacturing	325920, 325991, 325992, 325998

BEA Code	Description	Corresponding NAICS Codes
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	326111, 326112, 326113
326120	Plastics pipe, pipe fitting and unlaminated profile shape manufacturing	326121, 326122
326130	Laminated plastics plate, sheet (except packaging) and shape manufacturing	326130
326140	Polystyrene foam product manufacturing	326140
326150	Urethane and other foam product (except polystyrene) manufacturing	326150
326160	Plastics bottle manufacturing	326160
326190	Other plastics product manufacturing	326191, 326192, 326199
326210	Tire manufacturing	326211, 326212
326220	Rubber and plastics hoses and belting manufacturing	326220
326290	Other rubber product manufacturing	326291, 326299
	Wholesale and Retail Trade	
420000	Wholesale trade	423110, 423120, 423130, 423140, 423210, 423220, 423310, 423320, 423330, 423390, 423410, 423420, 423430, 423440, 423450, 423460, 423490, 423510, 423520, 423610, 423620, 423690, 423710, 423720, 423730, 423740, 423810, 423820, 423830, 423840, 423850, 423860, 423910, 423920, 423930, 423940, 423990, 424110, 424120, 424130, 424210, 424310, 424320, 424330, 424340, 424410, 424420, 424430, 424440, 424450, 424460, 424470, 424480, 424490, 424510, 424520, 424590, 424610, 424690, 424710, 424720, 424810, 424820, 424910, 424920, 424930, 424940, 424950, 424990, 425110, 425120
441000	Motor vehicle and parts dealers	441110, 441120, 441210, 441221, 441222, 441229, 441310, 441320
445000	Food and beverage stores	445110, 445120, 445210, 445220, 445230, 445291, 445292, 445299, 445310
452000	General merchandise stores	452111, 452112, 452910, 452990
4A0000	Other retail	442110, 442210, 442291, 442299, 443111, 443112, 443120, 443130, 444110, 444120, 444130, 444190, 444210, 444220, 446110, 446120, 446130, 446191, 446199, 447110, 447190, 448110, 448120, 448130, 448140, 448150, 448190, 448210, 448310, 448320, 451110, 451120, 451130, 451140, 451211, 451212, 451220, 453110, 453210, 453220, 453310, 453910, 453920, 453930, 453991, 453998, 454111, 454112, 454113, 454210, 454311, 454312, 454319, 454390
	Transportation and Warehousing	
481000	Air transportation	481111, 481112, 481211, 481212, 481219
482000	Rail transportation	482111, 482112

BEA Code	Description	Corresponding NAICS Codes
483000	Water transportation	483111, 483112, 483113, 483114, 483211, 483212
484000	Truck transportation	484110, 484121, 484122, 484210, 484220, 484230
485000	Transit and ground passenger transportation	485111, 485112, 485113, 485119, 485210, 485310, 485320, 485410, 485510, 485991, 485999
486000	Pipeline transportation	486110, 486210, 486910, 486990
48A000	Scenic and sightseeing transportation and support activities for transportation	487110, 487210, 487990, 488111, 488119, 488190, 488210, 488310, 488320, 488330, 488390, 488410, 488490, 488510, 488991, 488999
492000	Couriers and messengers	492110, 492210
493000	Warehousing and storage	493110, 493120, 493130, 493190
	Services (except government)	
511110	Newspaper publishers	511110
511120	Periodical publishers	511120
511130	Book publishers	511130
5111A0	Directory, mailing list and other publishers	511140, 511191, 511199
511200	Software publishers	511210
512100	Motion picture and video industries	512110, 512120, 512131, 512132, 512191, 512199
512200	Sound recording industries	512210, 512220, 512230, 512240, 512290
515100	Radio and television broadcasting	515111, 515112, 515120
515200	Cable and other subscription programming	515210
517110	Wired telecommunications carriers	517110
517210	Wireless telecommunications carriers (except satellite)	517210
517A00	Satellite, telecommunications resellers and all other telecommunications	517410, 517911, 517919
518200	Data processing, hosting and related services	518210
5191A0	News syndicates, libraries, archives and all other information services	519110, 519120, 519190
519130	Internet publishing and broadcasting and Web search portals	519130
52A000	Monetary authorities and depository credit intermediation	521110, 522110, 522120, 522130, 522190
522A00	Nondepository credit intermediation and related activities	522210, 522220, 522291, 522292, 522293, 522294, 522298, 522310, 522320, 522390
523A00	Securities and commodity contracts intermediation and brokerage	523110, 523120, 523130, 523140, 523210
523900	Other financial investment activities	523910, 523920, 523930, 523991, 523999
524100	Insurance carriers	524113, 524114, 524126, 524127, 524128, 524130
524200	Insurance agencies, brokerages and related activities	524210, 524291, 524292, 524298
525000	Funds, trusts and other financial vehicles	525110, 525120, 525190, 525910, 525920, 525990

BEA Code	Description	Corresponding NAICS Codes
5310HS	Housing	531210, 531320, 531390
5310RE	Other real estate	531210, 531320, 531390
532100	Automotive equipment rental and leasing	532111, 532112, 532120
532A00	Consumer goods and general rental centers	532210, 532220, 532230, 532291, 532292, 532299, 532310
532400	Commercial and industrial machinery and equipment rental and leasing	532411, 532412, 532420, 532490
533000	Lessors of nonfinancial intangible assets	533110
541100	Legal services	541110, 541120, 541191, 541199
541511	Custom computer programming services	541511
541512	Computer systems design services	541512
54151A	Other computer related services, including facilities management	541513, 541519
541200	Accounting, tax preparation, bookkeeping and payroll services	541211, 541213, 541214, 541219
541300	Architectural, engineering and related services	541310, 541320, 541330, 541340, 541350, 541360, 541370, 541380
541400	Specialized design services	541410, 541420, 541430, 541490
541610	Management consulting services	541611, 541612, 541613, 541614, 541618
5416A0	Environmental and other technical consulting services	541620, 541690
541700	Scientific research and development services	541711, 541712, 541720
541800	Advertising, public relations and related services	541810, 541820, 541830, 541840, 541850, 541860, 541870, 541890
5419A0	Marketing research and all other miscellaneous professional, scientific and technical services	541910, 541930, 541990
541920	Photographic services	541921, 541922
541940	Veterinary services	541940
550000	Management of companies and enterprises	551111, 551112, 551114
561100	Office administrative services	561110
561200	Facilities support services	561210
561300	Employment services	561311, 561312, 561320, 561330
561400	Business support services	561410, 561421, 561422, 561431, 561439, 561440, 561450, 561491, 561492, 561499
561500	Travel arrangement and reservation services	561510, 561520, 561591, 561599
561600	Investigation and security services	561611, 561612, 561613, 561621, 561622
561700	Services to buildings and dwellings	561710, 561720, 561730, 561740, 561790
561900	Other support services	561910, 561920, 561990
562000	Waste management and remediation services	562111, 562112, 562119, 562211, 562212, 562213, 562219, 562910, 562920, 562991, 562998
611100	Elementary and secondary schools	611110
611A00	Junior colleges, colleges, universities and professional schools	611210, 611310

BEA Code	Description	Corresponding NAICS Codes
611B00	Other educational services	611410, 611420, 611430, 611511, 611512, 611513, 611519, 611610, 611620, 611630, 611691, 611692, 611699, 611710
621100	Offices of physicians	621111, 621112
621200	Offices of dentists	621210
621300	Offices of other health practitioners	621310, 621320, 621330, 621340, 621391, 621399
621400	Outpatient care centers	621410, 621420, 621491, 621492, 621493, 621498
621500	Medical and diagnostic laboratories	621511, 621512
621600	Home health care services	621610
621900	Other ambulatory health care services	621910, 621991, 621999
622000	Hospitals	622110, 622210, 622310
623A00	Nursing and community care facilities	623110, 623311, 623312
623B00	Residential mental retardation, mental health, substance abuse and other facilities	623210, 623220, 623990
624100	Individual and family services	624110, 624120, 624190
624A00	Community food, housing and other relief services, including rehabilitation services	624210, 624221, 624229, 624230, 624310
624400	Child day care services	624410
711100	Performing arts companies	711110, 711120, 711130, 711190
711200	Spectator sports	711211, 711212, 711219
711A00	Promoters of performing arts and sports and agents for public figures	711310, 711320, 711410
711500	Independent artists, writers and performers	711510
712000	Museums, historical sites, zoos and parks	712110, 712120, 712130, 712190
713100	Amusement parks and arcades	713110, 713120
713200	Gambling industries (except casino hotels)	713210, 713290
713900	Other amusement and recreation industries	713910, 713920, 713930, 713940, 713950, 713990
721000	Accommodation	721110, 721120, 721191, 721199, 721211, 721214, 721310
722110	Full-service restaurants	722110
722211	Limited-service restaurants	722211
722A00	All other food and drinking places	722212, 722213, 722310, 722320, 722330, 722410
811100	Automotive repair and maintenance	811111, 811112, 811113, 811118, 811121, 811122, 811191, 811192, 811198
811200	Electronic and precision equipment repair and maintenance	811211, 811212, 811213, 811219
811300	Commercial and industrial machinery and equipment repair and maintenance	811310
811400	Personal and household goods repair and maintenance	811411, 811412, 811420, 811430, 811490
812100	Personal care services	812111, 812112, 812113, 812191, 812199
812200	Death care services	812210, 812220

BEA Code	Description	Corresponding NAICS Codes
812300	Dry-cleaning and laundry services	812310, 812320, 812331, 812332
812900	Other personal services	812910, 812921, 812922, 812930, 812990
813100	Religious organizations	813110
813A00	Grantmaking, giving and social advocacy organizations	813211, 813212, 813219, 813311, 813312, 813319
813B00	Civic, social, professional and similar organizations	813410, 813910, 813920, 813930, 813940, 813990
	Government	
S00500	Federal general government (defense)	NAICS not used to translate source data
S00600	Federal general government (nondefense)	NAICS not used to translate source data
491000	Postal service	NAICS not used to translate source data
S00101	Federal electric utilities	NAICS not used to translate source data
S00102	Other federal government enterprises	NAICS not used to translate source data
S00700	State and local general government	NAICS not used to translate source data
S00201	State and local government passenger transit	NAICS not used to translate source data
S00202	State and local government electric utilities	NAICS not used to translate source data
S00203	Other state and local government enterprises	NAICS not used to translate source data

12.3. Occupational Profiles

Estimates of the occupational profiles within different BEA categories were derived based on Bureau of Labor Statistics 2007 Occupational Employment Statistics (OES) (BLS, 2007). OES data are available at a 3-digit NAICS resolution. To incorporate occupational data into the WIO model, it was assumed that occupational profiles are consistent across all of the economic sectors grouped within the same 3-digit NAICS category. Using this simplifying assumption, occupational profiles were developed using the following approach:

- The twenty-two high-level occupational categories used in the OES were grouped into eight categories, as summarized in Table 20.
- Occupational profiles were created for each 3-digit NAICS category based on OES statistics.
- The profiles were applied to estimate the occupational distribution of total employment within each 6-digit NAICS category (or by BEA category for public administration).
- The profiles were applied to estimate the distribution of wages, by occupation, within each 6-digit NAICS category, and the results were calibrated to agree with total wage data.

Table 20: Correspondence between Occupational Categories Used in WIO Model and BLS OES

Grouped Category	BLS Occupational Category
Management (Mgmt)	11: Management occupations
Business and legal (B&L)	13: Business and financial operations occupations 23: Legal occupations

Grouped Category	BLS Occupational Category
Science, technology and engineering (STEM)	19: Life, physical and social science occupations 15: Computer and mathematical occupations 17: Architecture and engineering occupations
Sales and office administration (S&A)	41: Sales and related occupations 43: Office and administrative support occupations
Production, building services and transportation (P&T)	33: Protective service occupations 37: Building and grounds cleaning and maintenance occupations 45: Farming, fishing and forestry occupations 47: Construction and extraction occupations 49: Installation, maintenance and repair occupations 51: Production occupations 53: Transportation and material moving occupations
Education, healthcare and other services (EH&O)	25: Education, training and library occupations 27: Arts, design, entertainment, sports and media occupations 29: Healthcare practitioners and technical occupations 31: Healthcare support occupations 39: Personal care and service occupations 35: Food preparation and serving related occupations 21: Community and social services occupations

12.4. Corporate Taxes

Corporate taxes paid to federal, state and local governments were estimated using data from the 2007 U.S. Statistics of Income (SOI) (IRS, 2007), Table 6, Returns of Active Corporations. State and local taxes were estimated as reported taxes paid by corporations less foreign tax credit. Federal taxes were estimated as the income tax paid after credits. Where tax data were only available at a more aggregated resolution than the 6-digit NAICS, total taxes were allocated to sectors using total receipts data from the Agricultural Census or SUSB, as appropriate.

12.5. Summary of Employment and Tax Revenue Data

Table 21 summarizes the employment, wage, occupational and tax revenue data compiled for integration with the WIO model, rolled-up to the major economic sectors.

Table 21: Summary of Employment and Tax Revenue Data Used in the WIO Model, U.S. 2007

Sector*	Total Employment	Total Wages (\$ million)	Mgmt	B&L	STEM	S&A	P&T	EH&O	Total Tax Payments (\$ million)
Crop and animal production	5,973,955	\$46,235	2%	0%	1%	6%	90%	2%	\$2,916
Forestry, fishing and agricultural support services	172,105	\$5,564	2%	0%	1%	6%	90%	1%	\$976
Mining, quarrying, oil and gas extraction, utilities and construction	8,586,544	\$427,574	5%	3%	3%	12%	77%	0%	\$80,049
Manufacturing	13,275,432	\$624,422	5%	3%	8%	13%	70%	1%	\$158,152
Wholesale and retail trade	20,057,919	\$668,528	3%	2%	2%	64%	23%	6%	\$140,625
Transportation and warehousing	4,351,460	\$173,908	3%	2%	1%	22%	69%	4%	\$28,540
Services (except government)	72,006,244	\$3,063,248	5%	7%	6%	25%	17%	40%	\$342,034
Government	22,116,019	\$942,997	5%	13%	8%	19%	37%	18%	---***
Total	146,539,678	\$5,952,479	5%	6%	6%	27%	34%	23%	\$753,296

* See Table 20 for industries included in each sector.

** See Table 21 for key to category abbreviations and occupations included in each category.

*** Does not include inter-governmental transfers

**** **Occupational Profile**** (% employment by category)

13. Appendix G – Relevant input-output sectors—initial screening (2007 benchmark table classification)

Initial screening of the 2007 benchmark input-output table of the US Bureau of Economic Analysis (BEA) identified sufficient data to focus on following sectors.

Waste, waste management and recycling

562000	Waste management and remediation services
S00401	Scrap
S00402	Used and secondhand goods

Paper

322110	Pulp mills
322120	Paper mills
322130	Paperboard mills
322210	Paperboard container manufacturing
322220	Paper bag and coated and treated paper manufacturing
322230	Stationery product manufacturing
322291	Sanitary paper product manufacturing
322299	All other converted paper product manufacturing

Plastics and Rubber

325211	Plastics material and resin manufacturing
3252A0	Synthetic rubber and artificial and synthetic fibers and filaments manufacturing
326110	Plastics packaging materials and unlaminated film and sheet manufacturing
326120	Plastics pipe, pipe fitting and unlaminated profile shape manufacturing
326130	Laminated plastics plate, sheet (except packaging) and shape manufacturing
326140	Polystyrene foam product manufacturing
326150	Urethane and other foam product (except polystyrene) manufacturing
326160	Plastics bottle manufacturing
326190	Other plastics product manufacturing
326210	Tire manufacturing
326220	Rubber and plastics hoses and belting manufacturing

326290 Other rubber product manufacturing

Ferrous and non-ferrous metals

331110 Iron and steel mills and ferroalloy manufacturing
331200 Steel product manufacturing from purchased steel
33131A Alumina refining and primary aluminum production
33131B Aluminum product manufacturing from purchased aluminum
331411 Primary smelting and refining of copper
331419 Primary smelting and refining of nonferrous metal (except copper and aluminum)
331420 Copper rolling, drawing, extruding and alloying
331490 Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying
331510 Ferrous metal foundries
331520 Nonferrous metal foundries
33211A All other forging, stamping and sintering
332420 Metal tank (heavy gauge) manufacturing
332430 Metal can, box and other metal container (light gauge) manufacturing

Glass

327200 Glass and glass product manufacturing

Food and organic

622000 Hospitals
623A00 Nursing and community care facilities
623B00 Residential mental retardation, mental health, substance abuse and other facilities
624100 Individual and family services
624A00 Community food, housing and other relief services, including rehabilitation services
624400 Child day care services
721000 Accommodation
722110 Full-service restaurants
722211 Limited-service restaurants
722A00 All other food and drinking places

Construction and demolition

233210	Health care structures
233230	Manufacturing structures
233240	Power and communication structures
233262	Educational and vocational structures
233293	Highways and streets
2332A0	Commercial structures, including farm structures
2332B0	Other nonresidential structures
233411	Single-family residential structures
233412	Multifamily residential structures
2334A0	Other residential structures

Food and organics

112A00	Animal production, except cattle and poultry and eggs
221100	Electric power generation, transmission and distribution
31161A	Animal (except poultry) slaughtering, rendering and processing
325310	Fertilizer manufacturing
561700	Services to buildings and dwellings
624A00	Community food, housing and other relief services, including rehabilitation services

14. Appendix H – Standard Supply and Use Calculus

This appendix describes the standard supply and use framework drawn largely from Konijn (1994), and Suh et al. (2010).

For the sake of convenience, let both \mathbf{V} and \mathbf{U} be square matrices.²⁶ Then, the yearly product output, \mathbf{q} , and the yearly process output, \mathbf{g} , are calculated by:

$$(1) \quad \mathbf{q} = \mathbf{V}'\mathbf{i},$$

And:

$$(2) \quad \mathbf{g} = \mathbf{V}\mathbf{i},$$

Respectively, where the prime (') denotes transposition of a vector or a matrix, and \mathbf{i} is a summation column vector with relevant dimension containing only 1.

The primary factor input coefficient matrix, \mathbf{E} , which shows the amount of primary factor inputs to a sector/activity per unit of its output is calculated such that:

$$(3) \quad \mathbf{E} = \mathbf{B}\hat{\mathbf{g}}^{-1}.$$

Industry-technology model

Suppose that the inputs and outputs of a multi-output sector/activity are assigned over its multiple products based on the amount of output of each product in a common unit, such as U.S. dollar or kg, regardless of whether they are the primary, secondary or byproduct. This assumption is referred to as the industry-technology assumption. Under this assumption, the product-by-product symmetric direct requirement coefficient matrix, \mathbf{A}_i , is calculated by:

$$(4) \quad \mathbf{A}_i = \mathbf{U}\hat{\mathbf{g}}^{-1}\mathbf{V}\hat{\mathbf{q}}^{-1}.$$

²⁶ The commodity-technology model and the byproduct-technology model require this assumption. For the industry technology model, this assumption is not needed.

The corresponding primary factor-by-product coefficient matrix, E_I , is calculated by:

$$(5) \quad \mathbf{E}_I = \mathbf{B}\hat{\mathbf{g}}^{-1}\mathbf{V}\hat{\mathbf{q}}^{-1}.$$

The industry-by-industry table under the industry technology model can be derived by reversing the order of the right-hand-side in (4) ($\mathbf{V}\hat{\mathbf{q}}^{-1}\mathbf{U}\hat{\mathbf{g}}^{-1}$), which is the approach implicitly followed in the 2001 WIO model (Nakamura and Kondo 2002).

Commodity-technology model

Suppose that each product has the same amount of input requirements and primary factor inputs in producing one unit of a product, regardless of the industry where it is produced. This assumption is known as the commodity-technology assumption in the field of input-output economics. Under this assumption, the symmetric, product-by-product direct requirement coefficient matrix is calculated by:

$$(6) \quad \mathbf{A}_C = \mathbf{U}\mathbf{V}'^{-1}.$$

Likewise, the primary factor input by product coefficient matrix is calculated by:

$$(7) \quad \mathbf{E}_C = \mathbf{B}\mathbf{V}'^{-1}.$$

The industry-by-industry version of commodity-technology assumption is not intuitively meaningful, and therefore is not treated here.

Byproduct-technology model²⁷

Suppose that the production of a non-primary product by each sector/activity is fully dependent upon the production of the primary product. In other words, demand on non-primary products of a sector/activity does not directly affect the production schedule of the process, but produced non-primary products can be seen as consumed within the sector/activity. This assumption is referred to as the byproduct-technology assumption. In input-output convention, by-products are treated as negative inputs to the process. The direct requirement coefficient matrix and primary factor input coefficient matrix using the byproduct-technology model are

²⁷ This method is often called “Stone’s method” (Stone, 1961; Konijn, 1994).

determined by:

$$(8) \quad \mathbf{A}_B = (\mathbf{U} - \mathbf{V}'_{od}) \mathbf{V}_d^{-1},$$

and

$$(9) \quad \mathbf{E}_B = \mathbf{B} \mathbf{V}_d^{-1},$$

Respectively, where subscript *od* denotes off-diagonal and *d* denotes diagonal elements of corresponding matrices.

Mixed-technology model

More than one model among the three described earlier can be applied to the same system by partitioning the system into several subsystems. In that case, it is referred to as 'mixed-technology model', which combines more than one model described earlier in this appendix.

15. Appendix I – Prior REI Studies, Sources and Measures

15.1. Prior REI Studies

Recognizing the potential economic contributions of recycling activities, early research in the 1990s focused on key economic sectors including collection, processing, manufacturing and remanufacturing enterprises engaged in recycling activities. Studies also explored the economic contributions of the industry in terms of its effect on support industries (e.g., recycling equipment manufacturers), spending in the economy by wage-earners, government tax revenue and avoided disposal costs. There also were attempts to quantify trends in materials recovery and the incremental benefits of state policies designed to increase recycling rates.

In 1997, EPA commissioned the Northeast Recycling Council (NERC) to review existing state and regional studies and recommend a consistent methodology for quantifying the economic contributions of recycling in the United States. NERC recommended a data collection and analytical strategy, including economic input-output modeling, to quantify the direct, indirect and induced economic activity attributable to recycling (NERC, 1998). These recommendations formed the basis for regional and state REI studies and the 2001 *U.S. Recycling Economic Information Study*.

The 2001 national REI study was led by the National Recycling Coalition (NRC) and involved the joint efforts of EPA, 16 states and NERC. The study examined economic activity associated with 26 business categories directly engaged in recycling, reuse and/or remanufacturing and four additional business categories involved in providing support to the recycling industry. The study collected information on the number of establishments, employment, annual payroll, annual receipts and annual throughput (i.e. tons of recovered materials collected or processed) from public data sources, industry surveys and industry experts. The study analyzed the data and used input-output economic modeling to estimate the direct, indirect and induced economic activity and government tax revenues attributable to recycling in the U.S.

The 2001 national REI study estimated in 1997 that:

- More than 56,000 recycling, reuse and manufacturing establishments were operating in the U.S., employing approximately 1.1 million people, producing an annual payroll of \$37 billion and generating annual revenues of approximately \$236 billion.
- The recycling sector was supporting an additional 1.4 million jobs, annual payroll of \$52 billion and annual receipts of \$146 billion in businesses that were providing services to the sector.
- Household spending associated with individuals working in recycling and supporting industries induced additional economic activity supporting 1.5 million jobs, \$41 billion in annual payroll and \$146 billion in annual receipts.
- Government tax revenue of \$46 billion per year was being generated from federal, state and local taxes linked to direct, indirect and induced economic activity associated with recycling.
- Overall, that study estimated that 3.1% of the paid jobs in the U.S. and 2.7% of the gross domestic product (GDP) could be linked to direct, indirect and induced economic activity associated with recycling.

The 2001 national REI study recognized the limitations of the approach, including limitations in data availability and the economic modeling methodology. The study estimated that induced economic activity and government tax revenues could be over-estimated by as much as 15% due to methodological limitations (R.W. Beck/NRC, 2001).

During this same period, and in conjunction with the national effort, NERC completed an REI study for a 10-state region in the Northeast, which included state-level analyses for Delaware, Massachusetts, New Jersey, New York, Pennsylvania and Vermont (R.W. Beck/NERC, 2000). Ten other states also completed studies using the same or similar methodologies during this period: California, Florida, Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, Ohio and Wisconsin. (R.W. Beck/NRC, 2001).

15.2. Other Studies of Recycling Economic Activity

Other studies of the economic contributions of recycling in the U.S. have offered refinements to the 2001 REI methodology, used different market boundaries and considered different economic measures. Further, these studies have addressed prospective “what if” questions to support policy analysis and focus on market development. The following section reviews key, representative examples of these studies.

15.3. Alternative Boundaries, Data Sources and Measures

Since the 2001 national REI study, some states have conducted similar, but more narrowly focused analyses of the economic contributions of recycling, reuse and/or remanufacturing. For example:

In 2010 and 2011, the U.S. Bureau of Labor Statistics (BLS) conducted the Green Goods and Services (GGS) survey to measure jobs in businesses that produced goods and provided services that benefit the environment or conserve natural resources. The BLS survey sampled 120,000 establishments in industries identified as potential producers of GGS. BLS estimated employment associated with different types of GGS, including employment associated with “recycling and waste reduction” based on survey data identifying specific types of GGS produced and estimated percentages worksite sales and employment associated with GGS.²⁸

The North Carolina Recycling Business Assistance Center (RBAC) conducts periodic analyses of employment associated with North Carolina’s recycling industry. Employment estimates are based on a survey of businesses engaged in recycling activity, supplemented with data from the North Carolina Employment Security Commission. The analyses address direct employment only. North Carolina has conducted this analysis in 1994, 2000, 2004, 2008, 2010 and 2013 (RBAC, 2013).

In 2006, researchers at the College of Charleston conducted a study of economic activity associated with the recycling industry in South Carolina. The study followed a similar approach as prior REI studies, but focused on a smaller number of industry categories. The researchers used survey data and regional input-output modeling (IMPLAN) to estimate direct, indirect and induced economic activity in terms of jobs, wages, total output and contribution to state tax revenue. The results of the 2006 study were updated in 2014 (Hefner, 2014).

In 2007, researchers at the College of William and Mary conducted a study of the economic benefits of recycling in Virginia. The study focused on six industrial categories: recyclable material merchant wholesalers, materials recovery facilities, paper mills, industrial building construction, specialized long-distance trucking and solid waste collection. The study used data from the Institute of Scrap Recycling Industries (ISRI) and

²⁸ For a description of the BLS program, including technical notes and sample survey forms, as well as results of the 2010 and 2011 surveys, see <http://www.bls.gov/ggs/>.

state MSW statistics to estimate recycling-related activity for the manufacturing and transportation sectors (Miller, 2007).

The Connecticut Resources Recovery Authority (CRRA) sponsored a study, published in 2012, that estimated the direct, indirect and induced economic activity associated with recovered materials collection and hauling, materials recovery and recyclable materials wholesaling. Researchers used the regional input-out modeling approach (IMPLAN) and economic activity was measured in terms of jobs, total output and total value added. Reuse and remanufacturing activities and contributions to state and local tax revenues were not included in the analysis (CERC, 2012).

15.4. Use of Economic Impact Methods to Study Policy Alternatives

Other studies have incorporated the results of the 2001 national REI and similar studies to quantitatively explore how expansion in recycling industries could affect the economy. These studies have generally been used to inform waste management policy alternatives and promote policies designed to increase recycling rates.

Examples of these studies include:

Researchers at the University of California-Berkeley combined material flows analysis with economic data, using a modeling approach similar to the REI methodology, to estimate the economic impacts of waste diversion in California, including direct, indirect and induced impacts. The study also estimated the economic impacts of the waste disposal industry and developed a basis for analyzing the incremental impacts of diverting (in terms of employment, wages, value-added and total sales) of diverting versus disposing of waste. The study differed from the REI approach in terms of process scope (recycling only) and methods for allocating economic activity within industries that use both recycled and virgin materials (Goldman and Ogishi, 2001).

The Illinois state-wide REI study included a supplemental analysis of the potential incremental economic impacts that could be realized by increasing recycling rates to 35% and 50% and by banning electronics from landfills. The additional analysis used a linear extrapolation to estimate the net increase in activity of recovered materials collection and processing activities. Estimates of the impacts on manufacturing processes considered not only increased activity related to recycled materials but also displacement of economic activity associated with virgin materials (R.W. Beck, Inc., 2001).

NERC recommendations for the REI study methodology were based on part on a methodology used in a 1997 study of the economic impacts of recycling in Iowa commissioned by Recycle Iowa (NERC, 1998). Additional state-wide REI studies were completed in 2001 and 2007. The Iowa REI studies include detailed supplemental commodity flow analyses that support more in-depth understanding of drivers for economic activity associated with recycling over time, with implications for policy analysis and market development (R.W. Beck, 2001).

The Tellus Institute analyzed the potential economic impact of increasing MSW and construction and demolition waste diversion rates from 33% and 37%, respectively, to 75% (both streams) by 2030. Relative to the base case, Tellus estimated that the increased diversion rates could generate an addition 1.1 million jobs in the U.S. (Tellus Institute, 2011).

15.5. International Studies

The European Commission identified greater resource efficiency, including transition to a more circular economy that involves “closing the loop” through greater reuse and recycling, as a keys to achieving the

European Union’s job and growth priorities (European Commission, 2015). A number of studies have attempted to measure the economic impacts of improved resource efficiency in Europe (Ecorys 2015). Studies with a similar objectives and scope as the U.S. REI studies include:

- Ecorys and IDEA (2009) used Eurostat data on Environmental Protection Expenditures (EPEs) to estimate direct employment associated with ten economic sectors engaged in pollution or resource management. The study used average wage and other information to estimate job activity based on sector-specific EPEs. Eurostat EPE data were not available for the recycling sector, so proxy data were used to estimate recycling jobs. In its update to the study, Ecorys recognized that the potential for double-counting introduced by this approach and added assumptions to correct for this problem. The updated study estimated that approximately 0.11% of employment in the EU-27 member states in 2008 could be attributed to recycling (Ecorys, 2012).
- GHK et al. (2007) used input-output tables and multipliers to estimate the direct, indirect and induced employment associated with recycling in Europe, using an approach comparable to the U.S. REI studies. The GHK study estimated that direct employment in recycling activities accounted for approximately 0.09% of employment in the EU-27 member states in 2000 and that indirect and induced employment associated with recycling accounted for 0.12% and 0.06% of jobs during the same period, respectively. A re-analysis of the GHK study in 2015 indicated similar but slightly lower contributions of recycling to the European economy based on 2007 data (Ecorys, 2012).
- Morgan and Mitchell (2015) conducted a prospective analysis of the impacts of transformation to a circular economy on job growth, types of jobs (in terms of skills required) and potential job displacement. Data included in the study suggested that used closed and open loop recycling generally involve a greater proportion of low skilled labor relative to other “green jobs” included in the analysis and that remanufacturing generally involves a higher skill mix.

The first national-scale WIO model was developed in Japan to assess the impact of alternative waste management policies on waste incineration performance (Nakamura and Kondo, 2002). The model was developed by augmenting national economic input-output tables to better represent flows of wastes, recyclable and recycled materials and products through waste management and recycling sectors (Nakamura and Kondo, 2002; Kondo and Nakamura, 2004; Takase et al., 2005; Nakamura et al., 2007; Nakamura and Kondo, 2009). Suh et al. (2010) observed that Nakamura and Kondo framework is a special case of standard supply and use calculus and could be extended to other practical applications in input-output economics. Lenzen and Reynolds (2014) confirmed this observation and illustrated the practical uses of the WIO framework using economic and waste data for the Australian economy.

15.6. Trends in Recycling, Reuse and Remanufacturing

The size and structure of the recycling industry has changed significantly since the 2001 national REI study which was primarily 1997 data while this effort is primarily 2007 data. These changes have occurred in response to changes in several factors, including:

- Policies and economic considerations affecting material recovery rates;
- Consumer demand for greener products;
- Product formulation and engineering;
- Business models and product stewardship;

- Recycling technology; and
- Commodity exchange mechanisms.

These changes in turn affect the direct, indirect and induced economic activity associated with recycling including employment, wages and total economic output.